Partnership led strategy to monitor and manage the spread of Pacific oyster populations in south Devon and Cornwall

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Executive summary

Over the past five years there has been increasing concern around the spread of wild Pacific oysters in Marine Protected Areas (MPAs). In Devon and Cornwall, the abundance of Pacific oyster *Magallana gigas* (formerly *Crassostrea gigas*) within intertidal MPAs has led to some sites being reported as being in unfavourable condition. Natural England, in partnership with South Devon Area of Outstanding Natural Beauty (AONB) Estuaries Partnership and Cornwall Wildlife Trust, with funding from the European Maritime and Fisheries Fund, undertook an investigation into monitoring and control measures for Pacific oysters within MPAs.

Between 2017 and 2020, volunteers led by Cornwall Wildlife Trust and South Devon AONB Estuaries Partnership, conducted surveys around Cornwall and South Devon, to record the density of Pacific oyster populations and to test the effectiveness of culling as a method of controlling population expansion.

Pacific oysters may affect MPA features when they are present at densities of 1-9/m^2 or above. Densities of 1-9/m^2 are referred to as Common on the SACFOR scale, and at this level changes in community structure can occur. Densities of 10-99/m^2 (Abundant on the SACFOR scale) and over 100/m^2 (Superabundant) are levels which can trigger changes in intertidal biotopes. These densities are of particular concern when identified within designated MPAs.

A number of hotspots were identified in the south west where Pacific oyster settlement is a cause for concern. The worst affected areas were sites within the Fal and Helford SAC, the Plymouth Sound and Estuaries SAC, the Fowey estuary (adjacent to the Upper Fowey and Pont Pill MCZ), Whitsand and Looe Bay MCZ and the Exe estuary SPA (and their underlying SSSIs). Pacific oyster reefs (areas of 100% cover) were already established in some of these sites, and new or developing reefs were recorded on intertidal seagrass within the Salcombe to Kingsbridge SSSI and at other areas including within St John’s Lake SSSI.

Detrimental effects on human activity have been noted, including damage to slipways and vessels, as well as injury to humans and dogs caused by the oysters’ sharp shells. Pacific oysters in some areas cover 100% of the shore, making these sites unsafe to access.

Groups of volunteers successfully carried out a large number of culls on rocky shores over a period of two or more years. At many of these locations, where targeted culling was carried out across the site, population growth rate was

significantly reduced. Partial culling was less effective and population density increased over the study period in areas where control was not carried out. Although culls were effective where they occurred, the spatial and temporal distribution of culls to date has not been enough to reduce the growth of Pacific oyster populations overall.

Removal of Pacific oysters from sediment habitats was more hazardous and further investigation is required into methods than can safely remove large quantities of oysters, without causing damage to sensitive habitats. Pacific oyster reef formation on intertidal seagrass beds is of particular concern.

Abandoned structures and debris in estuarine areas often had significant Pacific oyster settlement and it would be prudent to explore the possibility of removing such items, in order to reduce available substrate for settlement.

As a substitute to culling, many alternative uses were proposed for Pacific oysters found to be at high densities within designated MPAs. A workshop provided an opportunity for interested parties to explore these ideas further. Although some small enterprises are finding economic uses for feral Pacific oysters, much more work is required to determine the logistical and economic viability of such ventures.

Volunteers who took part in the project were committed and motivated, and generally found it interesting and worthwhile. There were concerns, however, that if this work didn't continue, little value would arise from their effort.

This project has demonstrated that management works, and that it is possible for volunteer culls to effectively reduce the abundance of Pacific oysters on our shores. Efforts to remove Pacific oysters in MPA hot spots and at at-risk areas need to be prioritised and carried out along an entire length of shore rather than in a piecemeal fashion. Efforts need to adopt the guiding principle of 'containment not eradication' and ensure a focussed response based on monitoring.

We recommend that consideration is given to potential future funding for this work as it will have notable economic and environmental benefits in the longer term. Without a longer-term commitment to this work, we will continue to lose native habitats and species; and continue to detrimentally affect MPAs. For example, damage to seagrass beds could potentially reduce the carbon sequestration function of these important habitats.

Future work should target specific 'hot spot' problem areas (where Pacific oyster abundance is a cause for concern), along entire lengths of shore. Management should also target at-risk areas within MPA's where more recent settlement has occurred, to prevent populations becoming established in these sites and threatening their condition.

A project coordinator should be employed to ensure effective coordination of Pacific oyster management actions at a landscape scale. This is needed to ensure targeted action within problem areas and consistency of approach.

Further investigations are necessary to inform future Pacific oyster management, including:

- Research into Pacific oyster densities at which community composition and habitat function is altered on rock, sediment, and seagrass habitats.
- A specific review of costs and logistics associated with removal and disposal of large quantities of Pacific oysters from sediment habitats.
- An investigation into the most sensitive methods of removal (i.e. that do not cause abrasion, disturbance, or damage to sensitive intertidal habitats).
- Exploring the use of eDNA to investigate source populations of new settlement areas.

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1. Introduction

1.1 Project background

Increasing concerns over the last five years around the spread of wild Pacific oysters in the south west UK and their potential impact on the condition of MPAs in the region, warranted a more detailed investigation into Pacific oyster abundance and spread around Devon and Cornwall. Although some monitoring and control of this non-native invasive species had taken place, these events had been sporadic, with no systematic study across the region having been undertaken to address the scale of the issue or the effectiveness of control measures.

This project, funded by the European Maritime and Fisheries Fund, was proposed following a Condition Assessment of the Plymouth Sound and Estuaries Special Area of Conservation (Natural England 2016a), which classed the condition of some intertidal habitat features as unfavourable due to the formation of Pacific oyster reefs. The formation of these reefs had resulted in a change from one habitat type to another, with the reefs replacing intertidal mud habitat, and therefore a loss of an area of designated habitat within the site and a habitat of principle importance. The target condition for MPAs is ‘Favourable Condition’ when a feature is considered to be adequately conserved. More information on the Condition Assessment process can be found in section 2.

An earlier Natural England study had shown a rapid increase in Pacific oyster density in this site, as well as within parts of the Fal and Helford Special Area of Conservation (SAC) in 2015 (Russell 2019). There had also been anecdotal reports of increasing Pacific oyster settlement in other coastal areas around Devon and Cornwall and an apparent risk to other MPAs within the region was identified.

Natural England had been working with volunteers in Kent for several years - as part of the Coastbusters partnership project with Kent Wildlife Trust - to address similar concerns, where significant numbers of Pacific oysters were settling within a suite of MPAs and impacting intertidal habitats, in particular the chalk reefs (Chudleigh & McKnight 2009). Monitoring and control measures undertaken appeared to have been successful in the short term, with 221,000 oysters removed from some of the most sensitive areas within the sites. It had been demonstrated that groups of enthusiastic and committed volunteers could help control or even reduce numbers of Pacific oysters and therefore reduce the risk to intertidal habitats within MPAs (McKnight & Chudleigh 2015). Pacific oyster control has continued within the north east Kent MPAs as part of the Guardians of the Deep partnership project (Thanet Coast (NEKMPA) 2020).

Guy & Roberts (2010) undertook a pilot cull of Pacific oysters around Strangford Loch, Northern Ireland in 2008. The authors reported average population declines of 89% at culled sites and suggested that small scale hand removal can be effective in controlling wild settlement of Pacific oysters in the early stages of their spread. It had become clear that isolated, ad-hoc monitoring and control events were not sufficient to address the scale of the problem within Devon and Cornwall. It was evident that a larger scale approach was required across the region, particularly within the Fal and Helford and the Plymouth Sound and Estuaries SACs, to investigate whether sufficient effort could have an impact on the density and distribution of Pacific oysters and address threats to MPA habitat features.

In the south west, particularly in Cornwall, a number of active volunteer groups were already established, having been set up as part of Cornwall Wildlife Trust's Your Shore Network of Voluntary Marine Conservation Groups and the Shoresearch project. Natural England had recently been working closely with South Devon Area of Outstanding Natural Beauty (AONB) Estuaries Partnership to improve the condition of MPA features that had become unfavourable.

This project was conceived as a partnership project between the three organisations, to work collaboratively and investigate whether increased and targeted effort controlling Pacific oysters could have a tangible impact on their distribution and density, improving the condition of MPAs within the two counties. A regional collaborative approach to managing wild Pacific oyster settlement, involving multiple stakeholders and volunteers, was also outlined in Herbert et al. (2012, 2016).

1.2 Project partners

This study was undertaken as a partnership project between Natural England, Cornwall Wildlife Trust, South Devon Area of Outstanding Natural Beauty (AONB) Estuaries Partnership and the Marine Biological Association of the UK.

1.2.1 Natural England

Natural England is the government's adviser for the natural environment, with responsibilities that include promoting nature conservation, protecting biodiversity, and conserving and enhancing the landscape. Natural England has 14 area teams (as well as a number of national teams), with this project sitting within the Devon, Cornwall, and Isles of Scilly Area Team. Local and national advisors have contributed to this project and the project officer was based within this Area Team.

1.2.2 Cornwall Wildlife Trust

Cornwall Wildlife Trust is a charitable organisation founded in 1962 with the aim of protecting and conserving Cornwall's wildlife and habitats. Cornwall Wildlife Trust has had great success with its volunteer network which has helped manage over 50 nature reserves: both marine and terrestrial. Shoresearch Cornwall, a project of the Living Seas Team, works closely with volunteers to survey and record changes to Cornwall's rocky shore habitats and marine life. Matt Slater, Cornwall Wildlife Trust's Marine Awareness Officer has been coordinating, recruiting, and training volunteers and organising surveys via the Shoresearch project and throughout Cornwall's local marine groups for a number of years. In this network of marine groups, 13 have become trained in Pacific oyster monitoring and management with individual groups operating regular surveys within the Fal and Helford Special Area of Conservation (SAC) and further afield.

1.2.3 South Devon AONB Estuaries Partnership

South Devon AONB Estuaries Partnership is supported by the employment of a small staff unit. This partnership drives the implementation of the South Devon AONB Estuaries Management plan and supports the conservation practices dedicated to the enhancement of the protected area. The management plan brings together individual conservation plans for the Yealm, Erme, Avon, Salcombe-Kingsbridge, and Dart estuaries. The South Devon component of this project has been coordinated by Estuaries Officer, Nigel Mortimer.

The South Devon AONB Estuaries Partnership did not previously have a volunteer scheme and therefore have been reliant on gaining volunteers through the direct coordination and leadership of the South Devon AONB.

1.2.4 Marine Biological Association of the UK

The Marine Biological Association (MBA) is a Learned Society with the objectives to 'promote the investigation, and to disseminate knowledge, of the seas and marine life, including the use of marine and other organisms for basic biosciences for the benefit of the public (where biosciences means marine biology in its widest sense)'.

The Bishop Group is one of the MBA's research groups with a focus on non-native invasive species. This group has a wealth of experience in providing invasive non-native species (INNS) training and knowledge exchange events and was asked as part of this project, to provide training for all project staff and lead volunteer groups assisting with the project.

1.3 Project aims and objectives

This project's aims were to:

- Ascertain the existing distribution and population density of Pacific oysters around the coast of Cornwall and south Devon and identify Pacific oyster hotspots, focusing on Marine Protected Areas.
- Undertake population control methods to reduce feral populations and reduce population expansion
- Assess whether control of Pacific oysters using volunteer effort can be effective in reducing Pacific oyster density over a two-year period.
- Identify pathways to promote alternative uses of removed Pacific oysters
- Record other Invasive Non-Native Species (INNS)
- Monitor settlement rates

These aims would be achieved by:

- Coordinating a network of volunteers to monitor Pacific oyster populations and settlement rates around Cornwall and south Devon
- Training volunteer groups to carry out population control on feral oysters around Cornwall and south Devon
- Undertaking data analysis to determine the impact of reducing populations
- Liaising with stakeholders to identify pathways to promote economic use of collected Pacific oysters and investigate alternative uses

1.4 Pacific oyster ecology

The Pacific oyster, *Magallana gigas* is a non-native invasive bivalve mollusc originally native to North East Asia, but now recorded globally (Hughes 2008). Pacific oysters are present throughout coastal and estuarine environments with freshwater input and can settle on a range of substrates (Hughes 2008). The shell, comprising of two halves, has a rough texture and sharp frilled edges (Image 1). Individuals can reach lengths of 18cm in areas where conditions are suitable (Hughes 2008). Once settled, they become sessile and rely on passing seawater to supply plankton and organic matter for food (Miossec, Le Duff & Goulletquer 2009). Known as filter feeding, this method involves pumping seawater through the body and trapping food particles within specialised filters. Excess water is removed from the body and particles are then digested (Jørgensen 1990).

The Pacific oyster is a broadcast spawner, releasing eggs and sperm into the water column (Troost 2010; Herbert and others 2012). A sexually mature female can produce up to 100 million eggs in a single spawning event (Russell 2019) and once fertilised, these larvae drift until ready to settle and metamorphose (Herbert and others 2012). The duration of their pelagic larval stage is on average, 2 to 4 weeks, (Syvret, Fitzgerald, & Hoare 2008). It was considered not possible for Pacific oysters to reproduce and establish populations in northern European waters due to low water temperatures (McKnight & Chudleigh 2015). It is now clear that this is not the case. Spawning can occur throughout warmer months, being triggered when cumulative conditioning has been successful due to prolonged higher temperatures (Herbert and others 2012). Juveniles have been shown to survive in temperatures as low as 6 °C (Mills 2016; Child & Laing 1998). Despite this, Pacific oyster larvae are highly sensitive to changes in their surrounding environment and post settlement survival is dependent on a number of factors including:

- the nature of the physical environment (Troost and others 2009)
- the resilience of the receiving ecosystem (Troost and others 2009)
- nutrient content of the surrounding water (Syvret, Fitzgerald & Hoare 2008)
- unfavourable water conditions such as high levels of pollution (Syvret, Fitzgerald & Hoare 2008)
- the ability to acclimatise (Syvret, Fitzgerald & Hoare 2008)
- predation from other organisms (Troost and others 2009)

Pacific oysters typically settle on the rocky shore and on soft sediments (when hard fragments such as shells are present) within estuarine environments. Pacific oysters that settle on the rocky shore (hard substrate) tend to do so in the intertidal zone, between mean high water and mean low water (Herbert and others 2012). They settle onto the rock and metamorphose into juvenile Pacific oysters (Troost 2010). Their bottom shell becomes cemented onto the substrate and they remain sessile for the rest of their life cycle. Records have shown that Pacific oysters can thrive in areas that are sheltered, moderately exposed, and in areas with high energy conditions (Herbert and others 2012).

Like many sessile invertebrate species, Pacific oysters are primarily recorded in aggregations (Vasquez and others 2013). Living in proximity increases fertilisation success as the concentration of gametes in the water column is much higher during spawning. Fertilisation rates are even more enhanced if spawning is synchronised (Serrao and Havenhand 2009).

In soft sediment environments, Pacific oysters often settle and develop on top of existing oysters (or other bivalves) and together form ‘clumps’ that eventually create an oyster reef (Herbert and others 2012). These reefs are often vertically oriented and are so dense that little space exists for other species in the same habitat (Russell 2019; Herbert and others 2012). The density of these reefs however is dependent on the larval supply in the area and the rate of settlement success (Herbert and others 2012).

Anecdotal evidence from Cornwall Wildlife Trust (Matt Slater pers comms.) suggests that Pacific oysters rarely occur subtidally. They have been recorded in the Percuil river on the low tide mark but have not been recorded in the subtidal area. No pacific oysters were recorded in the 2018 Fal Oyster Survey or the 2019 Fal Oyster Survey conducted by the Cornwall Inshore Fisheries Conservation Authority (CIFCA) (Jenkin and others 2018 & Jenkin and others 2019).

Reports from the Wadden sea, Ireland and Scandinavia however have confirmed that it is possible for Pacific oysters to settle and thrive in deeper waters (Guy & Roberts 2010; Invasive species Ireland 2021).Further investigation would be required to assess the extent of wild Pacific oyster colonisation in subtidal habitats in Devon and Cornwall and how this may affect MPAs and their features.

It is suggested that drifting spat are attracted to pheromones released by mature Pacific oysters already established in an area (Vasquez and others 2013). Gregarious behaviour in oysters was first noted by Cole and Knight-Jones when studying the Native oyster, *Ostrea edulis* in 1939 (Vasquez and others 2013). It was later confirmed by Bayne (1969) who reported that tissue extracts applied to a surface of oysters were successful in promoting the settlement of spat (Vasquez and others 2013).

Image 1: Pacific oyster ©Matt Slater

1.5 Pacific oyster aquaculture

Pacific oysters were introduced to the UK for aquaculture possibly as early as 1890, following significant declines in native oyster fisheries. The first introduction is thought to have come from Arcachon, France, into Poole Harbour (Humphreys and others 2014; Mills 2016) but other sources state the first introduction occurred in 1926, into the Blackwater Estuary in Essex (GBINNS 2020; Hughes 2008). It is important to note the possible synonomy between the Portuguese oyster *Magallana angulata* and the Pacific oyster *M. gigas* (Hughes 2008) and this may have led to some confusion around the first introduction date. During the 1960s and 1970s, Pacific oysters were imported into the UK from Canada and the USA. Unfortunately, these imports brought with them diseases and other non-native species (Herbert and others 2012). Regulations later improved and new solutions were implemented for the importation of seed oyster supply.

Hatcheries are important for breeding disease resistant, faster growing oysters (Wallace, Waters & Rikard 2008). The technique of using hatcheries for the commercial production of Pacific oysters and other shellfish has become well established throughout the world (Wallace, Waters & Rikard 2008). Broodstock for use in hatcheries can now be sourced from designated shellfish areas that are regularly monitored to ensure there is no presence of disease (Herbert and others 2012). For further information on hatchery and nursery systems see Herbert and others (2012).

Pacific oyster spat is vulnerable to predation and therefore are often laid in trays and/or covered with a protective mesh bag (Herbert and others 2012). These are then typically placed above the seabed on trestles or on floating structures. Some operators may also lay Pacific oyster spat directly on the seabed. Pacific oysters are harvested in various ways, including tractor and trailer; dredging (when laid directly on the seabed) and hand picking, depending on the farming method and local conditions.

Pacific oysters are filter feeders and therefore can accumulate pathogenic microorganisms and toxins in higher concentrations than that of the surrounding seawater (Herbert and others 2012). Shellfish harvesting areas in the UK are closely monitored for various contaminants such as human sewage and animal faeces that can cause disease and food poisoning (Herbert and others 2012). Shellfish areas are classified in line with international standards that test for *E.coli* as an indicator of faecal contamination within an area. UK waters are classified on an A-C scale which determines what treatment the oysters need prior to sale for consumption (Herbert and others 2012).

Pacific oysters have been cultivated around England’s south west coast from the mid-1960s and 1970s. There are approximately 12 operations currently farming Pacific oysters in Devon and Cornwall, many of them within sheltered estuaries

(Cefas Sanitary Survey Reports 2007-2015). Stocks are grown from seed/spat bought in from hatcheries from other parts of the UK and Guernsey (Adamson, Woolmer & Syvret 2018).

The predominant aquaculture method in Devon and Cornwall is bag and trestle culture, with oysters being grown in bags that are raised above the seabed on trestle structures. Some are placed directly on the seabed and moved around depending on their growth stages and local hydrodynamic conditions. Juveniles are sometimes grown in bags on long lines, before being spread directly onto growing beds in either rivers, estuaries, or the sea.

In some areas, wild settlement in the vicinity of Pacific oyster farms has been significant, while other farming sites seem to have an absence of, or very minimal wild settlement. More research is needed into the effects of hydrodynamic conditions on larval settlement and the fate of settled spat.

Triploid oysters are those that contain an extra set of chromosomes. They are produced by chemical, pressure, or heat treatment in hatcheries to produce sterile oysters and to produce a better quality of meat (Laing and others 2004). Many aquaculture operations use triploid oysters where possible, to reduce the risk of spawning; however, supply can be a problem, with shortages of triploid stock meaning diploids are still required to ensure operations remain economically viable. Some operators have found that triploid oysters are not marketable due to rapid shell growth which can distort the shape of the oyster. Where feral Pacific oyster populations are already established, the use of triploids may not be effective as a method of preventing spread, as diploid x triploid crosses are known to sometimes produce viable embryos (Syvret, Fitzgerald & Hoare 2008). Triploid oysters have also been known to sometimes revert to diploid (Herbert and others 2016).

1.6 Impacts of Pacific oysters

Feral populations of Pacific oysters have become established in Natura 2000 sites, Sites of Special Scientific Interest (SSSI) and Marine Conservation Zones (MCZs) in the south west UK. Monitoring conducted between 2012 and 2017 has shown a large increase in Pacific oyster density in these sites. There are concerns that the colonisation of this species will have a negative effect on the designated intertidal features of these protected areas. This has already contributed to some sites declining into unfavourable condition, due to the alteration of the biotopes, and therefore the loss of original biotopes which make up the protected habitat features within MPAs. As set out in Natural England’s revised MPA condition assessment method (Natural England 2020a) extent and distribution is a principal conservation objective for most habitats, and significant loss of extent leads to features being classed in unfavourable condition. If populations are left unmanaged the expansion of dense Pacific oyster populations will most likely reduce the extent of habitat features of the sites and could reduce species richness and change community composition, as well as the diversity of biotopes making up the habitat.

Natural England is the government's adviser for the natural environment in England and as such has a statutory responsibility to provide advice to enable protection and improvement for all MPAs within English territorial waters. Strategies need to be implemented to assess and reduce the impact of invasive alien species on protected habitat features.

1.6.1 Pacific oyster settlement on hard substrates

Pacific oysters are now a common sight on the rocky foreshore in some parts of Devon and Cornwall (Image 2) and colonisation has been significant in some areas. As well as settlement on rocky reef, other hard surfaces such as harbour walls, pontoon pilings and slipways have been found to have significant Pacific oyster settlement. Pacific oysters can significantly change the physical characteristics of substrates and as such, are known as ecosystem engineers (Padilla 2010). Although changes in habitat from one type to another occur more commonly on soft sediment, Pacific oysters may alter biotopes on rocky substrates and cause changes in community structure (Lejart & Hily 2011; Zwerschke and others 2018). This may affect the attributes of intertidal rock features within MPAs, therefore, contributing to the failure of condition targets.

A study by Lejart & Hily (2011) looking at the difference between rocky intertidal habitats with and without Pacific oysters, noted a lower proportion of total mollusc species present on bare rock, and a greater diversity of molluscs present on Pacific oyster colonised rocks. There was an increase in crustaceans, with isopods and amphipods only on areas colonised by Pacific oyster compared to bare rock. Although biomass was greater on rock colonised by the Pacific oysters, the community structure altered, with a change in proportions of trophic groups.

Zwerschke and others (2018) recorded an increase in barnacles with increased Pacific oyster cover on intertidal rock, and a decrease in abundance of *Fucus vesiculosus* and *Littorina* sp. The presence of dense macroalgae on rocky reef may limit the settlement potential of Pacific oysters (Kochman and others 2013; Hooper 2020).

The effect of Pacific oyster settlement on rocky intertidal communities is potentially very complex and may vary with habitat type, local hydrodynamic conditions, and oyster density (Zwerschke and others 2018; Kochman and others 2013). It is an area that would benefit further research, particularly into the effects at varying densities of Pacific oyster settlement.

Image 2: Pacific oysters on intertidal rock, Turnaware ©Matt Slater

1.6.2 Pacific oyster settlement on sediment

In intertidal sediment habitats, Pacific oysters have now become so well established in several areas around south west England, they have formed oyster reefs (Image 3). These reefs are formed when a high density of wild Pacific oysters settle or merge on top of one another (Herbert and others 2012). Across Europe, the formation of these oyster reefs has threatened the habitat features of protected sites (Herbert & others 2016; Russell 2019). In the south west UK, Natura 2000 sites are failing to meet their Conservation Objectives, for example in the Plymouth Sound and Estuaries Special Area of Conservation (SAC), where intertidal sediment features have changed significantly due to the colonisation of Pacific oysters and are in unfavourable condition. There is increasing concern that the condition of other MPAs will also deteriorate due to Pacific oyster colonisation and spread. The eventual smothering of sediment habitats by Pacific oysters may prevent some native bird and fish species feeding on infauna such as worms, molluscs, and crustaceans. In Kent, McKnight (2011) documented Pacific oysters displacing sand mason worm reefs, *Lanice concilegera*, and *Sabellaria spinulosa* reefs. have also been overrun by Pacific oysters (McKnight 2011; McKnight 2012) as have mussel beds in the Wadden Sea (Reise 1998). It is likely that this change from soft to harder substrate will favour some species and disadvantage others. Estuarine soft sediment communities can be ecologically species-poor and strongly dominated by just a few species, however this is a natural state of such habitats and low measures of biodiversity may belie their importance in terms of productivity and biomass. Pacific oyster reefs artificially add layers of habitat complexity to a site, which may lead to an increase in species diversity and richness, however it is an alteration to the natural native biotopes. A new species which dominates others, could lead to a loss in diversity of native biotopes and species overall.

A study was conducted by Herbert and others (2018) on the impact of Pacific oyster reefs on the distribution and feeding behaviour of coastal birds. There was very little evidence of coastal birds feeding directly on *Magallana gigas* with the exception of the Eurasian oystercatcher and herring gull. Although the oyster reef provided some food resource, it was noted that most bird species avoided the oyster reefs. Nehls and Buttger (2007) also documented herring gulls and oystercatchers feeding on Pacific oysters in the Netherlands, however both species did this infrequently. Other species of shore birds did not benefit from increased populations of Pacific oysters as a food resource, and potentially suffered from a reduced area for foraging (Nehls and Buttger 2007).

There have been no studies to determine a threshold for the impact of Pacific oysters in a protected site. However, the EU Habitats Directive states that it is important to determine whether the integrity of a whole site is adversely affected. Many competent authorities conclude that even the loss of less than 1% of designated sites could have a significant impact and adversely affect site integrity (Hoskin and Tyldesley 2006).

Image 3: Pacific oyster reef on mixed sediment – Yealm estuary ©Nigel Mortimer

1.6.3 Pacific oyster settlement on seagrass

Seagrass beds are listed as a Habitat of Principal Importance in England. They are rich in biodiversity, are important nursery areas for juvenile fish and a highly efficient carbon store (Jackson and others 2001; Jackson and others 2013; Dahl 2017).

There are currently no UK-based studies on the impacts of Pacific oysters on seagrass beds. However, there is evidence that Pacific oysters are having a detrimental impact on intertidal seagrass beds in the US. Reductions in seagrass density (Tallis, Ruesink & Dumbauld 2009; Wagner and others 2012) and shoot size (Wagner and others 2012) have been recorded, suggesting that Pacific oysters can inhibit seagrass growth. Some studies however have reported increased water clarity, allowing seagrass to grow in deeper areas (Herbert and others 2012).

Seagrass beds are present in many bays and estuaries around the south west UK – areas where Pacific oysters have been recorded. Allowing Pacific oyster populations to spread to the intertidal and subtidal areas around seagrass meadows would potentially result in degradation of these important habitats.

There are two species of seagrass found in the south west – *Zostera marina* and *Zostera noltii*. *Z. marina* is the larger of the two species and the most common.

It is found predominantly in subtidal areas. The dwarf seagrass *Z. noltii* is an intertidal species and is only found in a handful of estuaries in the south west. Due to its intertidal distribution *Z.noltii* is at higher risk of being impacted by Pacific oysters through smothering and habitat loss.

Image 4: Pacific oysters within dwarf seagrass (Z. noltii) bed in the Salcombe estuary ©Adele Morgan

1.6.4 Potential benefits of Pacific oysters

It is possible that oyster reef formation may be beneficial to some species. Reefs create a complex three-dimensional structure that provides a substrate for attachment (for example: for mussels, using their byssal threads), or as a refuge for invertebrates such as shore crabs and gammarid shrimps (Snover and Commito 1998). An increase in surface area also provides space for algal and epifauna colonisation.

Barnacles, particularly the non-native Darwin's barnacle *Austrominius modestus*, have been shown to thrive on oyster reefs (Green and Crowe 2014). In areas of high oyster density, mud enriched with pseudofaeces from the oysters could result in high species diversity and biomass (Herbert and others 2018). Biodiversity has been shown to be greater on Pacific oyster reefs than within the sediment on which the oysters settle (Herbert and others 2012).

Studies have also suggested that Pacific oysters could have some potential benefits on the wider ecosystem. These benefits could include an increase in ecosystem services such as coastal defence, nutrient remediation, and carbon sequestration (Mangerud & Gulliksen 1975; Schatte and others 2018). As filter feeders molluscs remove nitrogen, phosphorus, and pathogenic microorganisms from the water column (Cerco and Noel 2007) and the filtering effect may improve water clarity. Other benefits include the provision of habitats for other organisms (Schatte and others 2018).

It is important to note the significant decline in native oyster (*Ostrea edulis*) populations around the UK, a species that would have previously performed many of these ecological functions. UK native oyster populations have declined by 95% since the mid-19th century (Native Oyster Network 2020), predominantly due to over harvesting (Helmer and others 2019). Other factors contributing to their decline include habitat loss, disease, competition from the non-native slipper limpet *Crepidula fornicata* (Helmer and others 2019), pollution (Rees and others 2001) and occasional severe winters (Crisp 1964). The Native Oyster Network for the UK and Ireland is currently working to restore native oyster populations through a partnership of academics, conservationists, industry, and NGOs. It is beyond the scope of this project to investigate the relationships between native oyster populations and feral Pacific oyster populations. Some studies have demonstrated potential coexistence of the two species (Christianen and others 2018; Zwerschke and others 2017) while others suggest little spatial overlap in preferred habitats, with native oysters being found predominantly in the subtidal area and Pacific oysters inhabiting the intertidal (Herbert and others 2016; Native Oyster Network 2021; Stagličić and others 2020). In south Devon and Cornwall there is currently no known spatial overlap between populations of the two species.

2. Distribution of Pacific oysters and the condition of Protected Areas in south Devon and Cornwall

The description of MPAs below focuses on target sites for this project and sites where there are known issues with Pacific oysters in south Devon and Cornwall; it is not exhaustive.

Features listed are those that have the potential to be impacted by Pacific oysters. Primarily these are intertidal features and bird species that rely on them. Saltmarsh National Vegetation Classification (NVC) communities have been combined together under Saltmarsh. Geological and geomorphological features have not been included, however there is the potential that Pacific oysters could impact geological features occurring in the intertidal area. Pacific oysters have the potential to cover geological features from view, especially as they form reefs, and this could lead to the features being assessed as being in unfavourable condition.

As set out in Natural England's revised MPA condition assessment method (Natural England 2020a) , when undertaking a Condition Assessment for an individual feature within an MPA, a suite of ecological and environmental attributes for that feature are assessed against its Conservation Objective targets to ascertain if met.

The Condition Assessment of features in MPAs contributes to the aggregation of network scale reporting required for international legislation (Habitats Directive and Birds Directive) and UK legislation (Marine and Coastal Access Act (MaCAA)). There is potential to use the assessments for reporting against the Marine Strategy Framework Directive and OSPAR in the future, which require information on the success of MPAs.

The presence of Pacific oysters in low numbers may not necessarily cause a feature to be considered to be in unfavourable condition. The assessment is made against specific attributes as detailed in either the Supplementary Advice on Conservation Objectives (a component of the Conservation Advice Packages published by Natural England) for each SAC, SPA and MCZ; or the Favourable Condition Table for SSSIs.

For SACs, SPAs and MCZs, there are both 'Principal' attributes and 'Secondary' attributes for each feature and sub feature. If one Principal attribute fails to meet its target, the whole of that feature (or sub feature) will be considered to be in unfavourable condition. This is also the case if two Secondary attribute targets fail. An example is shown in Table 1, which lists the Principal and Secondary attributes for intertidal rock within Plymouth Sound and Estuaries SAC that are relevant to Pacific oyster settlement. Intertidal rock is a sub feature of the features Estuaries, Reefs and Large shallow inlets and bays within the site. Where a site's features also have sub features, assessments are carried out at the sub feature level.

Table 1: Example from Plymouth Sounds and Estuaries SAC. Attributes of the Intertidal rock sub feature that may be or are already considered to have been impacted by Pacific oysters. Plymouth Sound and Estuaries SAC.

Feature	Sub feature	Principal Attribute	Target
Estuaries/ **Reefs/**	Intertidal rock	Distribution: presence and spatial distribution of biological communities	Restore the presence and spatial distribution on intertidal rock communities

Large shallow inlets and bays		Structure: species composition of component communities	Maintain the species composition of component communities
		Secondary Attribute	Target
		Structure: non-native species and pathogens	Reduce the introduction and spread of non-native species and pathogens, and their impacts.

For SSSIs the condition of each feature is assessed at the site scale using the attributes and site-specific targets detailed within the site's Favourable Condition Table (FCT). The FCTs have been developed using the Common Standards for Monitoring (CSM) and associated guidance for feature assessment agreed by the UK country agencies and the Joint Nature Conservation Committee (JNCC) (Natural England 2019a). The FCT sets the minimum standard for favourable condition for the designated feature. SSSIs have both Mandatory attributes and Discretionary attributes. If at least one of the designated features' mandatory attributes is not meeting its target the feature will be assessed as being in unfavourable condition. 'Discretionary attributes' are 'early warning signs' that whilst the feature is currently favourable, without timely intervention the feature will decline (Natural England 2019b). All SSSIs in England are divided into one or more units which typically separate different areas of habitat and/or land ownership. Units are used to link the condition of a designated site feature to the risks, remedies and management relevant to a particular part of that site, and hence be more specific about where on a site the management is having the desired effect, or requires some adaptation (Natural England 2019b).

If attributes do not meet their condition targets due to Pacific oyster abundance, and the feature concerned is assessed as being in unfavourable condition, a requirement for management is triggered.

At lower Pacific oyster densities, for example Occasional or Rare on the SACFOR scale (Table 4) (Connor and others 2004), intertidal rock biological communities may not be impacted. However, once a certain density is reached, community structure may be altered with Pacific oysters dominating the communities and altering the species composition. At higher density thresholds, for example Abundant or Superabundant on the SACFOR scale, a habitat may change from one type to another (i.e. loss of the designated habitat). The density at which Pacific oysters cause a change from habitat to another will be dependent on the specific habitats present. For some habitats changes may be seen at even lower densities.

There are no described biotopes that include Pacific oysters, presumably due to their absence from large areas of British and Irish coasts when biotopes were first described as part of JNCC's Marine Nature Conservation Review in the 1990s. However, this may also be in part due to the fact that the biotope descriptions only highlight the key species that help to define the biotope. The Marine Habitat Classification of Britain and Ireland was first published in 1997 (Connor and others 1997 a & b) and updated in 2004 (Connor and others 2004). Pacific oysters do not feature in either version. It may now be necessary make updates to the classification to describe new Pacific oyster characterised biotopes where this species dominates and to update some previously existing biotope descriptions if Pacific oysters now form a prominent part of the community.

Work to improve Natural England's Condition Assessment process, attribute targets and target measurability has been undertaken and the method now incorporates a more rigorous assessment using an ecosystem approach. This is enabling more rigorous assessment of the extent, distribution, structure, functions and supporting processes of features, but further in-depth research is required to improve our understanding of community adaptation to Pacific oyster invasions.

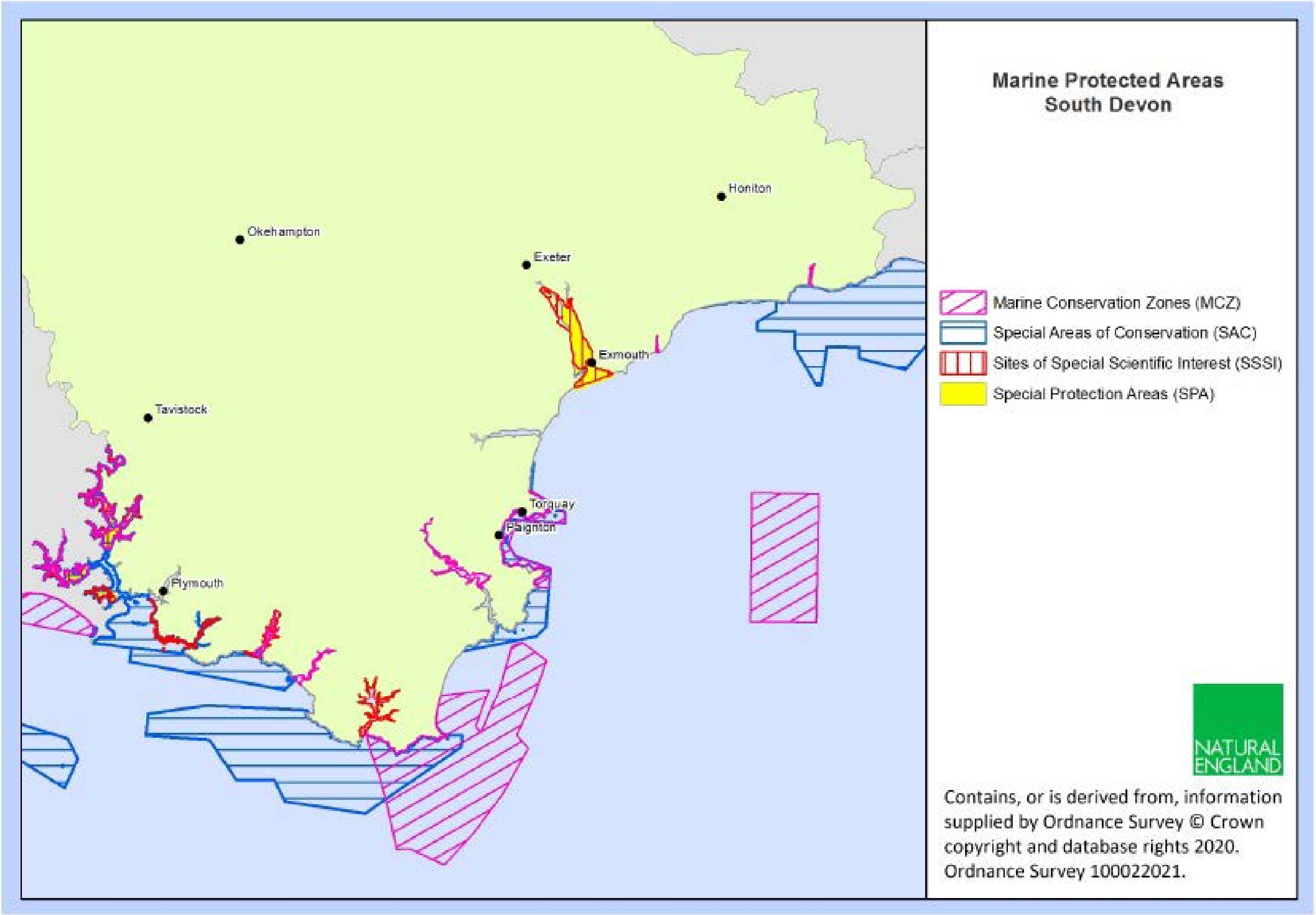


Figure 1: MPAs in south Devon

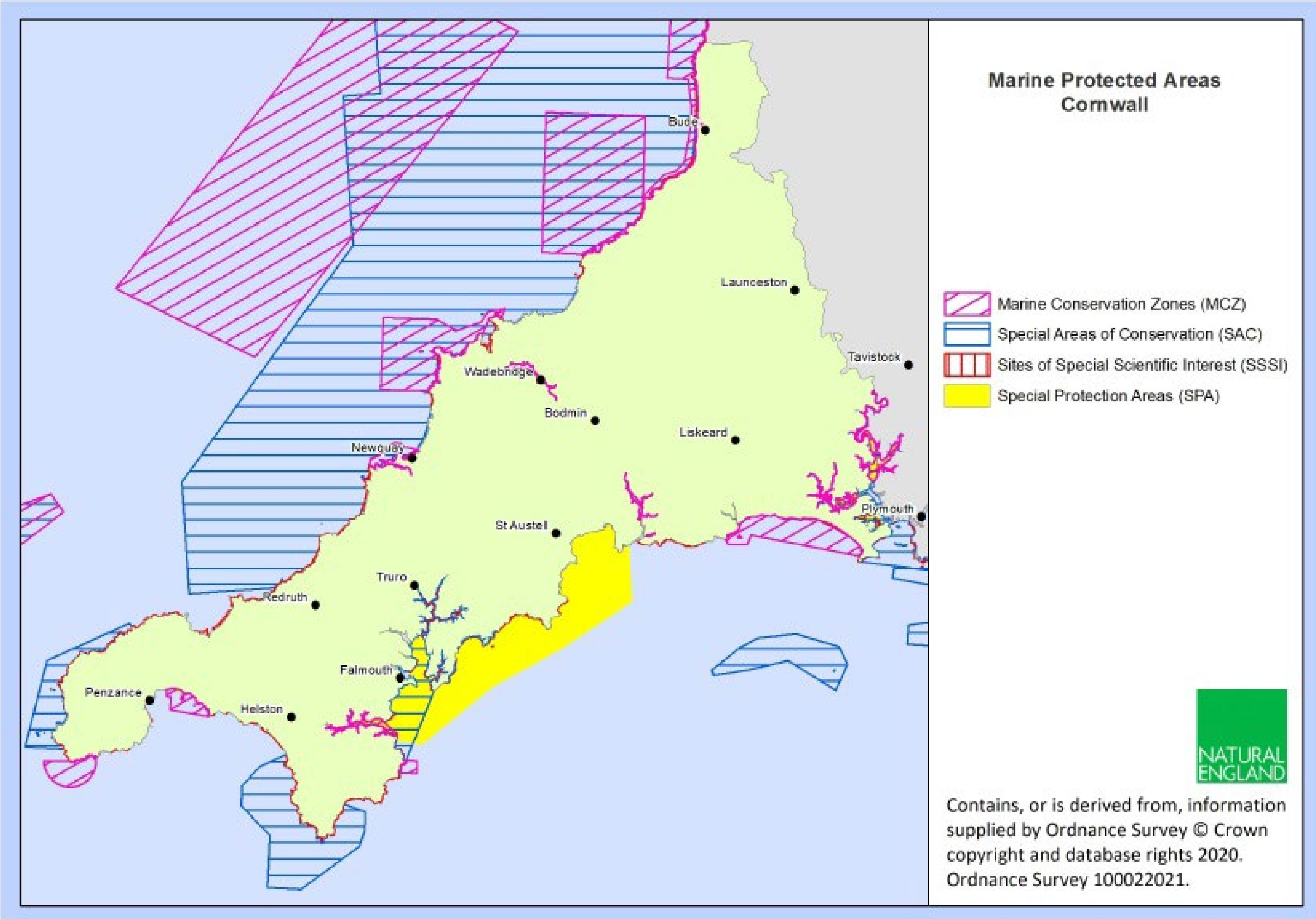


Figure 2: MPAs in Cornwall

2.1 Pacific Oysters within MPAS in south Devon and Cornwall

This section summarises data on Pacific oysters in south Devon and Cornwall that Natural England either held or was aware of prior to the start of this project, along with results of other surveys that were carried out during the timeframe of this project but were separate to it. Quadrat surveys are used to work out species abundance. This is often recorded using the SACFOR scale (Table 4). Further information on the observations and surveys listed in table 2 can be found in Appendix 4.

Table 2: Pacific oyster records within south Devon and Cornwall MPAs.

MPA	Location	Density / No. of Pacific oysters	Date	Source
Mounts Bay MCZ	St Michael's Mount	Present	2005	National Biodiversity Network Atlas 2002
	St Michael's Mount and Marazion	Present	2016 & 2017	
	Penzance & Newlyn	Present	2018	
Fal & Helford SAC	Fal	75 collected for research	2009 – 2011	Lallias and others 2015
	Fal Estuary	Av. density 0.07 per m²	2014	Russell 2019
	St Mawes to Turnaware Point	Max. density 48 per m²	2017	Natural England 2017e
	Mouth of Carrick Roads	Present	2016 - 2018	National Biodiversity Network Atlas 2020
	Percuil River	Present	2018	

	St Mawes	Present	2019	
	Near Tregothnan Estate & Roundwood Quay	Present	2020	Gall, A. personal communication 2020
	Men-aver Point, Helford Estuary	Present	1994	National Biodiversity Network Atlas 2020
	Helford	Max. density 1.12 per m^2	2014	Russell 2019
	Port Navas Creek, Helford	Max. density 12.3 per m^2	2015	
	Calamansac (small area of shore)	38 individuals (juveniles) 190 individuals (adults)	2014	
	Calamansac (small area of shore)	2695 individuals (juveniles) 1029 individuals (Adults)	2015	
	North of Ponsence cove	Present	2015	National Biodiversity Network Atlas 2020
	Near Treath	Present	2017	
Upper Fowey and Pont Pill MCZ	Fowey	Present	2005	
	Outer Fowey Estuary	Present Present	2012 2017	National Biodiversity Network Atlas 2020 Natural England 2017f
	Penpoll Creek to Pont Pill	Max. density 2.7 per m^2	2014	Evans 2014

	Wiseman's Reach to Pont Pill	Common to Abundant (SACFOR scale) Superabundant on one area of intertidal mud.	2017	Natural England 2017f
	Pont Pill	Max. density 356 per m² Superabundant on northern shore	2017 2018	Natural England 2017f Natural England 2019g
Whitsand and Looe Bay MCZ	East Looe Seaton	Present	2005	National Biodiversity Network Atlas 2020
	Long Sands	Present	2016	
	Whitsand Bay	Occasional to Frequent (SACFOR scale)	2019	Natural England 2020c
Plymouth Sound and Estuaries SAC	Yealm Estuary	Present Present (established populations on bedrock and boulders)	1997 onwards 2001	National Biodiversity Network Atlas 2020; Bunker and others 2002
	Newton Ferrers, Yealm Estuary Passage Wood Court Wood	Present Av. density: 4.4 per m² Av. density: 30.9 per m² Av. density: 32 per m²	2007 2014 2014 2014	National Biodiversity Network Atlas 2020 Russell 2019 Russell 2019 Russell 2019

	Outer Yealm Estuary Clitters Wood, Yealm Estuary	Present Common 188 per m²	2006 - 2007 2009 2011 2016	Bishop Group – Marine Biological Association - unpublished) Natural England 2011 Marine Ecological Surveys Limited 2017
	Yealm Estuary – various locations	Common (average densities at various sites) Abundant to superabundant in some areas and significant increases in all areas from 2014	2014 2015	Russell 2019
	Yealm Estuary - Noss Mayo (Ship Inn to Kilpatrick Steps)	Peak densities of 80 per m²	2017	Natural England 2018c
	Yealm Estuary – various locations	Occasional to abundant	2017	Curtis 2018
	Yealm Estuary – Cellar Beach	Present	2018	Bishop Group – Marine Biological Association - unpublished)
	Mountbatten/ Batten Bay	Present	From 2004	Bishop Group -Marine Biological Association Unpublished; National Biodiversity Network Atlas 2020
	Jennycliffe	Present	From 2007	

	Wearde Quay	2.4 per m²	2014	Russell 2019
	Beggars Island	Present 15.5 per m² Reef	2008 2014 2019	Bishop Group -Marine Biological Association Unpublished; National Biodiversity Network Atlas 2020 Russell 2019 Hooper 2019
	Mount Edgcumbe	Present	2019	Curtis 2018; National Biodiversity Network Atlas 2020
	Lynher Estuary	Present	2015 & 2016	Jenkin and others 2016
	St John's Lake	Common (or higher) Reefs present	2017 2019	Curtis 2018 Hooper 2019
	Lower Tamar-Tavy Estuary	Frequent	2017	Curtis 2018
	Upper Tamar – Hole's Hole Kingmill Lake	Present	2018	Bishop Group – Marine Biological Association – unpublished
	Kingsand	Average density 0.48 per m²	2019	Hooper 2020
	Cawsand	Average density 1.02 per m²	2019	

	Sandways	Average density 0.86 per m²	2019	
	Cremyll	Average density 0.07 per m² Reefs present	2019	
	Empercombe	Reefs present	2019	Hooper 2020
	Cove Point	Reefs present	2019	
Erme Estuary MCZ	Erme Estuary mouth	Present	2005 & 2007	National Biodiversity Network Atlas 2020
Devon Avon Estuary MCZ	Devon Avon Estuary	Present	2013 & 2016	Natural England 2013b; 2018d
Salcombe and Kingsbridge Estuary SSSI	Salcombe estuary	Present	2009-2011 2016	Lallias and others 2015 Natural England 2018d
Dart Estuary MCZ	Galmpton Creek, Middle Back & Dittisham Creek Duncannon Greenway & Mill Point	Common to Abundant Frequent to Common Abundant to Superabundant	2013 & 2014 & 2016 2017-2019	Natural England 2013c; 2014c, 2018c Bishop Group – Marine Biological Association – unpublished
Exe Estuary SPA	Cockwood & Dawlish Warren oyster beds Between Starcross & Cockwoodd	Present Present	1985 & 2009-2014 2016	National Biodiversity Network Atlas 2020; Bishop Group – Marine Biological Association – unpublished Natural England 2017g; 2018c

	Cockwood foreshore	Av. density 16.8 per m²	2020	Boyle 2020
	Lympstone	Pacific oyster bed present	2017	Devon & Severn IFCA 2017

2.2 Summary of features currently known to be in unfavourable condition due to Pacific oyster presence

Table 3 below summarises MPA features in south Devon and Cornwall MPAs that have had a Condition Assessment and where Pacific oysters have been identified as a reason for unfavourable condition. This is based on the latest Condition Assessments prior to the publication of this report. The location of these MPAs can also be seen in Figure 3 below.

This report highlights the increasing distribution and abundance of Pacific oysters and therefore it is likely the list of features tabled below will increase once further MPA features undergo an updated Condition Assessment. This study highlights additional sites where high densities of Pacific oysters have been found. This may lead to a change in condition or the factors contributing to unfavourable condition status for some features when a new Condition Assessment is undertaken. With the increasing levels of Pacific oysters in the area, it is likely that this may also be the case for other MPAs in the future.

Table 3: Features of MPAs in south Devon and Cornwall that have been assessed as in unfavourable condition due to Pacific oysters based on latest Condition Assessment or MCZ vulnerability assessment prior to this report being published. N.B. There may also be other factors affecting the condition of the features.

Marine Protected Area	Feature	Subfeature
Fal and Helford SAC	Estuaries	Intertidal mixed sediments
		Intertidal mud
		Intertidal sand and muddy sand
Fal and Helford SAC		Intertidal mixed sediments

	Mudflats and sandflats not covered by seawater at low tide	Intertidal mud
		Intertidal sand and muddy sand
Fal and Helford SAC	Large shallow inlets and bays	Intertidal rock
		Intertidal sand and muddy sand
Fal and Helford SAC	Reefs	Intertidal rock
Helford MCZ	Native oyster (*Ostrea edulis*)*	n/a
Plymouth Sound and Estuaries SAC	Estuaries	Intertidal mud
		Intertidal rock
Plymouth Sound and Estuaries SAC	Mudflats and sandflats not covered by seawater at low tide	Intertidal mixed sediments
Plymouth Sound and Estuaries SAC	Reefs	Intertidal rock
Yealm Estuary SSSI	Exposed rocky shores (predominantly extremely exposed to wave action)	n/a
Yealm Estuary SSSI	Moderately exposed rocky shores	n/a
Yealm Estuary SSSI	Moderately exposed sandy shores (with polychaetes and bivalves)	n/a
Yealm Estuary SSSI	Muddy gravel shores Sheltered muddy shores (including estuarine muds)	n/a
Yealm Estuary SSSI	Sheltered rocky shores (predominately sheltered to very sheltered from wave action)	n/a

Yealm Estuary SSSI	Shores of mixed substrata (stones AND sediment)	n/a
Dart Estuary MCZ	Estuarine rocky habitats*	n/a
Dart Estuary MCZ	Low energy intertidal rock*	n/a

*Based on a risk-based vulnerability assessment undertaken as part of the MCZ designation process.

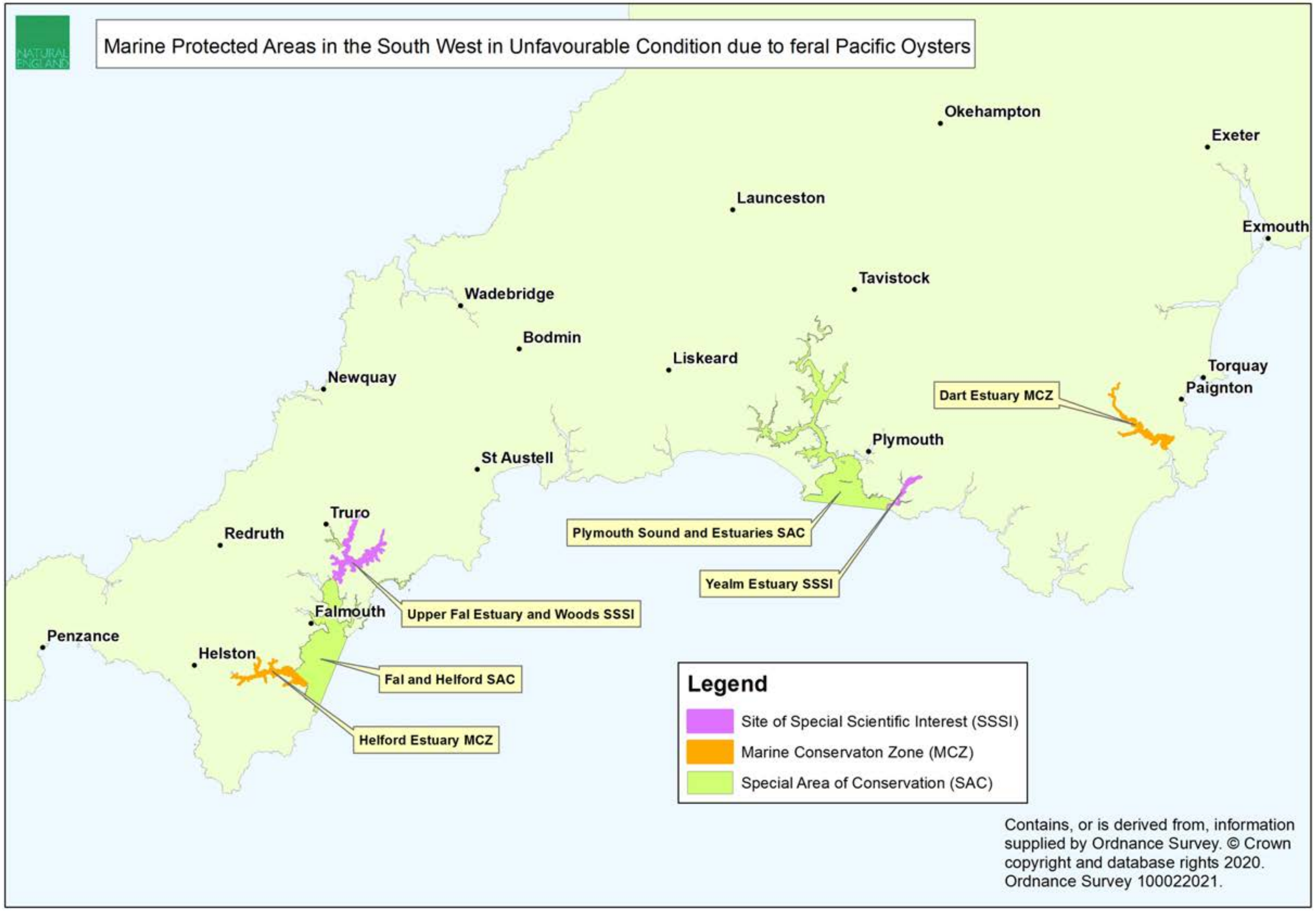


Figure 3: Marine Protected Areas in the south west with features in unfavourable condition due to Pacific oysters (Table 2 lists the unfavourable features of each MPA)

3. Pacific oyster surveys with volunteers

3.1 Aims

The project's aims for Pacific oyster surveys were to:

- Ascertain the existing distribution and population density of Pacific oysters around the coast of Cornwall and south Devon and identify Pacific oyster hotspots, focusing on Marine Protected Areas
- Record other Invasive Non-Native Species (INNS)
- Monitor settlement rates

These aims would be achieved by:

- Coordinating a network of volunteers to monitor Pacific oyster populations and settlement rates around Cornwall and south Devon

3.2 Survey Methodology

3.2.1 Volunteer recruitment

Cornwall Wildlife Trust

Work to monitor and manage Pacific oysters had already begun before the start of the project in 2017 by a few dedicated volunteer teams; Roseland National Trust, Helford Voluntary Marine Conservation Group and Friends of the Fowey estuary. Between 2018 and 2019, 13 volunteer groups were trained in Pacific oyster monitoring and management through Cornwall's 'Your Shore' Network. These volunteer groups operated regular surveys within the Falmouth and Helford Special Area of Conservation (SAC) and further afield.

These groups are:

- Helford Marine Conservation Group
- Friends of the Fowey estuary
- Ladies who Launch (Mylor Yacht Club)
- Falmouth Marine Conservation Group
- Restronguet Creek Society
- Mount's Bay Marine Group
- St Ives Marine Group
- Three Bays Wildlife Group

- Friends of Par beach
- National Trust Roseland
- National Trust Trelissick
- Looe Marine Conservation Group
- Rame Peninsula Beach Care

Four additional groups were asked to look out for Pacific oyster settlement in their areas:

- Polzeath Marine Group
- St Agnes Marine Group
- Newquay Marine Group
- Bude Marine Group

South Devon AONB

The South Devon AONB Estuaries Partnership did not previously have a volunteer scheme and it took considerably longer than anticipated to set up. Various issues including hesitation from the local community and a lack of insurance meant that they were reliant on gaining volunteers directly through the coordination and leadership of the South Devon AONB unit. This system worked well however, and they were able to maintain a high quality of individual events with their dedicated volunteers.

3.2.2 Surveyor training

Volunteer training was provided by both project partners and took place before and/or during surveys. Individuals were trained on:

- The background of the project and survey method
- Pacific oyster identification vs European/native oyster (Fig 4)
- Health and safety procedures including risk assessments and personal protective equipment (PPE)

During training, community groups were provided with hard copy documents of the survey method and flyers that could be given out to landowners and members of the public when necessary. These were designed and produced by Natural England (Copy available upon request).

Figure 4: Oyster identification poster. ©Cornwall Wildlife Trust

Image 5: South Devon AONB Training day ©Adam Davison

3.2.3 Marine Biological Association non-native species training

Early in the project it was recognised it would be beneficial to offer volunteers the opportunity to attend a course on non-native species at the Marine Biological Association. This was in order to increase awareness and reporting of invasive non-native species (INNS) by volunteers as they undertook Pacific oyster surveys. The course was led by Dr John Bishop and Christine Wood, who gave an illustrative talk on different non-native species, key identification, biology and ecology, history, and the impacts that these species have on our shores. Fresh and preserved specimens were incorporated into the training.

Image 6: Marine Biological Association Non-Native Species training day ©Matt Slater

3.2.4 Permissions

Permissions from key landowners were obtained for access to the foreshore for both surveys and culling events. Where multiple small private landowners were identified, a good attempt to contact them was made.

Obtaining relevant permissions proved time consuming and volunteer groups had to undertake much of this work to ensure permissions were in place in time. Cornwall Wildlife Trust ensured that Falmouth oyster fishermen were aware of the project. A meeting was held with the Fal estuary fishermen, and the Fal Fishery Advisory Group were kept updated at their biannual meetings. Surveys carried out within some parts of the Fal and Helford Special Area of Conservation required permission from Cornwall Inshore Fisheries & Conservation Authority (CIFCA) who have responsibility for the management of shellfisheries within the Fal Fishery area (under the Fal Fishery Regulation Order). A licence was obtained for surveys and manual control work to be carried out within this area by named groups until the end of March 2020.

The groups were informed by CIFCA that permission from them was not necessary for areas outside of the Fal Fishery. CIFCA requested however, that all groups carrying out oyster surveys and culls could please contact them by phone or email before the event to give prior warning of their activities, should it cause concern to members of the public and result in CIFCA being contacted.

3.2.5 Health and safety considerations

It was ensured that all volunteers wore the correct PPE before surveying. This was to prevent injury, not only to themselves but also to other volunteers. PPE such as goggles, masks, gloves and a first aid kit were provided by project partners prior to the start of the survey. It was the responsibility of the volunteers to wear suitable footwear, either tough wellingtons or steel toe cap boots and suitable clothing.

Before surveying, a risk assessment was submitted, and on the shore a health and safety briefing was carried out by project partners to remind people of the risks and hazards involved. When working on challenging terrain it was advised that buddy systems were in place so that volunteers could keep an eye on each other at all times.

Volunteers were also reminded to take care to avoid injury from lifting, bending over and repetitive strain.

Image 7: Sharp Pacific oyster bed. ©Nigel Mortimer

3.2.6 Equipment

- Copy of the survey methodology (Copy available upon request)
- Survey recording sheets (as many as required) (Appendix 3)
- pencil x2
- counter x1
- 0.25m^2 quadrat (0.5m X 0.5m) x1
- 5m (or longer) measuring tape or rope x1
- GPS tracker x1
- camera (optional)
- clipboard x1
- first aid kit X1

3.2.7 Walkover survey

For areas which exhibit a low to medium density of Pacific oysters (<2 oysters per 0.25m^2), a walkover survey method was used to count the number of individuals in a set area of the shore.

Before the survey begun, the date, time, location, substrate, and surveyor names were recorded on the survey recording form. The GPS location was also noted to mark the start of the survey area and a photo of the route was taken if necessary.

The surveyors walked in a line between the upper and lower shore parallel to the water's edge. The survey area covered 2m either side of the route. The GPS coordinates of the location were recorded once 50 Pacific oysters had been counted on the handheld clicker and/or the direction of the route dramatically changed mid route. The total number of Pacific oysters observed between each set of coordinates were recorded on the survey form alongside the substrate type and other notes deemed important.

3.2.8 Quadrat survey

If the number of Pacific oysters recorded were approximately 2 or more within a 0.25m^2 area, a quadrat survey was recommended. Similar to the walkover survey, the GPS coordinates were recorded at the start of the survey area. A measuring tape (5m or longer) was usually positioned along the survey route parallel to the water's edge. A 0.25m^2 quadrat was placed every 5m along the tape though some were estimated. The GPS coordinates were recorded at each quadrat (though for a few surveys without GPS positions, positions were estimated retrospectively using a computer algorithm), in addition to the substrate type and Pacific oyster count. If the quadrat was positioned over an area with seaweed cover or loose rocks, they were turned over to check for Pacific oysters and carefully replaced to reduce disturbance to the habitat. If the density of oyster's decreased to below 2 oysters per quadrat, it was recommended that the survey method should switch back to the walkover method.

3.2.9 Mapping and density calculations for this report

Mapping walkover survey data

For the walkover surveys, the raw data was used to calculate density/m^2 for each segment of cull data. The distance surveyed was measured using ArcGIS. The distance was then multiplied by the width of the shore supposed to be covered (4m) to estimate the surveyed area (m^2) per segment. The individual counts of Pacific oysters in each segment were added and the total number recorded was divided by the area to calculate the density per m^2 within each of the walkover survey segments.

Area (m^2) = Distance surveyed (m) X 4m width

Density per m^2 = Number of Pacific oysters ÷ Area (m^2)

Mapping quadrat survey data

For the quadrat surveys the density per m^2 was estimated by dividing the individual quadrat oyster counts by the quadrat size (0.25m^2).

Density per m^2 = Individual oyster count per quadrat ÷ 0.25

Mapping

Both sets of density results were split into similar numeric categories to the SACFOR scale (Table 4). Each numeric category was assigned a colour to show the lowest and highest densities in an area.

Table 4: SACFOR scale

Category	No. Pacific oysters (m^2)
Rare	<0.009
Occasional	0.01 - 0.09
Frequent	0.1 - 0.9
Common	1 – 9
Abundant	10 – 99
Superabundant	100 – 999

3.3 Results

3.3.1 Pacific oyster distribution and densities in Devon and Cornwall

Pacific oysters have been recorded during this study from St. Ives Bay and Newlyn in west Cornwall to the Salcombe and Kingsbridge estuaries in south Devon. They are present in every estuary to some degree along this stretch of the Cornwall and Devon coast. The Avon estuary in Devon was not surveyed as part of this project, however a small number of Pacific oysters have been seen there in the past (Natural England 2018d). Data collected and submitted to us from the Exe Estuary Partnership also recorded Pacific oysters on the Exe estuary (Boyle 2020).

Figure 5 shows the locations of the quadrat surveys and Figure 6 shows the location of the walkover surveys undertaken in the project area.

Quadrat surveys were carried out at the Helford estuary, Fal estuary, Par, Fowey estuary, Looe river and Plymouth Sound and estuaries including the Yealm estuary.

Quadrat survey data from Cockwood on the Exe estuary was also submitted to us by the Exe Estuary Partnership.

Walkover surveys were carried out at St Ives, Mount’s Bay, Helford estuary, Maenporth, Fal estuary, Portholland, Goran Haven, Par, Fowey estuary, Looe river, Whitsand Bay, Plymouth Sound, and estuaries including the Yealm estuary, Erme estuary and Salcombe and Kingsbridge estuaries.

Pacific oysters are likely to be present at many other locations not identified within this results section. A lack of data should not be taken to mean that no Pacific oysters are present as it was beyond the scope of this project to survey the entire coastline. There were however a few very small sections of shore identified during walkover surveys where Pacific oysters were not seen during this study. These were:

- Fal estuary: between Penpol Creek and Tallack’s Creek on the northern side of Restronguet Creek
- Par Beach: a very small section of the shore in the north east corner
- Plymouth: a very short length of shore at the southern end of Sand Acre Bay; a short section on the southern side of Torpoint; the southern shore of Millbrook Lake; and Plymouth Breakwater.

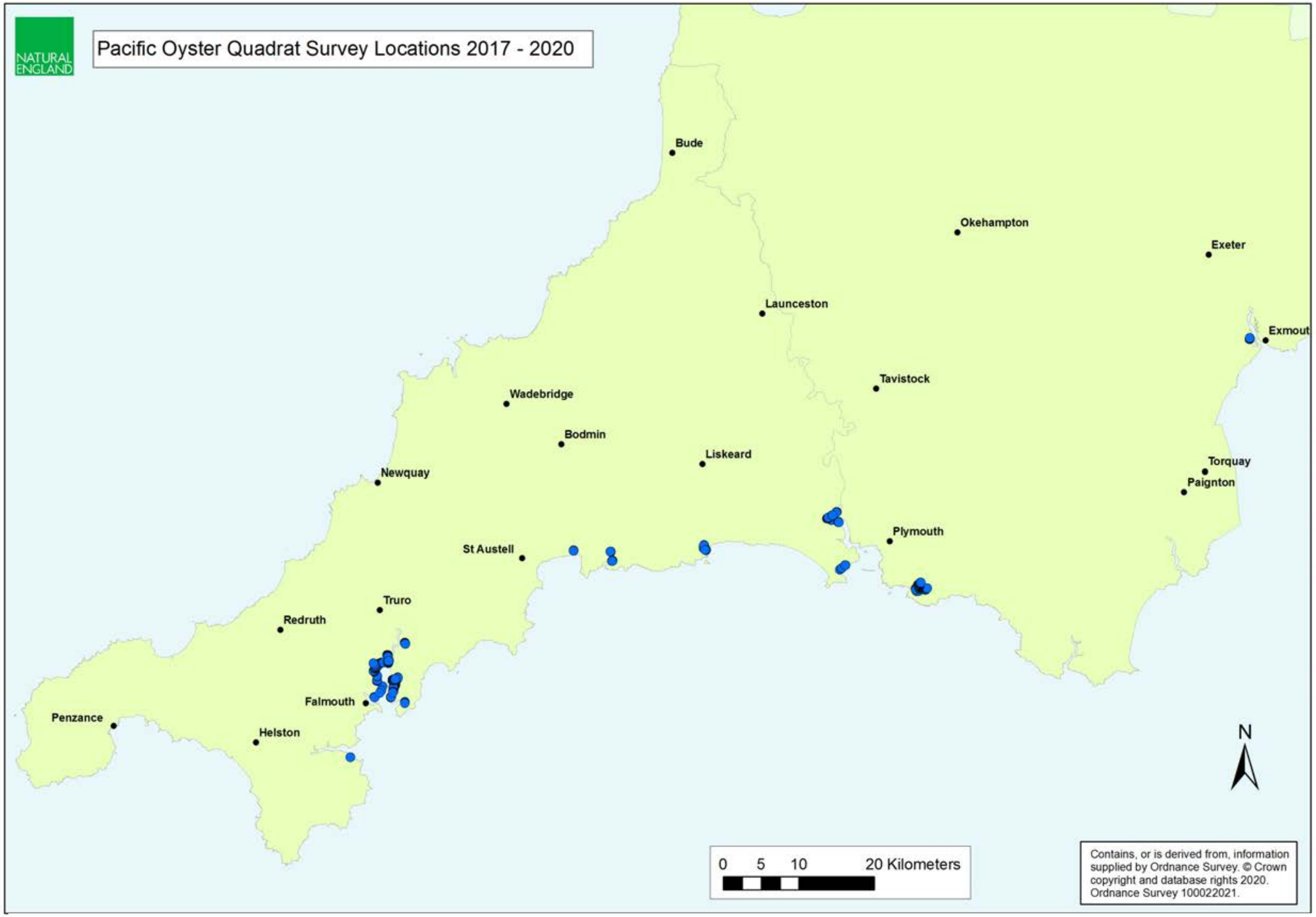


Figure 5: Locations of quadrat surveys within the project area

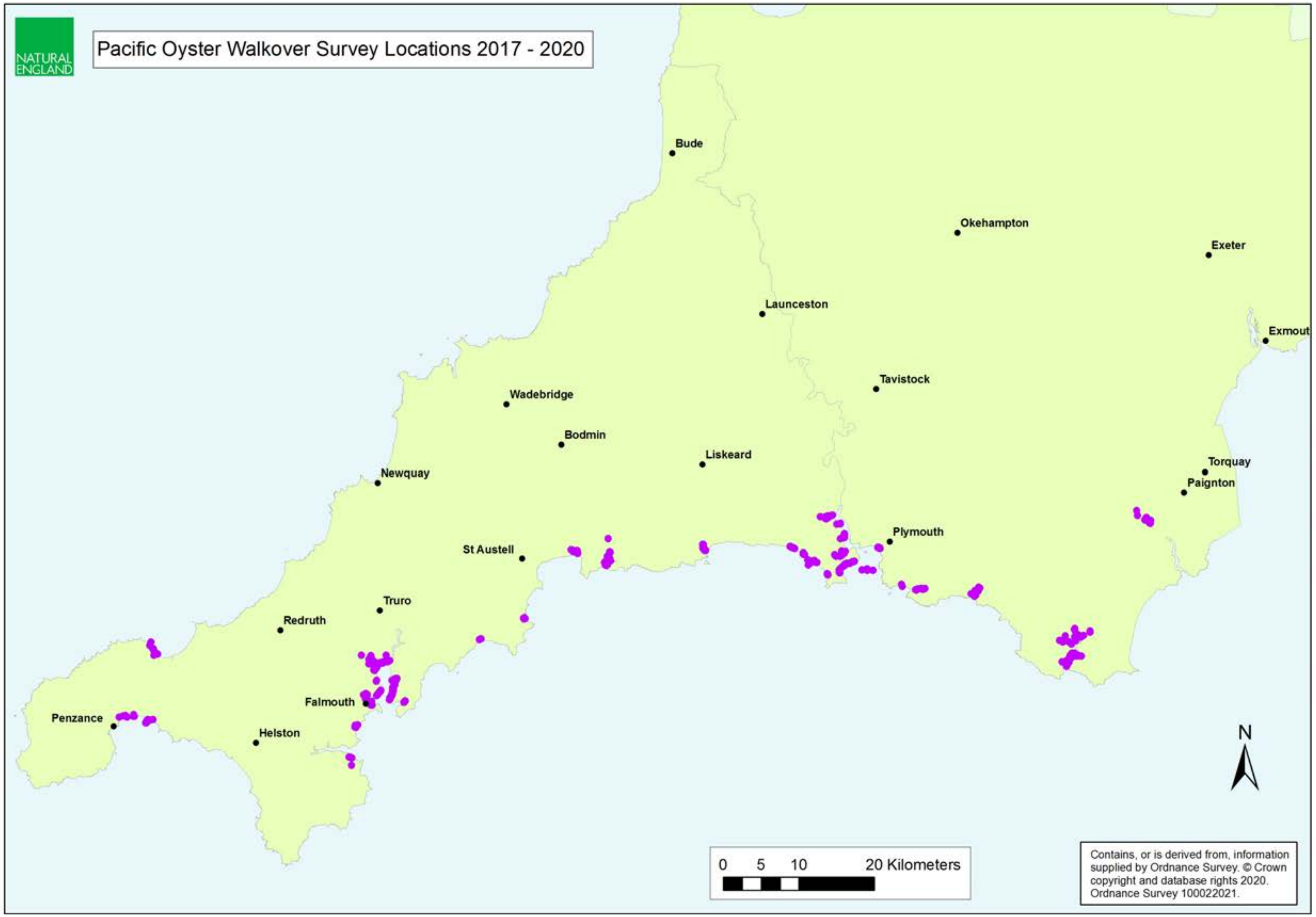


Figure 6: Location of walkover surveys within the project area

3.3.2 Pacific oyster hotspots and reefs

Although Pacific oysters were widely distributed across the study area, the density of Pacific oysters varied throughout the region.

Hotspots were identified at several locations. In these areas Pacific oysters were Superabundant on the SACFOR scale, and densities of more than 100/m^2 were recorded in at least one area. Pacific oysters were Superabundant at the following locations:

- Fal estuary: Restronguet Creek, Loe Beach, Tregothnan Park (Deer Park) and south of St Just Pool
- Fowey estuary: Mixtow Pill and Pont Pill
- Plymouth: The Cove, near Wilcove
- Yealm estuary: Machine Beach, Newton Ferrers and Noss Mayo.

On the Fowey, Pacific oysters were also recorded as Superabundant on average along a section of shore to the south of Mixtow Pill with 280/m^2. Similarly, at Plymouth Sound, at The Cove near Wilcove, Pacific oysters were on average Superabundant with 164.5/m^2.

The highest densities of Pacific oysters recorded were:

- 396/m^2 at Wilcove on Torpoint in Plymouth Sound
- 356/m^2 to the south of Mixtow Pill (2017) on the Fowey estuary
- 280/m2 to the west of Loe Beach
- 220/m^2 at Noss Mayo on the Yealm estuary*

  * *Data received post analysis in 2020 show maximum density of 336/m^2* (Mortimer, personal communication 2020).

Prior to the start of this project Pacific oysters were only known to be forming reefs in the project area within the Yealm estuary (Image 3). A previous survey in the Yealm estuary for Natural England (2018c) defined reefs as areas where there was 100% cover or more of Pacific oysters. Project officers have noted that Pacific oyster reefs are now present or starting to form at several locations. However, it should be noted that this is subjective opinion and not based on the above definition. These areas are:

- Helford estuary: the beginnings of reef formation at the entrance to Port Navas Creek on both sides, at Port Navas, and around Helford Point and Treath
- Fal estuary: St Just Pool, Tregothnan (Deer Park), and Channals Creek

- Fowey estuary: Mixtow and Pont Pill
- Plymouth Sound: Cove Point at Torpoint
- Yealm estuary
- Salcombe estuary: in intertidal seagrass to the west of Gerston Point at the entrance to Collapit Creek on the northern shore

The majority of the suggestions reflect those areas where very high densities of oysters were recorded during the quadrat surveys; with the exception of Channals Creek on the Fal, all sites on the Helford, and at Collapit Creek on the Salcombe estuary where Pacific oysters were observed in the seagrass beds. At Channals Creek the quadrat surveys found Pacific oysters to be Abundant (10-99/m^2). No quadrat surveys were carried out at this location on the Helford estuary or on the Salcombe estuary.

3.3.3 Areas with high densities of Pacific oysters

In addition to the hotspots noted above, Pacific oysters were also found to be Abundant (10-99/m^2) in many areas. This is of concern as previously in Devon and Cornwall, features of MPAs that were found to have Abundant levels of Pacific oyster's present have been determined to be in unfavourable condition. Areas where Pacific oysters were on average found to be Abundant (using quadrat data) were:

Fal estuary:

- Greatwood Quay
- Restronguet Creek
- to the east and west of Loe Beach at Feock
- west side of Channals Creek
- Turnaware Point
- Tregothnan Park
- St Just Pool
- Messack Point to Messack House
- St Just Creek
- near Halwartha

Par beach

Fowey estuary:

- South of Mixtow Pill
- Pont Pill

Looe

Plymouth:

- near Churchtown Farm Nature Reserve
- Beggars Island to Juniper Point
- Cawsand

Yealm estuary:
- Machine Beach
- Passage Wood
- Clitters Wood
- between Court Wood and Newton Ferrers Harbour Office
- near Newton Ferrers Harbour Office
- north shore of Newton Creek
- Noss Mayo
- southern shore of Newton Creek

Exe estuary:
- Cockwood

In addition to these areas the walkover surveys suggest there are also Abundant levels of Pacific oysters near Freathy in Whitsand Bay, and at Mount Batten in Plymouth.

3.3.4 Areas with notable densities of Pacific oysters

Additional areas had on average Common (1-9/m^2) levels of Pacific Oysters. A previous survey in the Yealm estuary for Natural England (2018c) defined areas where Pacific oysters were Common on the SACFOR scale as notable. These are areas to watch as they could become Abundant. These additional areas include all the other areas that were surveyed using quadrats: Helford estuary – St Anthony; Fal estuary – Flushing beach, Penarrow Point at Trefusis, Mylor Beach, Weir Point at Feock, Restronguet Weir Beach to Pandora Inn, St Mawes towards St Just, Back Rock at Lowlands Beach and the north shore of St Just Creek; Plymouth – Wearde Quay.

In addition to these areas the walkover surveys suggest there are also Common levels of Pacific oysters by Falmouth, at Par, in Whitsand Bay, and at Salcombe and Snapes Point on Salcombe estuary.

The walkover surveys appear to have routinely underestimated the densities of Pacific Oysters by one category on the SACFOR scale when compared to the quadrat surveys (note that this has not been statistically analysed).

3.3.5 Site specific density information

Site specific information is provided from west to east. Survey location site names from the datasheets are provided in brackets to aid future reference as these were not always intuitive or correctly labelled with respect to the location on the map.

3.3.6 St Ives (Figure 6)

Walkover surveys suggest that Pacific oysters are Frequent (0.1-0.9/m^2) at St Ives.

3.3.7 Mounts Bay (Figure 6)

Walkover surveys suggest that Pacific oysters are Frequent (0.1-0.9/m^2) throughout much of the bay. However, there were two pockets where they were found to be Common (1-9/m2). One on a pipe near Eastern Green Road and the other on the eastern pier of the harbour at St Michael's Mount.

3.3.8 Helford Estuary (Figure 5)

Results from only three quadrats were available from the Helford estuary, surveyed at St Anthony-in-Meneage in 2017. Pacific oysters were Common (1-9/m^2) in all three quadrats with an average density of 6.67/m^2 and a maximum of 8/m^2. A walkover survey in this area recorded Frequent Pacific oysters between 0.01-0.09/m^2 (Figure 6). Extensive culling has taken place throughout the Helford estuary since then by the Helford Marine Group.

3.3.9 Fal Estuary

Abundant levels of Pacific oysters (10-99/m^2 or greater) were recorded at all sites surveyed throughout the estuary at some point during the course of this project. At this level Pacific oysters are dense enough to be considered to be causing the underlying habitats to be in unfavourable condition.

Extremely high numbers of Pacific oysters were found at four locations around the estuary where Superabundant (≥100/m^2) densities were recorded.

Western side:

- Restronguet Creek (Figure 9)
- Loe Beach (Figure 9)

Eastern side:

- Tregothnan Park (Deer Park) (Figure 11)
- south of St Just Pool (Figure 13).

Trefusis Point to Penarrow Point (Figure 7)

On the western side of the Fal estuary between Trefusis Point and Penarrow Point, densities of up to Abundant (10-99/m^2) were recorded. At Flushing beach, the average density of Pacific oysters in 2017 was 6.18/m^2 with a maximum density of 12/m^2. On the section of shore between Trefusis Point and Penarrow Point in 2019 the average density was 9.33/m^2 with a maximum density of 28/m^2. To the north of this at Penarrow Point (site name = Mylor Beach) in 2017 the average density was 8/m^2 with a maximum of 12/m^2.

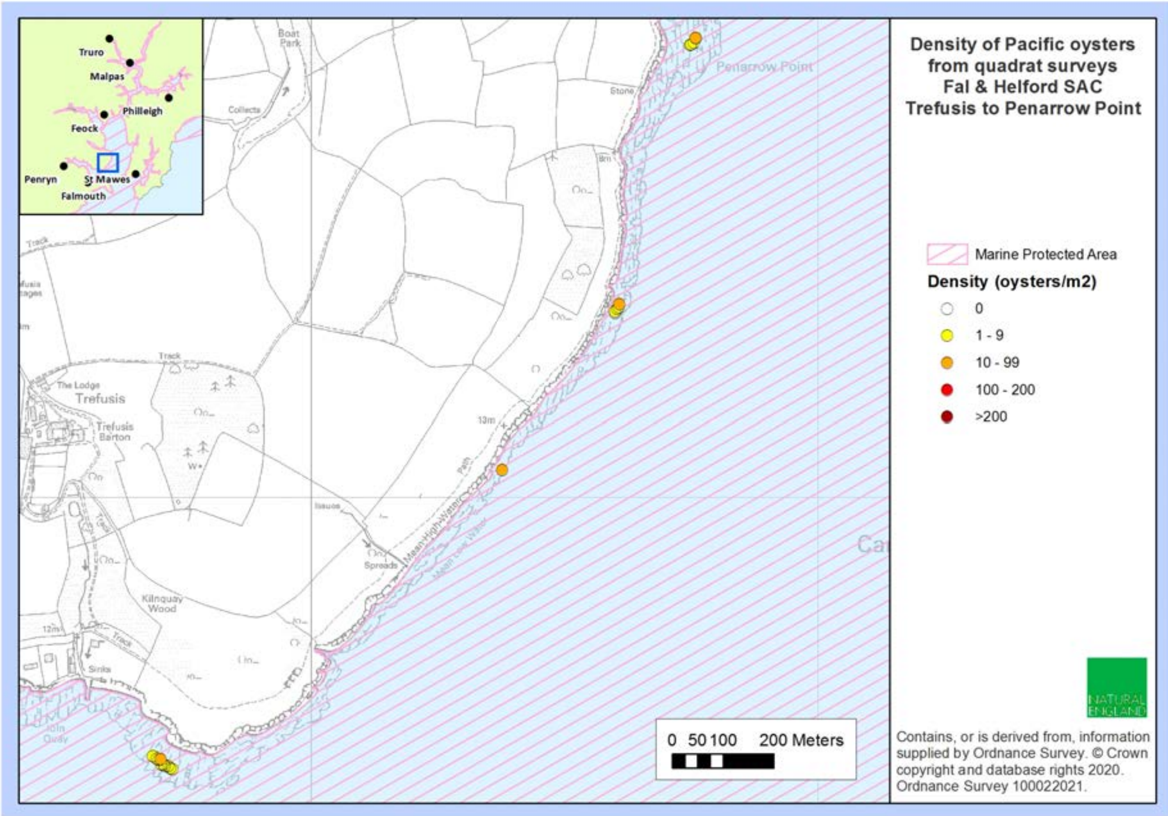


Figure 7: Pacific oyster densities calculated from quadrats between Trefusis and Penarrow Point in the Fal Estuary

Greatwood Quay (Figure 8)

At Greatwood quay to the north of the mouth of Mylor Creek (site name = Kingsand beach - North) Pacific oysters were Common to Abundant (1-99/m^2). The average density of Pacific oysters here in 2019 was 11.16/m^2 with a maximum of 48/m^2.

However just to the north at Greatwood slipway (site name = Weir Point – Feock) densities were lower with Pacific oysters mostly being either Common (1-9/m^2) or not present at all in 2019. Average Pacific oyster density was 2.2/m^2 although one location had a density of 12/m^2.

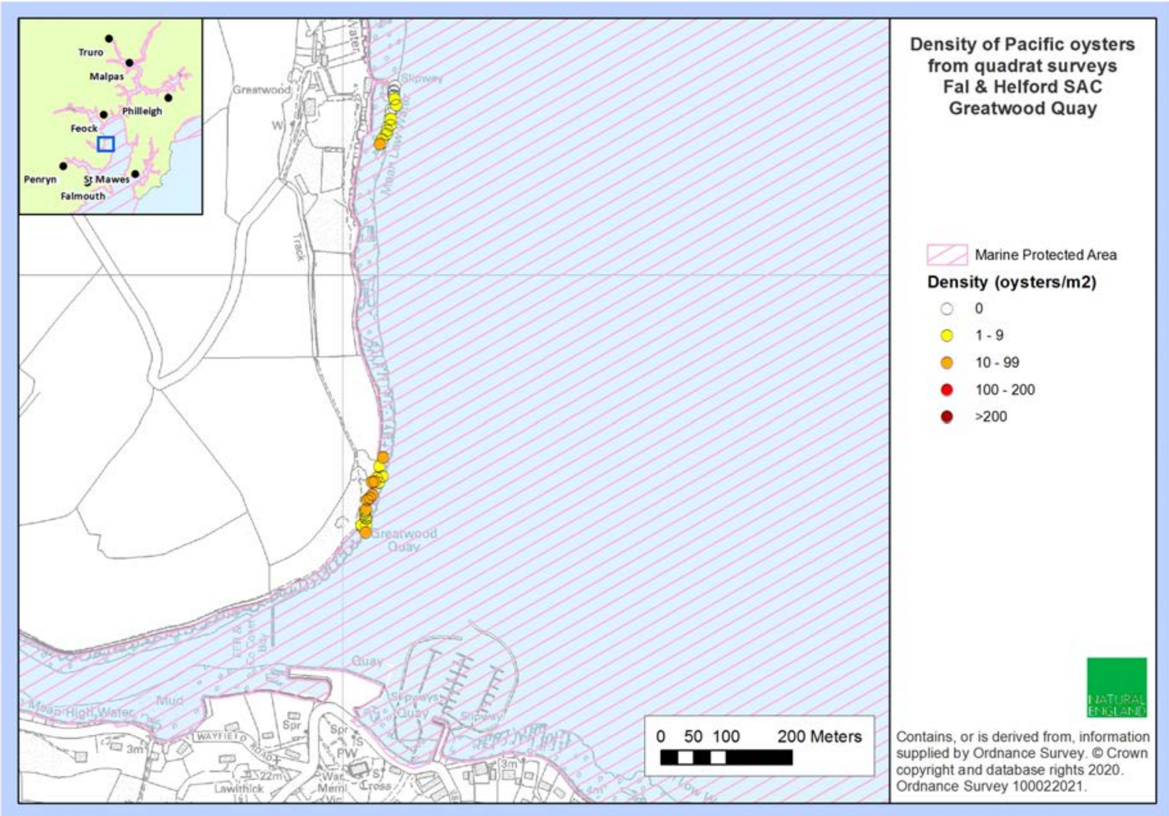


Figure 8: Pacific oyster densities calculated from quadrats at Greatwood Quay in the Fal estuary

Restronguet Point (Figure 9)

Further north at Restronguet the majority of locations found Abundant (10-99/m^2) densities of oysters. On the northern shore of Restronguet Creek and at Porthgwidden, Pacific oysters were found at Superabundant densities (>100/m^2).

At the back of the spit up onto the northern shore of the creek, a large number of quadrats were surveyed in 2019 (N= 105) and Pacific oysters were found mostly to be at Abundant levels (10-99/m^2). Data was combined for the whole of this section (site names = Feock; Restronguet Creek; two points at this location from Restronguet creek north shore). In 2019 the average density of oysters was 12.89/m^2. However, at one location at the very north of this section (on the northern shore of the creek) a density of 120/m^2 was recorded, Superabundant on the SACFOR scale.

Following culls along parts of this section in 2019 a large proportion of this area was resurveyed in 2020 although there were some gaps along the shore (N=65). Data was again combined for the whole of this section (site names = North Restroguet creek shore; North Restronguet Creek shore). The average density of Pacific oysters in 2020 was 12.74/m^2 with a maximum density of 28/m^2. As areas of the shore here were culled and resurveyed the statistical analysis below should be referred to.

On the outer edge of the spit at Restronguet Point (site name = Lower West Shore Restronguet Creek) in 2018 an average oyster density of 12/m^2 was observed with a maximum of 28/m^2.

In 2020 the section of the shore between Restronguet Weir and Pandora Inn on the southern side of the creek from Restronguet Point was surveyed and this had an average of 9.64/m^2 with a maximum density of 32/m^2.

To the north of Restronguet Point at Porthgwidden (site name = West of Loe beach) in 2020 higher densities of Pacific oysters were found. Abundant levels were recorded with an average density of 24.83/m^2. However Pacific oysters were Superabundant or 280/m^2 at one location.

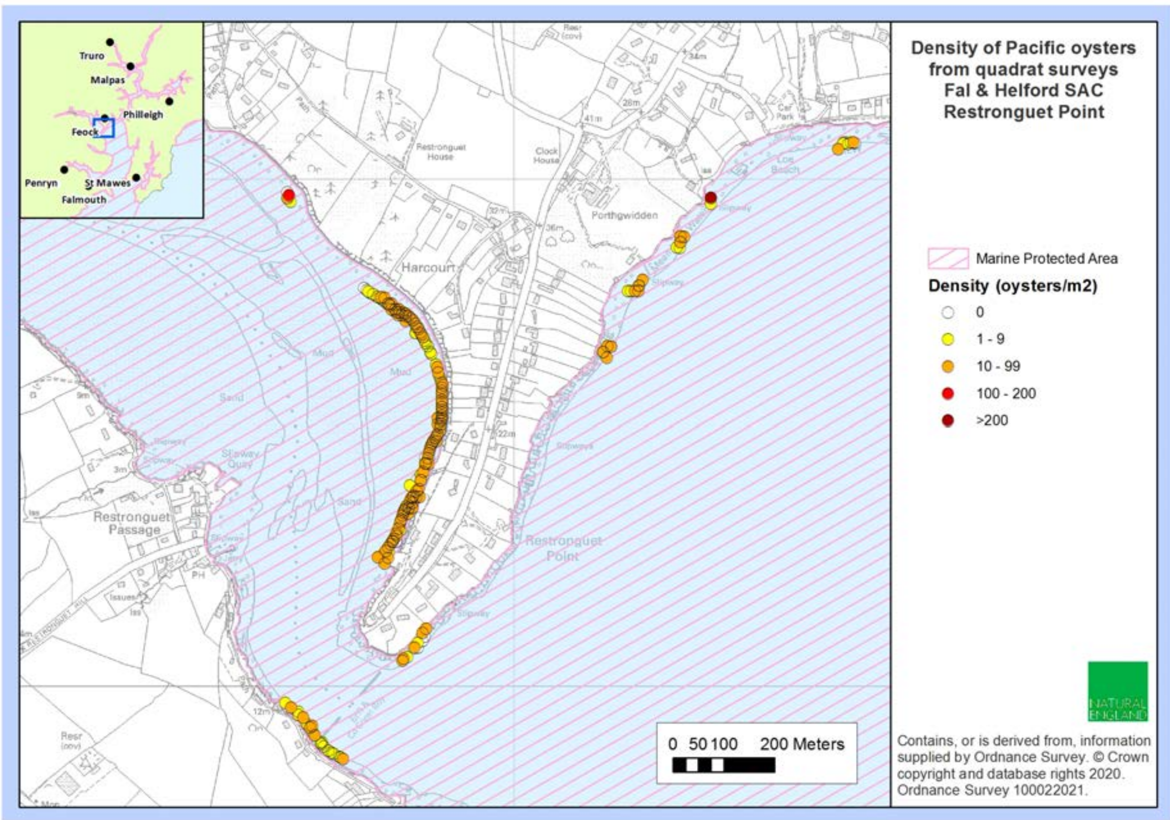


Figure 9: Pacific oyster densities calculated from quadrats at Restronguet Point in the Fal estuary

Turnaware Point (Figure 10)

To the eastern end of Loe Beach at Pill Point in 2020 Pacific oysters were Abundant with an average density of 14.07/m^2 with a maximum of 36/m^2.

Similarly, at the northern end of Carrick Roads on the west side of Channals Creek in 2019 there was an average density of 19.44/m^2 with a maximum of 44/m^2.

At Turnaware Point on the eastern side of the estuary the majority of locations recorded Abundant (10-99m^2) densities of Pacific oysters. In 2017 (N=54) the average oyster density around the point was 12.22/m^2 with a maximum of 48/m^2. Following culls in 2017 and 2019 in parts of this area the average oyster density increased slightly in 2019 and was 15.2/m^2 with a maximum density of 44/m^2. However, it should be noted that only around half the number of quadrats (N=21) were surveyed and these were restricted to short sections at the northern end, middle and southern end of the area surveyed in 2017. In 2020 (N=44) a much larger section of the shore was surveyed with a similar number of quadrats as 2017 but becoming much sparser at the northern end and stopping short of the point itself. The average density was 15.27/m^2 with a maximum of 64/m^2. As this site was partially culled and resurveyed **the statistical analysis should be referred to.**

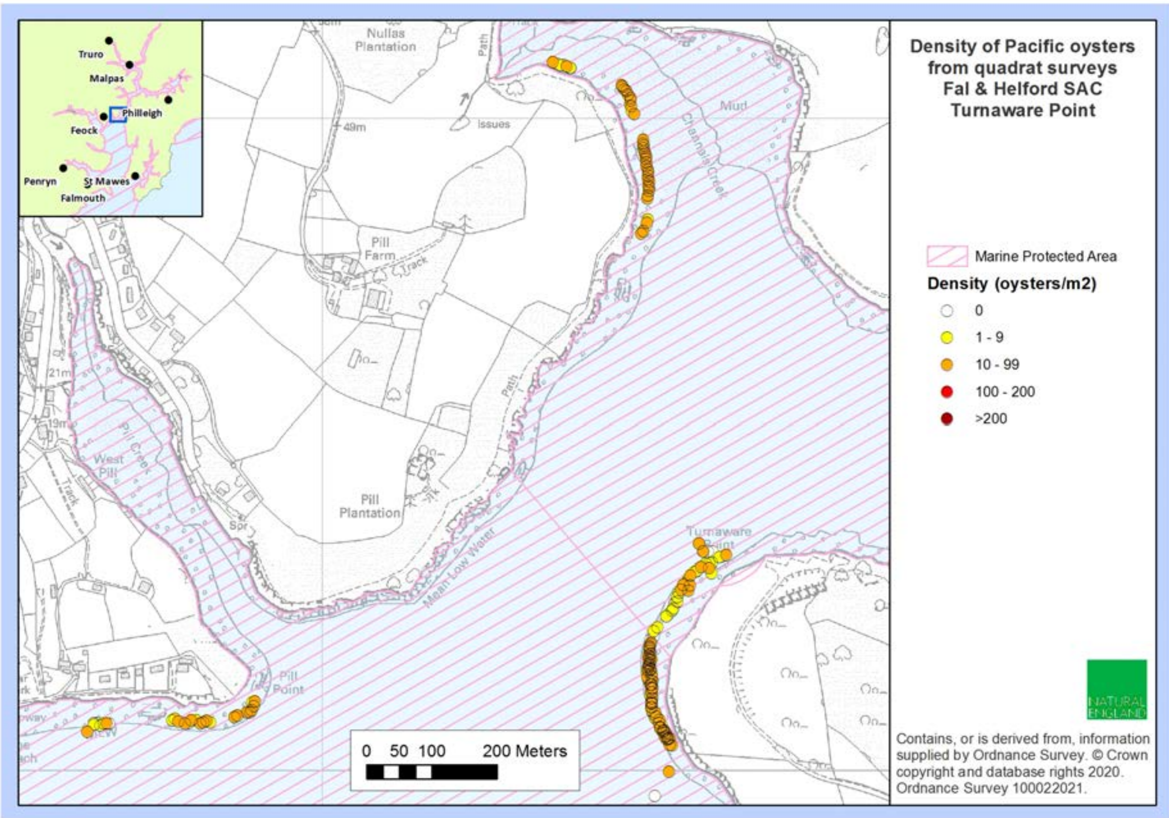


Figure 10: Pacific oyster densities calculated from quadrats at Pill Point, Channals Creek and Turnaware Point in the Fal estuary

Tregothnan Park (Figure 11)

To the north on the southern edge of Tregothnan Park (Deer Park) located on the northern shore of the Fal-Ruan estuary (site name = St Michael Penkevil) high levels of Pacific oysters were recorded with several locations showing Superabundant densities (>100/m^2). In 2019 the average density was 49.1/m^2 with the maximum density of oysters being recorded as 112/m^2.

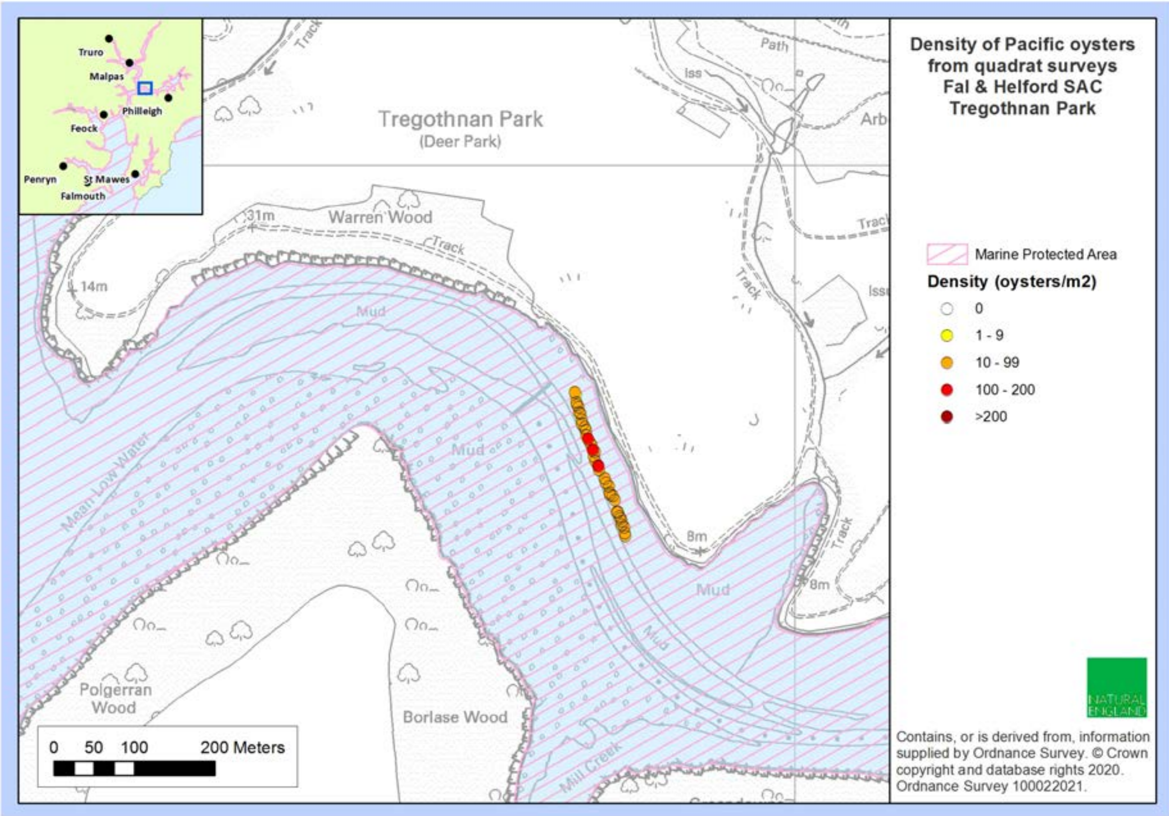


Figure 11: Pacific oyster densities calculated from quadrats at Tregothnan Park in the Fal estuary

St Just (Figure 12)

Further south on the eastern side of the estuary at St Just Creek the majority of locations showed Abundant (10-99/m^2) levels of oysters.

On the northern shore of St Just Creek from the mouth of the estuary at Messack Point to Messack House (St Just – site 6, Restronguet creek north shore minus the two points at Restronguet, & STJUST combined) in 2019 Pacific oysters were Abundant with an average density of 21.32/m^2 and a maximum of 56/m^2. This area was culled in 2019. In 2020 this area was resurveyed (Site name - St Just Creek North Shore) and the average abundance decreased to Common with an average density of 8.36/m^2 with a maximum of 24/m^2. **As this area was culled and resurveyed the statistical analysis should be referred to.**

The area east of Messack House and up into St Just Creek on the southern side of the main channel was surveyed in 2019 (ST JUST_CREEK & St Just Creek (Messack House) combined). Pacific oysters were Abundant with an average density of 19.69/m^2 and a maximum of 68/m^2. This area was culled in 2019 but not resurveyed.

Walkover surveys suggest that Pacific oysters are also Frequent (0.1 – 0.9/m^2) on the south side of St Just Creek by St Just (Figure 17).

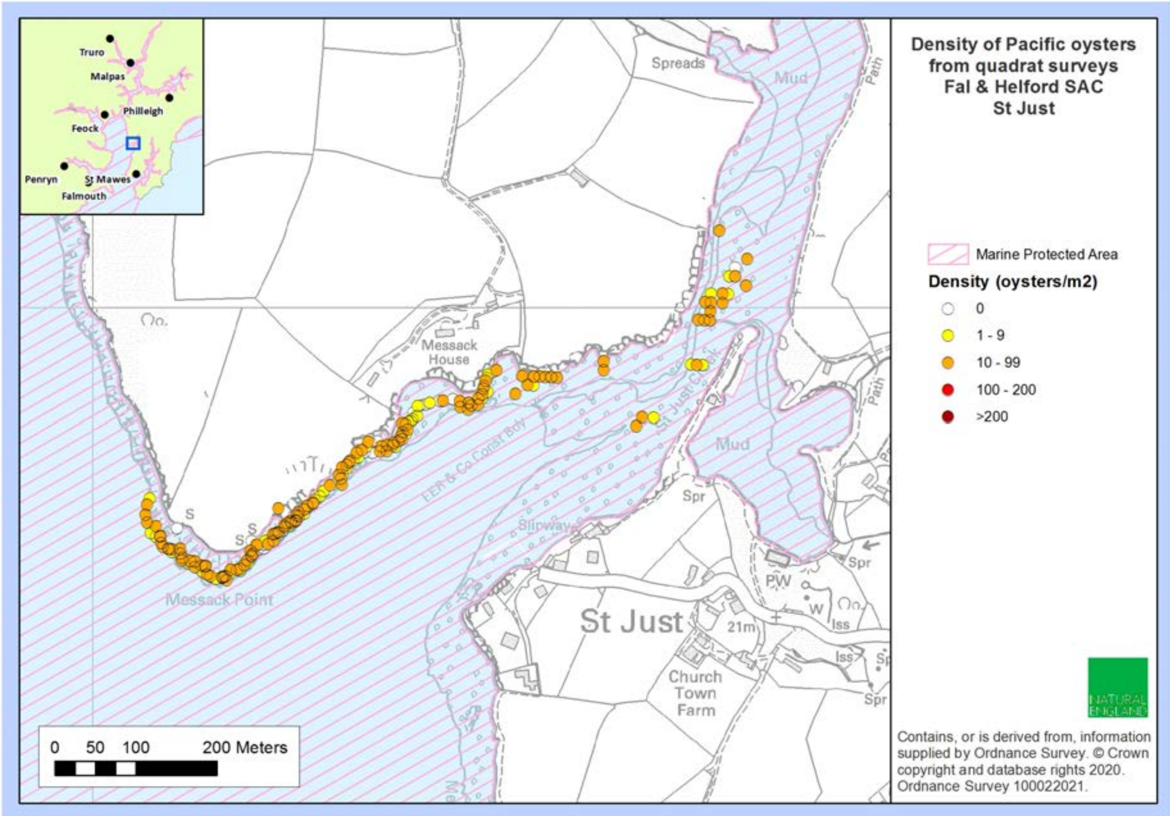


Figure 12: Pacific oyster densities calculated from quadrats at St Just Creek in the Fal estuary

Trevennel (Figure 13)

To the south of St Just, Abundant levels of Pacific oyster were recorded at St Just Pool (10-99/m^2).

In 2017 (St Just – Site 3 & St Just – Site 4 combined) much of the shore was surveyed with some gaps towards the middle of the section and Pacific oysters were found to be Abundant (10-99/m^2). There was an average density of 12.92/m^2 and a maximum 92/m^2. At the northern end of this section towards St Just the numbers of oysters were higher. This can be seen by the average for ‘St Just – site 4’ as when analysed alone the average density was 28.8/m^2. At the very southern tip of the section, the densities were much lower. Here records showed 4/m^2 or no oysters at all.

Following a cull in 2019 (St Just – Site 5 & St Just – Site 7 combined) the average density of Pacific oysters along this section of shore was 13.91/m^2 but reached a maximum of Superabundant levels with densities of 100/m^2. This section was also culled in following the 2019 survey. **As this site was culled and resurveyed the statistical analysis should be referred to.**

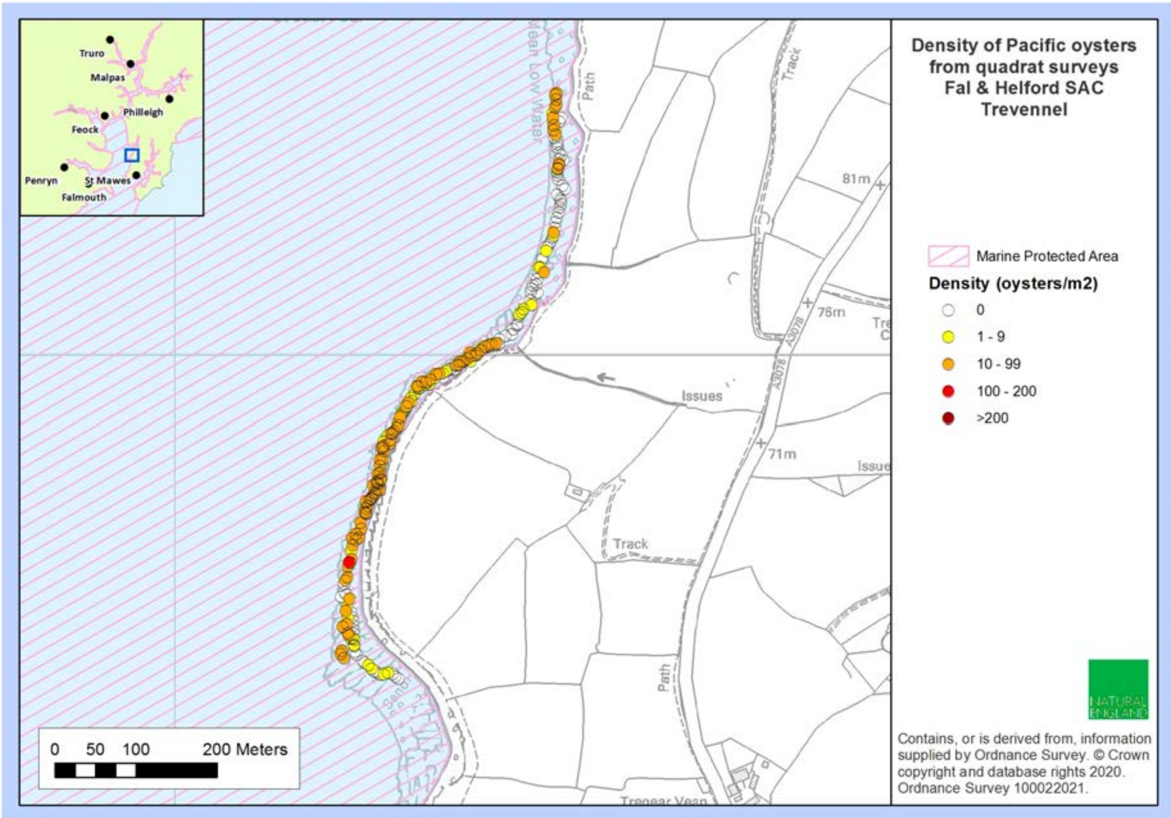


Figure 13: Pacific oyster densities calculated from quadrats at Trevennel in the Fal estuary

Halwartha (Figure 14)

Between Halwartha and St Mawes densities were Common and Abundant (1-99/m^2), except for one quadrat where there were no oysters.

Near Halwartha (site name = Roseland: St Mawes) in 2019 the average oyster density was 12.55/m^2 with a maximum of 28/m^2. South of this near the northern edge of St Mawes and the sewage works (site name = St Mawes towards St Just-Fal estuary) in 2017 the average density was 9.33/m^2 with a maximum of 20/m^2.

Walkover surveys suggest that Pacific oysters are Frequent (0.1 - 0.9/m^2) or Common (1 – 9/m^2) along this whole length of shore (Figure 17).

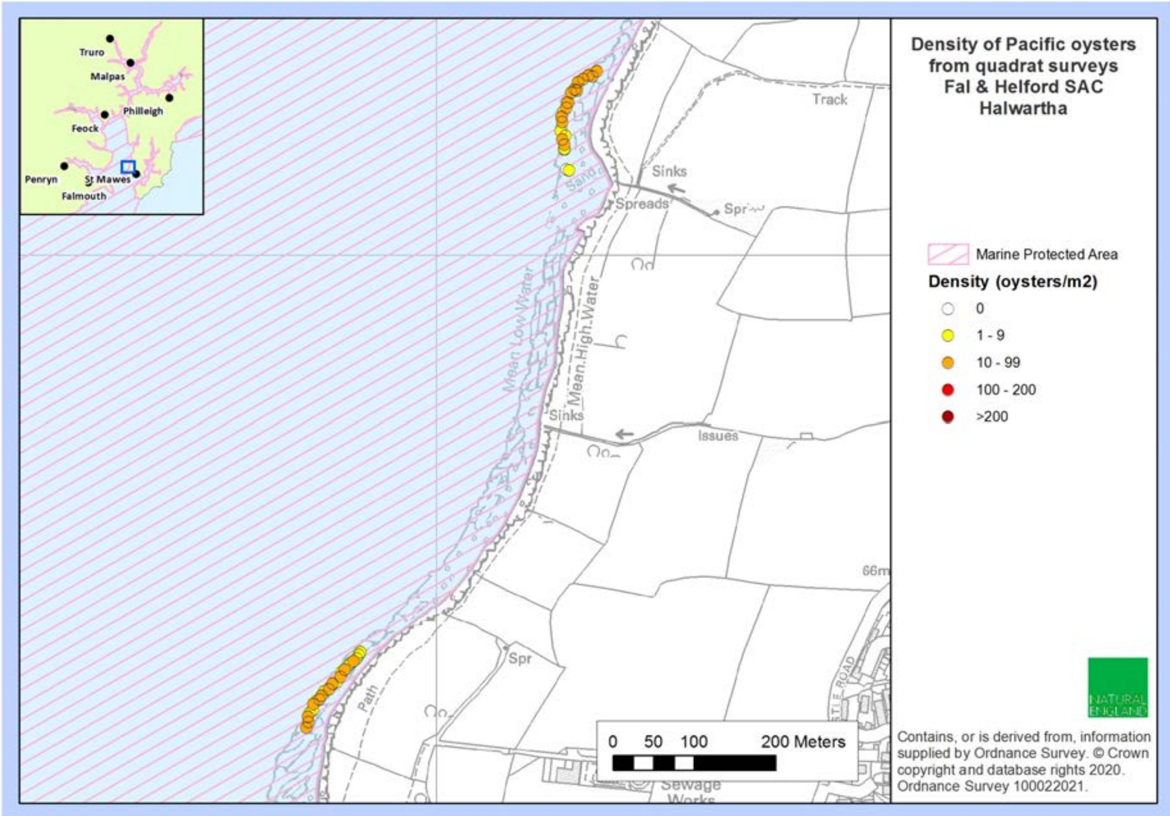


Figure 14: Pacific oyster densities calculated from quadrats at Halwartha in the Fal estuary

Black Rock (Figure 15)

At Black Rock on the southern side of the Percuil river opposite St. Mawes (site name = Lowlands beach Roseland) Pacific oysters were found in up to Abundant densities (10-99/m^2). The average density in 2018 was 9.6/m^2 with a maximum of 20/m^2.

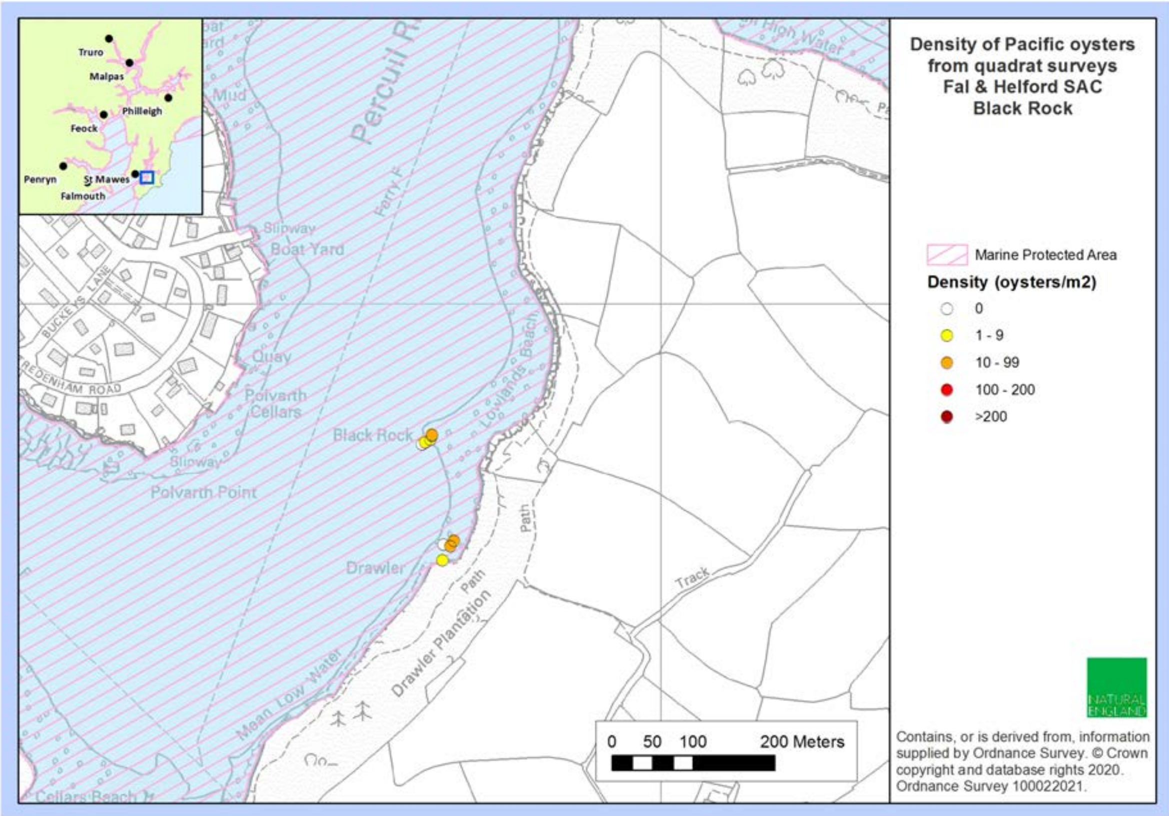


Figure 15: Pacific oyster densities calculated from quadrats at Black Rock in the Fal estuary

Additional information from walkover surveys (Figure 16)

Walkover surveys in the Fal support the quadrat data and suggest there are notable levels of Pacific oysters, Common (1-9/m^2), throughout the estuary with higher levels that may be of concern, Abundant (10-99/m^2), around Loe Beach at Feock. Interestingly walkover surveys further up Restronguet Creek at Penpol Creek and westward to Tallack's Creek did not record any Pacific oysters.

Walkover surveys were also additionally carried out at Falmouth and at Maenporth in Falmouth Bay where they suggest Pacific oysters were Frequent to Common (0.1 – 9/m^2).

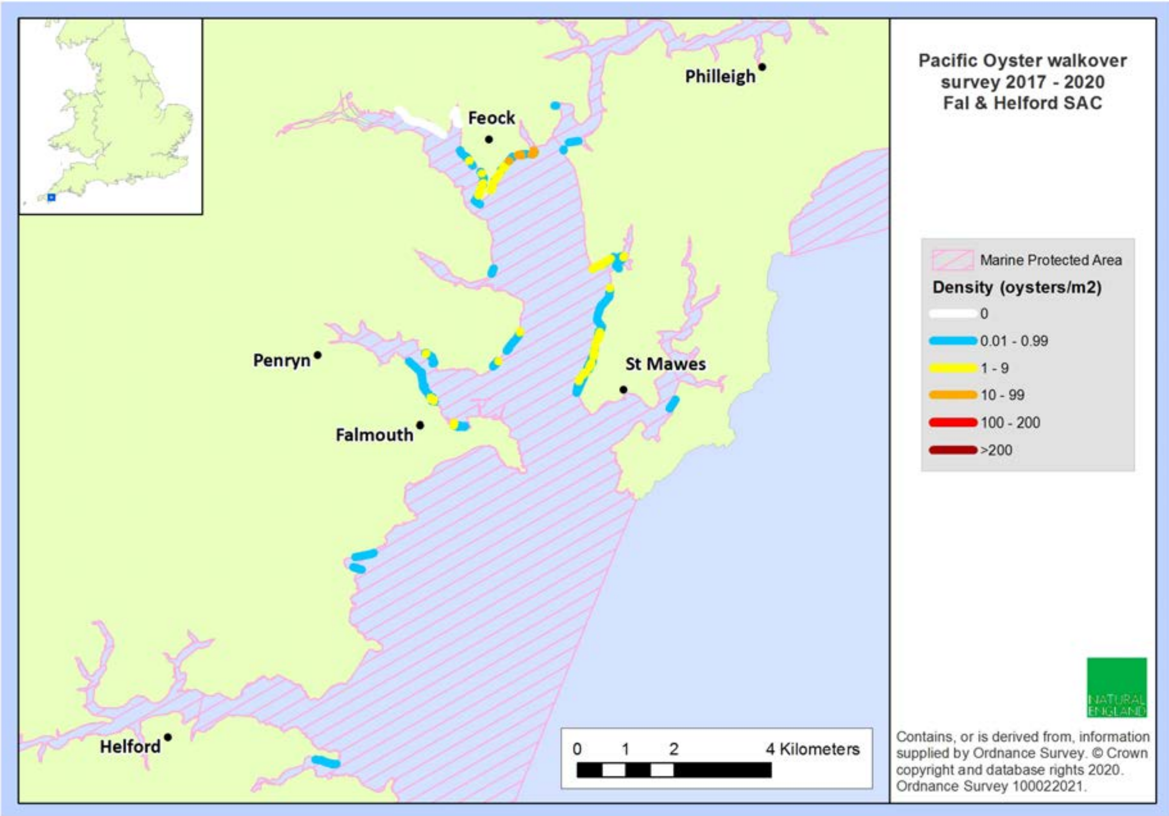


Figure 16: Pacific oyster densities calculated from walkover surveys in the Fal and Helford SAC

3.3.10 West Portholland and East Portholland Cove (Figure 6)

Walkover surveys suggest that Pacific oysters are Frequent (0.1-0.9/m^2) at West Portholland Cove and East Portholland Cove in Veryan Bay.

3.3.11 Portmellon Cove (Figure 6)

Walkover surveys suggest that Pacific oysters are Frequent (0.1-0.9/m^2) at Portmellon in Mevagissey Bay.

3.3.12 Par (Figure 17)

Seven quadrats were surveyed at Par breakwater in 2018 ('Par beach' & 'Par beach – West Rock Groyne' were combined). Pacific oysters on average were Abundant with 15.43/m^2 with a maximum of 24/m^2.

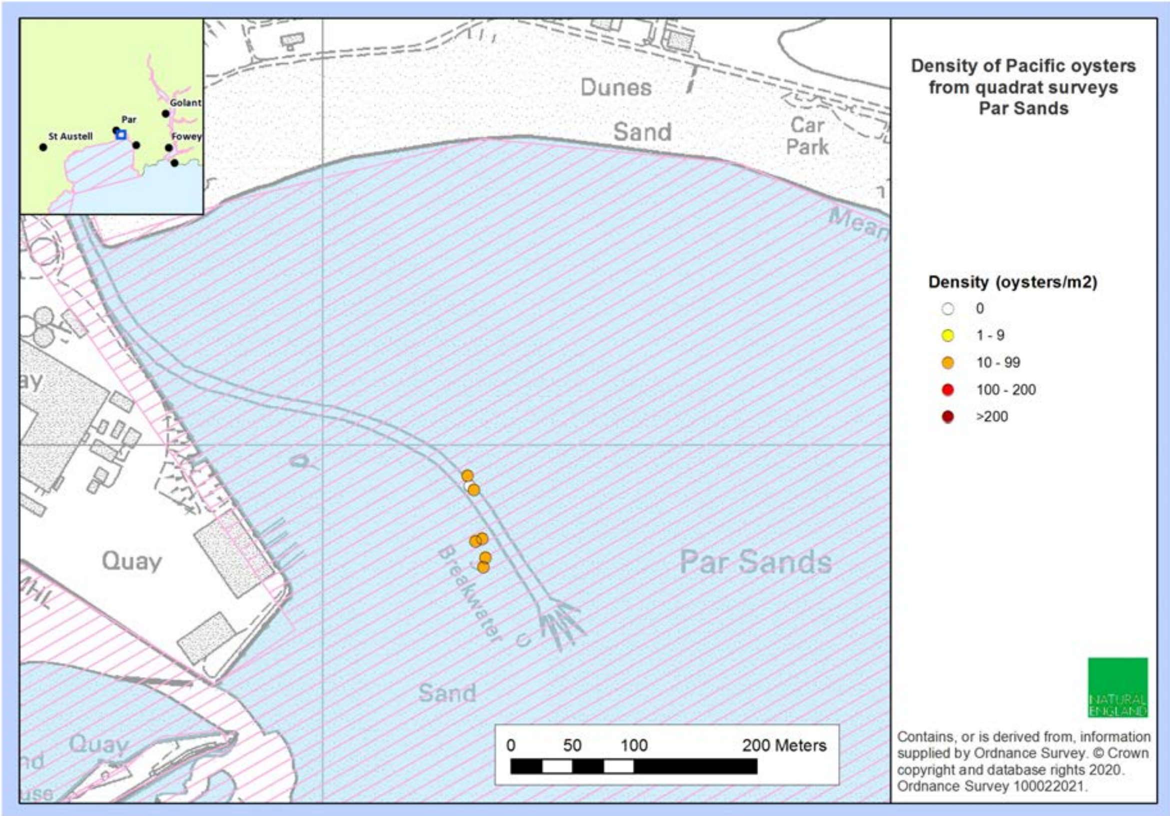


Figure 17: Pacific oyster densities calculated from quadrats at Par

Additional information from walkover surveys (Fig 21) suggest that there are Frequent to Common (0.1-9/m^2) abundances of Pacific oysters on the eastern side of Par Beach with none being recorded in the far north eastern corner.

3.3.13 Fowey (Figure 18)

Quadrats were surveyed at two locations in the estuary, just south of Mixtow Pill (Figure 18) and on the northern shore of Pont Pill near to its confluence with the river Fowey (Figure 19).

South of Mixtow Pill in 2017 (site name: Fowey- Wisemans Creek & two points from Fowey-Pont Pill that are combined at this location). Pacific oysters were Superabundant (>100/m^2). The density of Pacific oysters was extremely high with an average of 280/m^2 (N=8), and a minimum oyster density of 196/m^2 and maximum of 356/m^2. In 2019 four quadrats were surveyed at this location and oysters were Abundant (10-99/m^2) (site name = Grid Irons, Fowey). The average density of Pacific oysters was 29/m^2 with a maximum of 68/m^2.

On the northern shore of Pont Pill in 2017 Pacific oysters were on average Abundant (10-99/m^2) with an average of 36/m^2. However, two locations had Superabundant (>100/m^2) levels. One had a density of 100/m^2, and the other 112/m^2.

Culls have taken place on the Fowey estuary since the winter of 2018 by the Friends of the Fowey Estuary local conservation group.

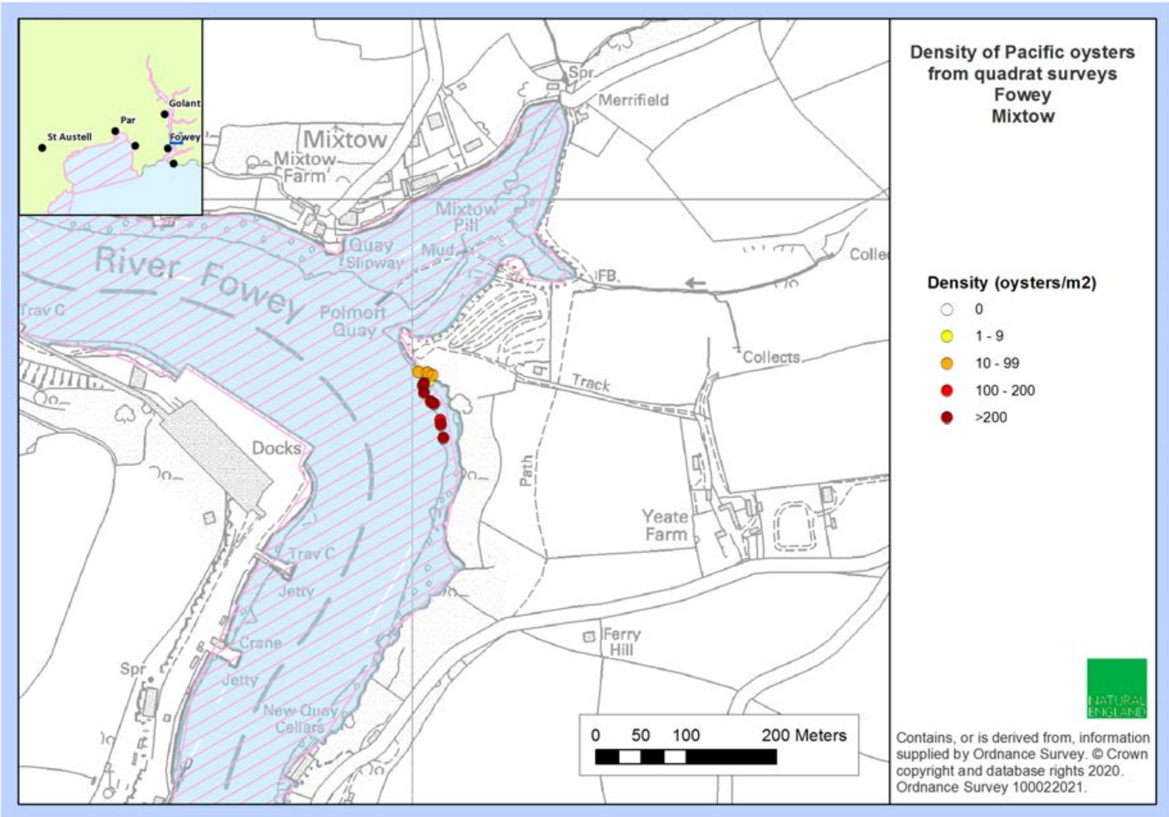


Figure 18: Pacific oyster densities calculated from quadrats at Mixtow Pill in the Fowey estuary

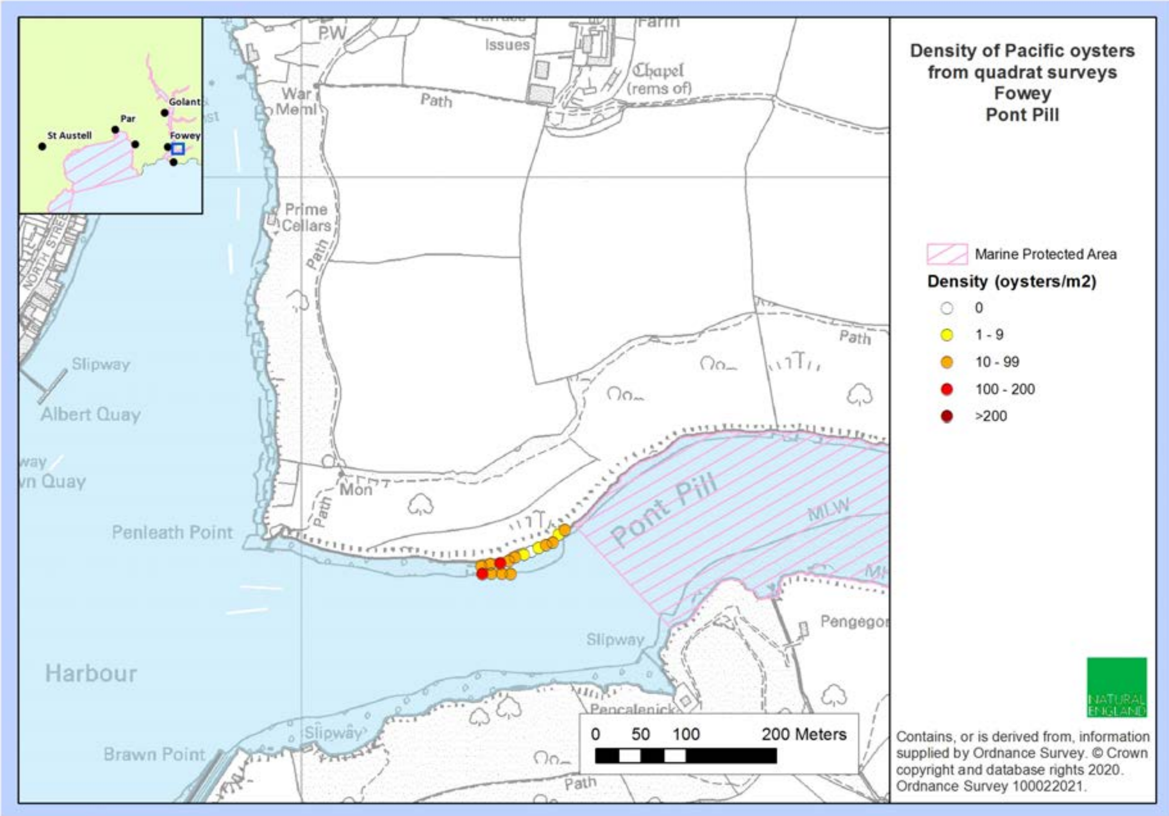


Figure 19: Pacific oyster densities calculated from quadrats at Pont Pill in the Fowey estuary

Additional information from walkover surveys (Figure 20) also suggest that Pacific oysters are Occasional to Common (0.01-9/m^2) on the western side of the estuary near Fowey; and Frequent (0.01 -0.9/m^2) on the estuary side of Polruan on the eastern side of the estuary.

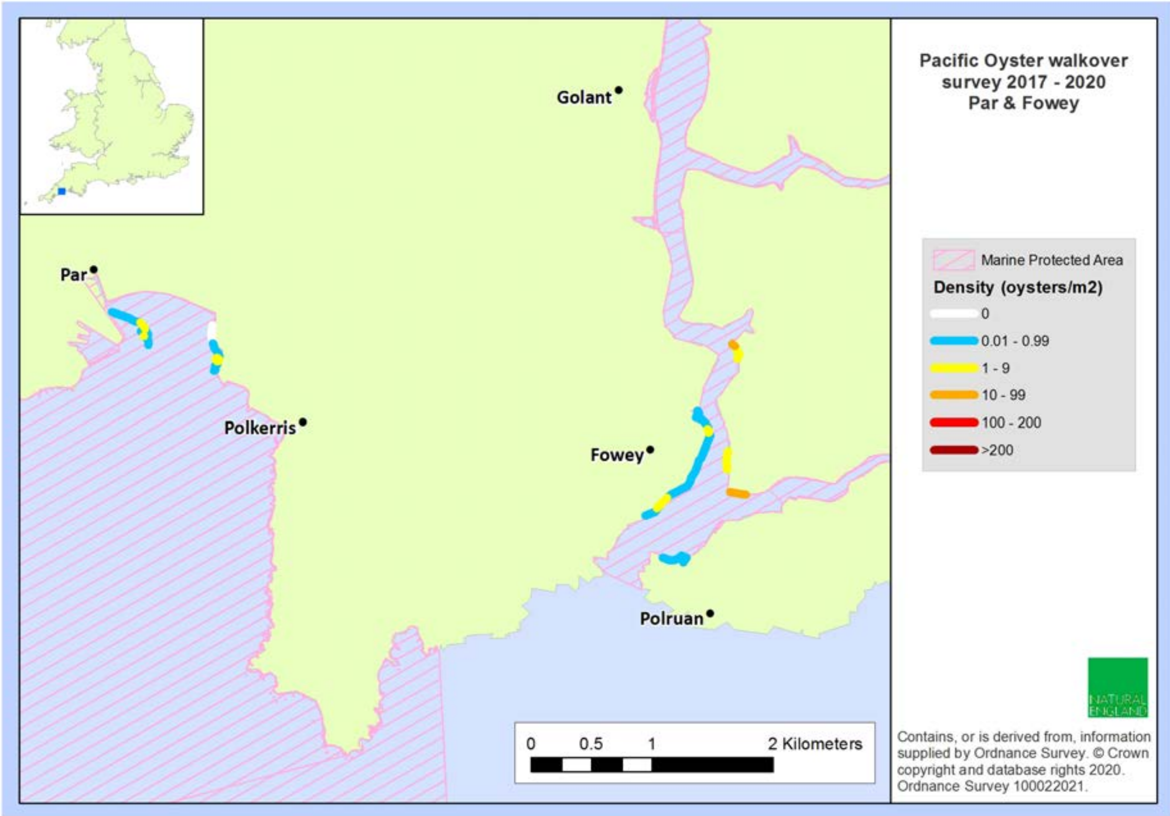


Figure 20: Pacific oyster densities calculated from walkover surveys at Par and the Fowey estuary

3.3.14 Looe (Figure 21)

Surveys at Looe were undertaken over the winter of 2018/2019. The western side of Looe river was surveyed in November 2018 and the eastern side in January and February 2019. Pacific oysters were mostly Common or Abundant along the river, although there were several quadrats where no oysters were found. All quadrats were combined (site name = Looe river; LOOE_WEST SHORE; LOOE_NE; East Looe Beach & East Looe beach) and in winter 2018/2019 overall Pacific oysters were found to be Abundant at Looe with an average of 12.47/m^2 and a maximum of 32/m^2.

Walkover surveys show Frequent (0.1-0.9/m^2) levels of oysters along the river at Looe with slightly higher abundances of Common (1-9/m^2) at the mouth of the river on the pier on the northern bank.

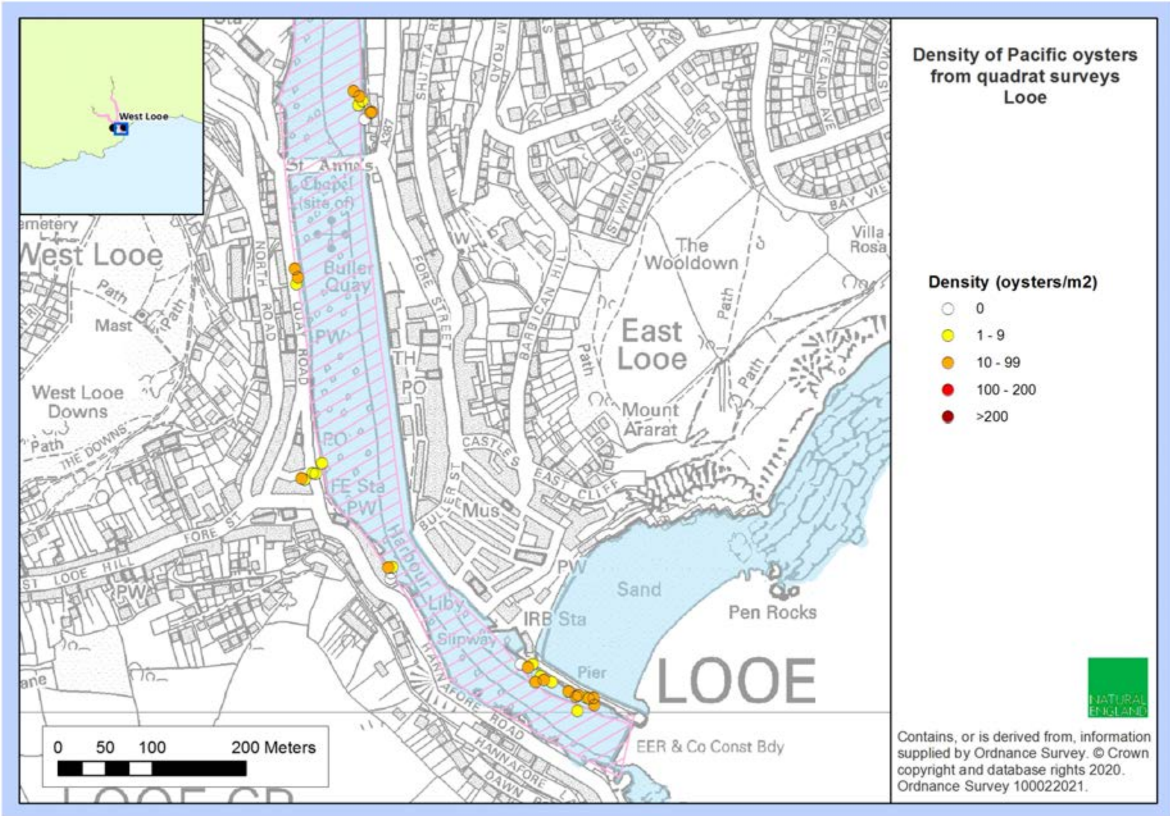


Figure 21: Pacific oyster densities calculated from quadrats at Looe

3.3.15 Whitsand and Looe Bay (Figure 22)

No quadrat surveys were undertaken in Whitsand and Looe Bay. However, walkover surveys suggest that Pacific oysters are Frequent to Common (0.1-9/m^2) near Portwrinkle and in the northern half of the bay and Frequent (0.1-0.9/m^2) in the southern half of the bay. At the centre of the bay, near Freathy, higher levels of Pacific oysters were recorded and in one area they were seen to be Abundant (10 99/m^2)

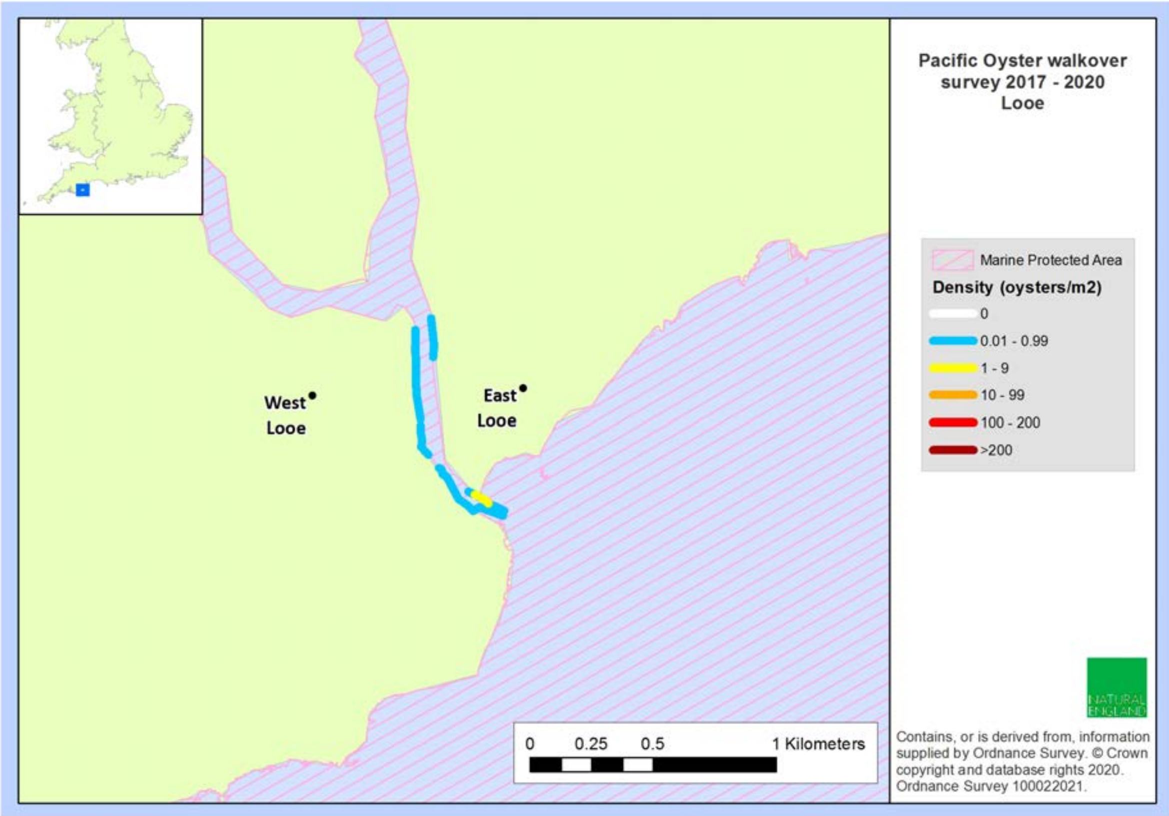


Figure 22: Pacific oyster densities calculated from walkover surveys at Looe

3.3.16 Plymouth Sound and Estuaries

Extremely high numbers of Pacific oysters were found at four locations around Plymouth where Superabundant (>100/m^2) densities were recorded.

Plymouth Sound and Estuaries:

- The Cove, near Wilcove

Yealm estuary:

- Machine Beach, Outer Yealm estuary
- Newton Ferrers
- Noss Mayo

North of Henn Point (Figure 23)

To the north of Henn Point (site name = Tamar) eight quadrats were surveyed in 2014 and no Pacific oysters were found.

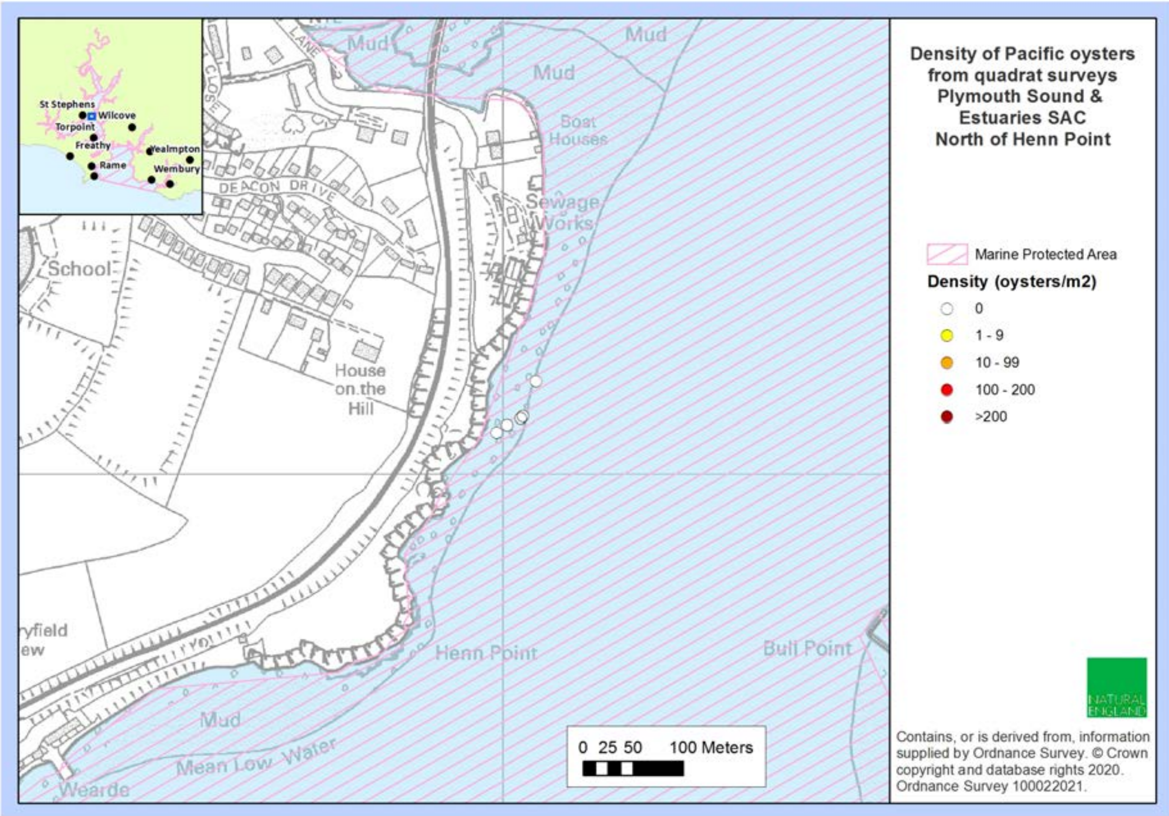


Figure 23: Pacific oyster densities from quadrats to the north of Henn Point in the Tamar Tavy estuaries, Plymouth

Wearde Quay (Figure 24)

At Wearde Quay (13 points from site = Churchtown Farm Community Nature Reserve to Wearde quay) in 2020 Pacific oysters were Common (1-9/m^2) with an average density of 7.69/m^2.

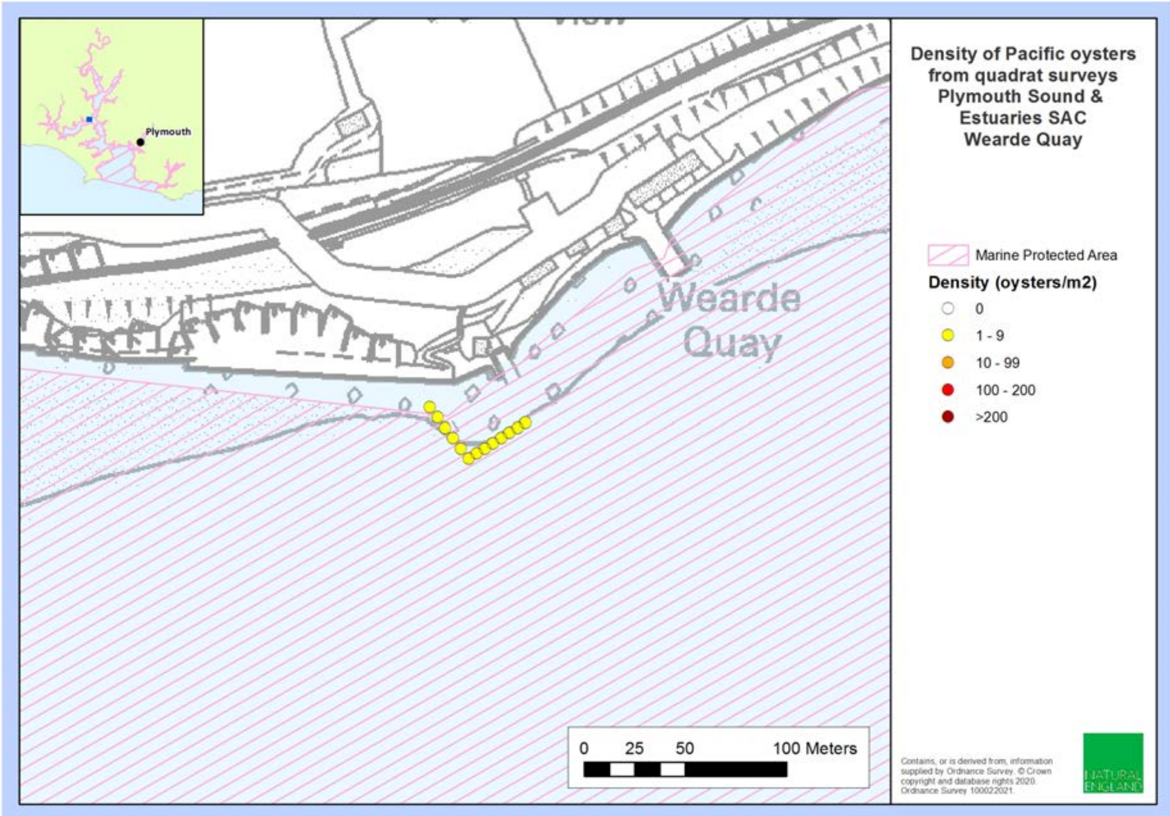


Figure 24: Pacific oyster densities calculated from quadrats at Wearde Quay on the Lynher estuary, Plymouth

South of Sand Acre Bay (Figure 25)

At Churchtown Nature Reserve in 2020 (site names = Churchtown Farm Community Nature Reserve to North of Passage Point Ferry landing & Churchtown Farm Community Nature Reserve to Wearde quay combined (excluding the 13 points at Wearde Quay)) there were higher levels of oysters and they were found to be Abundant (10-99/m^2) with an average of 11.72/m^2 and a maximum of 56/m^2.

Immediately to the north of here in Sand Acre Bay itself, walkover surveys did not record any Pacific oysters in the southern half of the bay and suggested they were Occasional to Frequent (0.01-0.9/m^2) in the northern half of the bay (Figure 30).

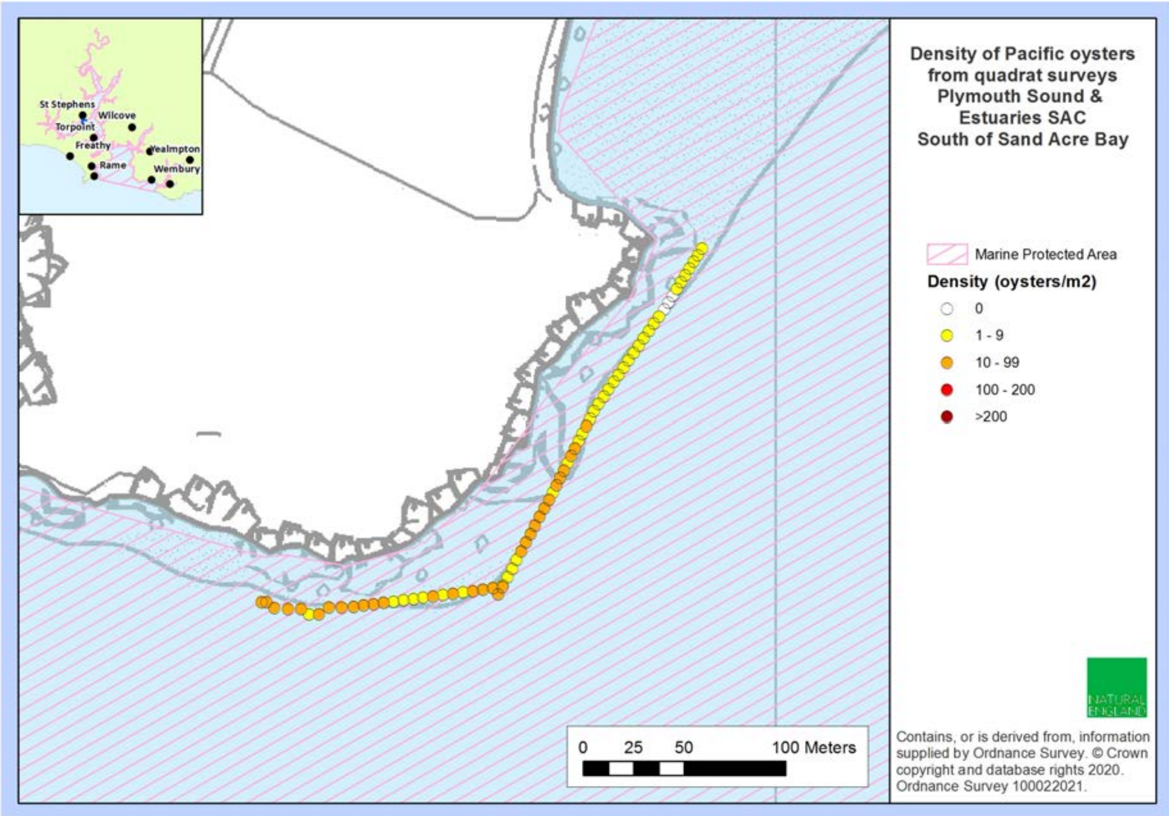


Figure 25: Pacific oyster densities calculated from quadrats at Churchtown Farm Nature Reserve on the Lynher estuary, Plymouth

Beggar's Island (Figure 26)

At Beggar's Island (site name = Beggar's Island to Juniper Point (Site 11)) in 2014 Pacific oysters were Abundant (10-99/m2) with an average of 13.33/m^2 (N=3) and maximum density of 16/m^2.

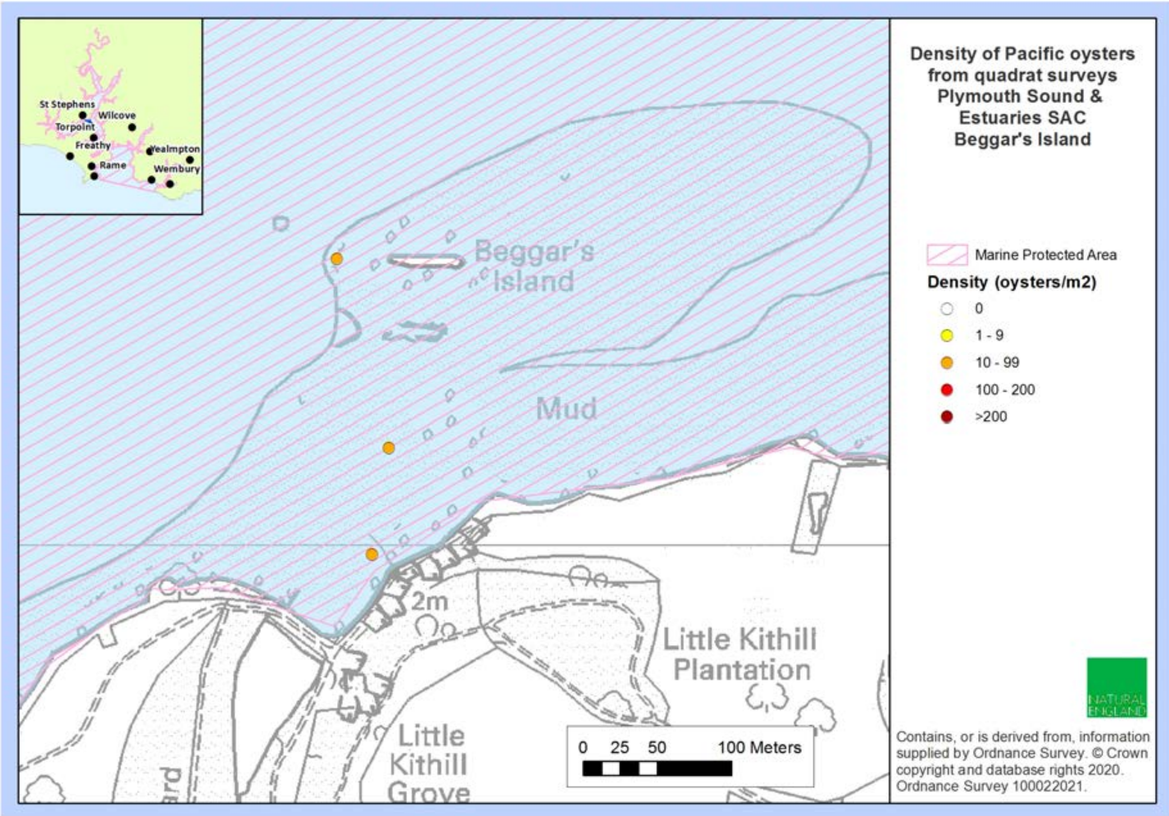


Figure 26: Pacific oyster densities calculated from quadrats at Beggar's Island on the Lynher estuary, Plymouth Sound and Estuaries SAC

Wilcove (Figure 27)

There were extremely high levels of Pacific oysters near Wilcove at The Cove (site name = Torpoint) in 2019. On average Pacific oysters were Superabundant (>100/m^2) with a density of 164.57/m^2. The maximum density was 396/m^2. 11 of the 21 quadrats had Superabundant densities (>100m^2). However, at the very northern end of the cove the last three quadrats did not find any oysters.

Just to the south of here on the northern shore at Cangapool walkover surveys suggested that Pacific oysters were Occasional to Frequent (0.01 – 0.9/m^2) (Figure 30)

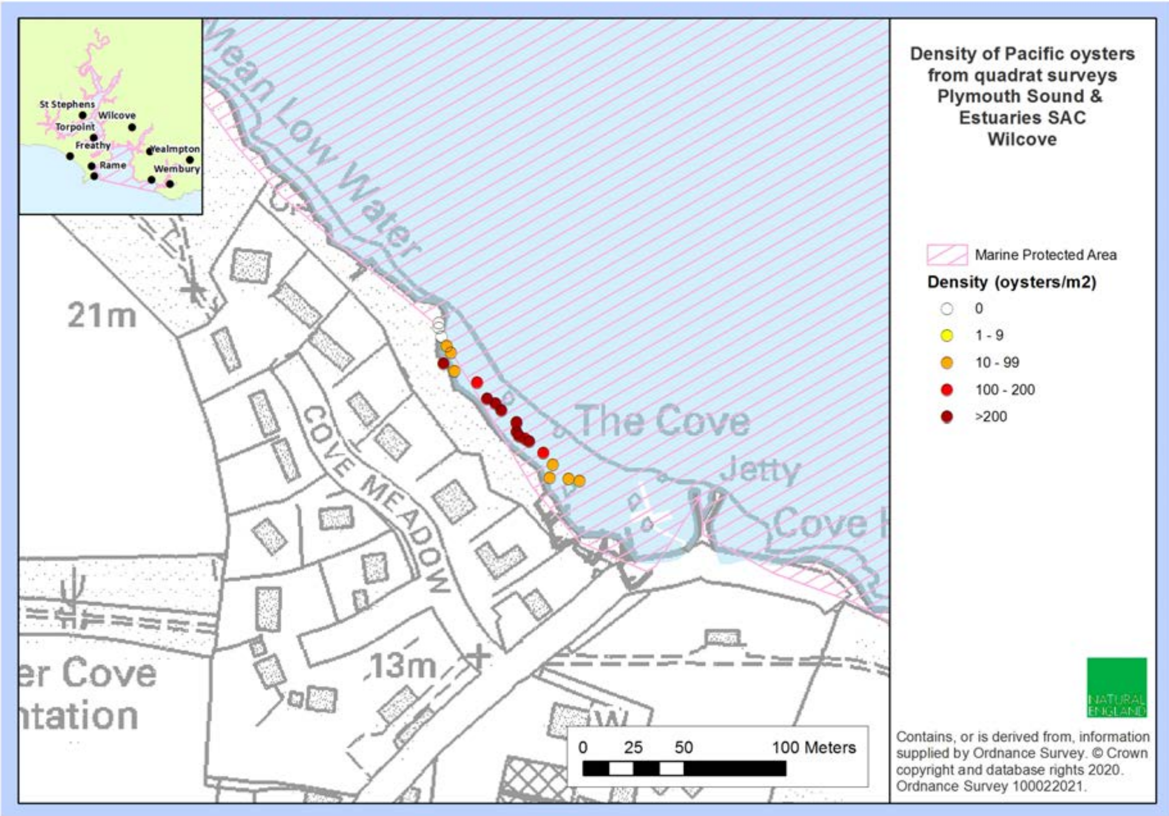


Figure 27: Pacific oyster densities calculated from quadrats at Wilcove in the Hamoaze, Plymouth Sound and Estuaries SAC

Cawsand (Figure 28)

Cawsand was surveyed in 2019 (site name = Sharrow?, Kingsand beach - North and Sandways to Plymouth were combined except the 19 points labelled Kingsand beach – North that are located on the Fal). Pacific oysters were Abundant (10-99/m^2) with an average density of 22.5/m^2 and a maximum of 48/m^2.

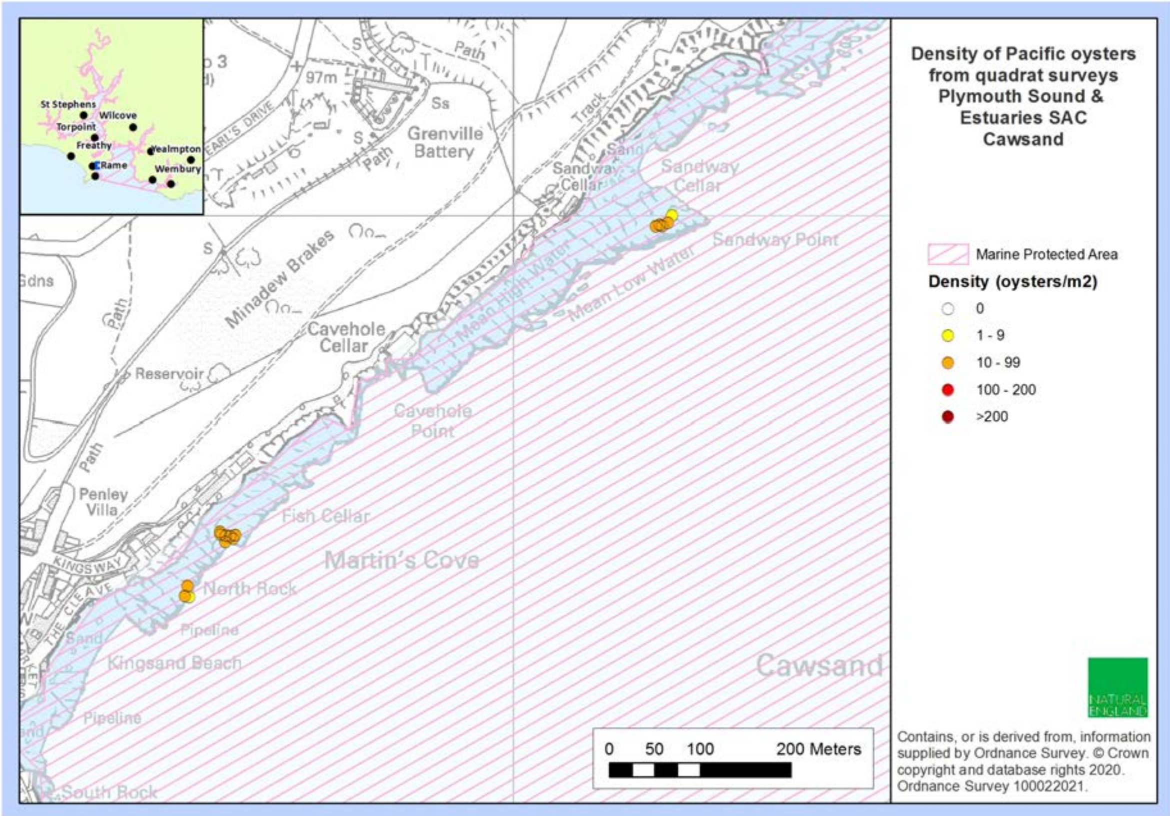


Figure 28: Pacific oyster densities calculated from quadrats at Cawsand in Plymouth Sound and Estuaries SAC

3.3.17 Yealm Estuary (Figure 29)

At Machine Beach (site name = Red Cove to Warren point, Yealm estuary) in 2020 Pacific oysters were Abundant (10-99/m^2) with an average density of 21.92/m^2. However, Pacific oysters were Superabundant in one location where a density of 116/m^2 was recorded.

Clitters Wood on the west side of the river Yealm north of Warren Point was surveyed in 2014. Here Pacific oysters were Abundant (10-99/m^2) with an average of 13.33/m^2 and a maximum of 20/m^2. Further north in 2014 opposite Court Wood only one quadrat was recorded, and that location had a density of 32/m^2.

On the eastern side of the Yealm river in 2014 four quadrats were surveyed along a short section of shore by Court Wood (site name = Newton Ferrers (Site 1)). Pacific oysters were Common here (1-9/m^2).

In 2020 the shore between Court Wood and south to Newton Ferrers Harbour Office had Abundant (10-99/m^2) levels of Pacific oysters (N=149) and an average density of 26.12/m^2. However, six individual points had Superabundant levels (>100/m^2). One of these was to the north by Court Wood and the other five were on the shore near the Newton Ferrers Harbour Office, including the quadrat with the most oysters (47) and a density of 188/m^2.

The below quadrat surveys lie outside the boundary of the Plymouth Sound and Estuaries SAC as the site only goes up to Mean Low Water along Newton Creek.

A small section of the shore by the Newton Ferrers Harbour Office was surveyed in 2019 (site name = Yealm Harbour Office) (N=13) and Pacific oysters were Abundant with an average density of 35/m^2 and a maximum of 80/m^2.

A little further to the east, a short section of the shore was surveyed in 2018 (site name = Newton Ferrers_North Shore and Newton Ferrers Shore combined) which had an average density of 33.42/m^2 and a maximum of 72/m^2.

In 2020 a large section of the north shore of Newton Creek was surveyed from the harbour office eastwards to the slipway off Riverside Road E (site name = Newton Ferrers, N=206). Pacific oysters were also Abundant here with an average density of 12.64/m^2. However, three locations had Superabundant levels (>100/m^2). Two had 100/m^2, and one had 112/m^2, the maximum recorded along this stretch. These three locations were all located to the east of the Harbour Office in the same area that was surveyed in 2018. Culls were undertaken further east of where the quadrats were surveyed. **As this site was resurveyed the statistical analysis should be referred to.**

Additional quadrat surveys were undertaken in June 2020 at: Yealm Harbour Office to Yealm Yacht Club; Noss Mayo ferry steps towards estuary mouth; Newton Ferrers Harbour Office west & north into main creek; and head of Shortaflete Creek and along eastern shore of main Yealm channel. Due to data not being received prior to the analysis, these could not be included. Raw data however are available upon request.

Surveys of the southern side of Newton Creek near Noss Mayo were undertaken in 2017 and 2020. In 2017 the western end of Newton Creek (site name = Nos Mayo, Yealm) was surveyed and Pacific Oysters were Abundant (10-99/m^2) with an average of 25.73/m^2 and max of 80/m^2. In 2020 the entire length of shore between Noss Creek and the ferry jetty was surveyed (site name = Noss Mayo to Ferry Jetty) and Pacific oysters were Abundant with an average of 36.66/m^2. However, in locations towards the centre of this stretch of shore Pacific oysters were Superabundant with a maximum of 220/m^2. Culls were not undertaken in this area.

This final location is once again within the boundary of the Plymouth Sound and Estuaries SAC. On the southern side of the estuary at Passage Wood in 2014 six quadrats were surveyed. Pacific oysters were Abundant (10-99/m^2) with an average density of 29.33/m^2 and a maximum of 44/m^2.

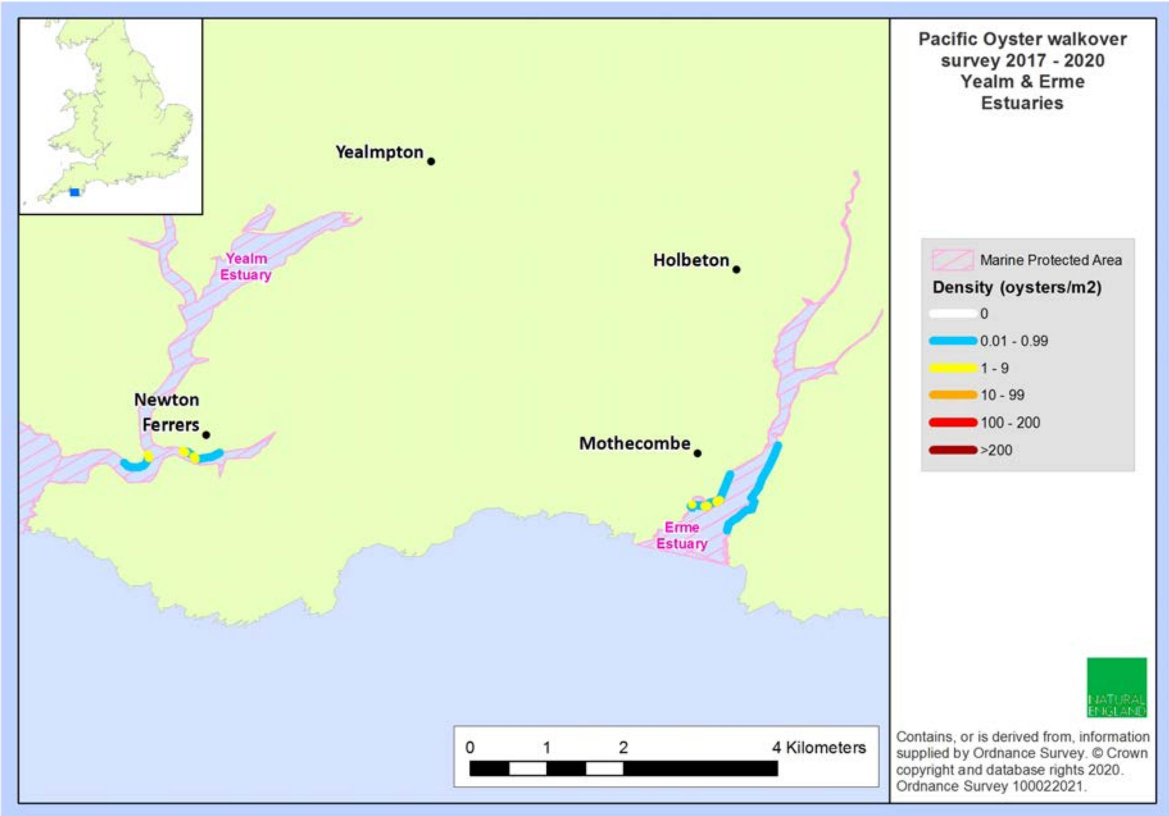


Figure 29: Pacific oyster densities calculated from walkover surveys in the Yealm estuary and Erme estuary

3.3.18 Erme Estuary (Figure 29)

Walkover surveys suggest that Pacific oysters are Frequent (0.1-0.9/m^2) on both the western and eastern shores of the estuary. However, at the mouth of the estuary around Meadowsfoot Beach and below Owen's Hill oysters appear to be more prevalent and were Common (1-9/m^2).

3.3.19 Salcombe to Kingsbridge Estuary (Figure 30)

No quadrat surveys were undertaken in the Salcombe to Kingsbridge estuary. However, walkover surveys suggest that there are Frequent levels (0.1-0.9/m^2) of Pacific oysters throughout the estuary with higher densities seen (Common = 1-9/m^2) by Salcombe village and at Snapes Point.

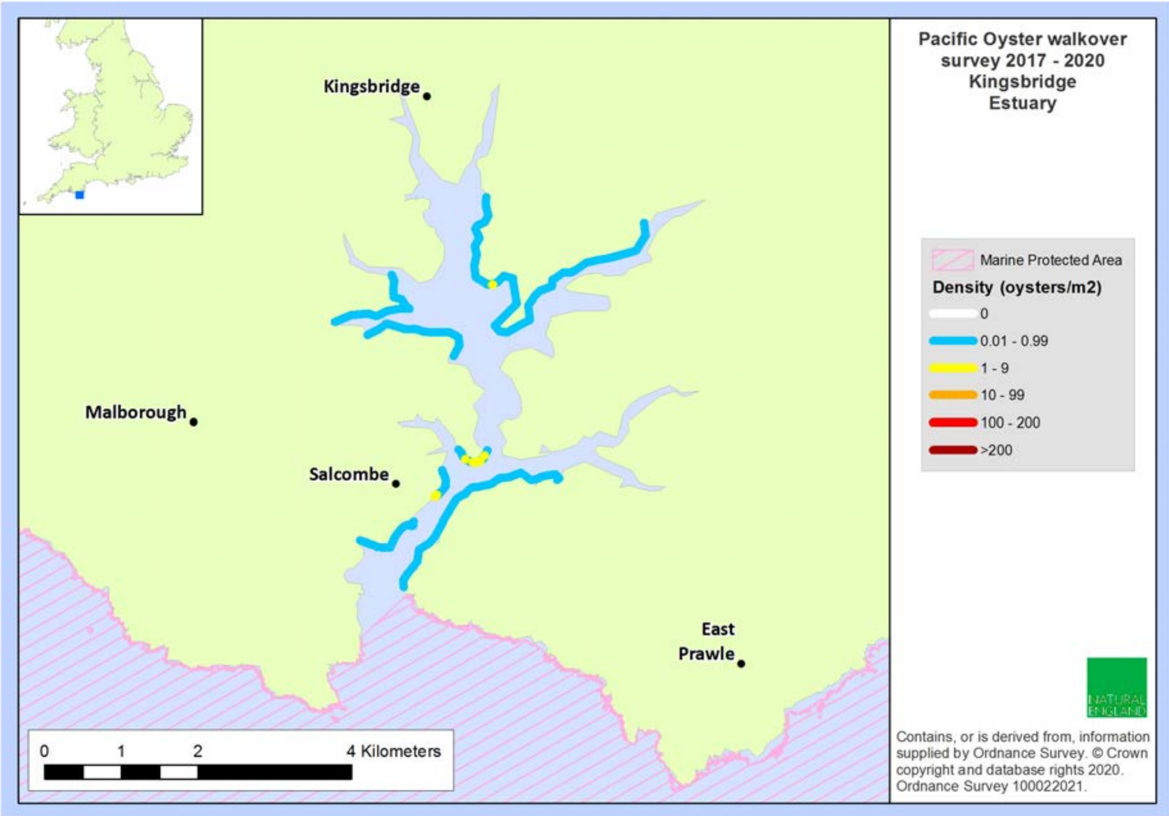


Figure 30: Pacific oyster densities calculated from walkover surveys in the Salcombe and Kingsbridge estuaries

3.3.20 Exe Estuary (Figure 31)

On the Exe estuary in 2020 the Exe Estuary Partnership officer surveyed 33 quadrats at Cockwood near Starcross. Although this survey was not part of this project, the same methodology was followed, and the data submitted to Natural England (Boyle 2020). Here Pacific oysters were mostly Common (1-9/m^2) to Abundant (10-99/m2), only one quadrat had no oysters. The average density of Pacific oysters was 16.85/m^2 with a maximum of 56/m^2.

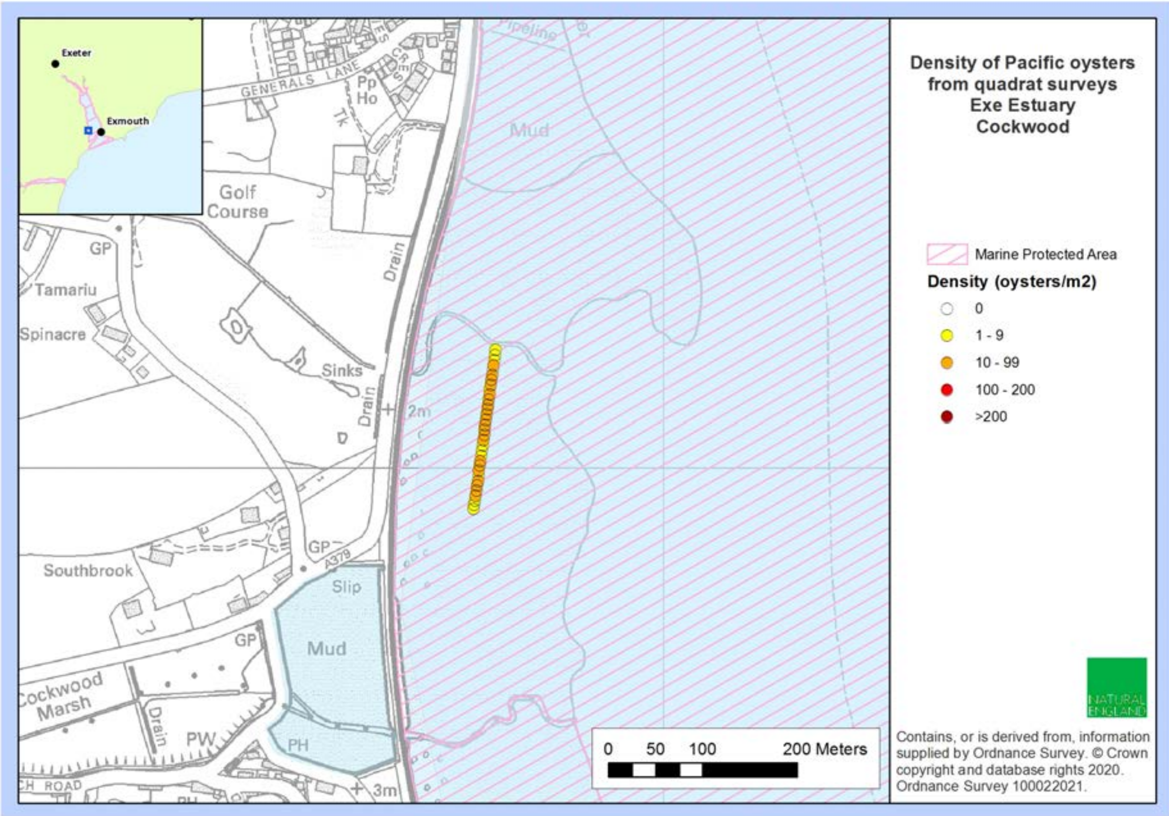


Figure 31: Pacific oyster densities calculated from quadrats at Cockwood, Exe estuary

3.3.21 Additional information from walkover surveys (Figure 32)

Many of the areas where walkovers surveys took place recorded Occasional to Frequent abundances of Pacific oysters (0.01 – 0.9/m^2), (Fig 30). There were also some sections where no Pacific oysters were seen. These were: the southern end of Sand Acre Bay; southern side of Torpoint; southern shore of Millbrook Lake; Plymouth Breakwater (although they were Common to Frequent adjacent at the Breakwater Fort). Walkover surveys also suggest that Pacific oysters are Common to Abundant (1-99/m^2) at Mount Batten.

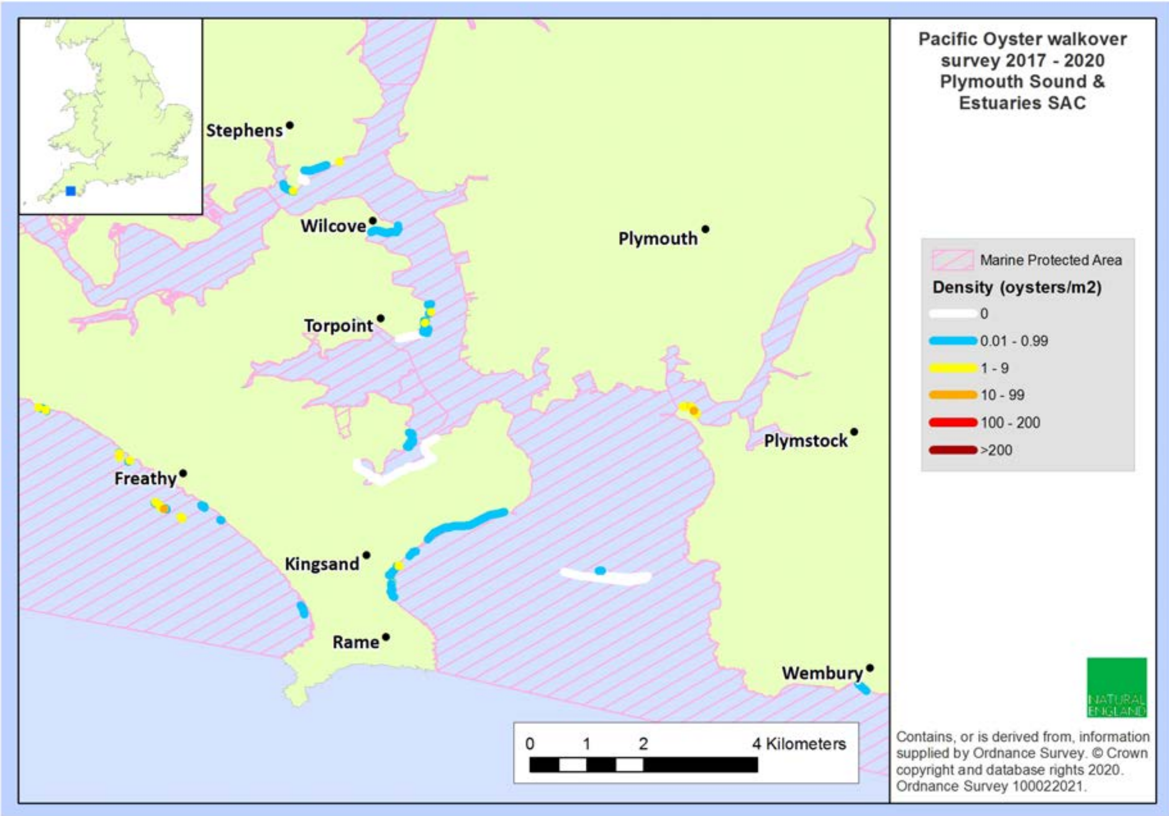


Figure 32: Pacific oyster densities calculated from walkover surveys in Whitsand and Looe Bay and Plymouth Sound and Estuaries SAC (excluding the Yealm estuary)

3.3.22 Pacific oysters and Seagrass

This project has identified significant Pacific oyster settlement on intertidal dwarf seagrass in the Salcombe and Kingsbridge Estuary SSSI. It is also possible that an unmapped seagrass bed exists within the outer mouth of the Erme estuary, with some seagrass having been observed here during the project (Mortimer. N, Personal communication 2020).

3.3.23 Impacts on human activity

Anecdotal evidence from harbour authorities, volunteers, and community groups on the impacts of Pacific oyster presence on human activity was recorded as part of this project. A major concern was the physical danger presented by the oysters' large, sharp shells.

The Yealm Harbour Authority recorded numerous accounts of people becoming seriously injured by Pacific oyster shells when crossing the foreshore. Individuals have required hospital visits and occasionally stitches (Yealm Harbour Authority, personal communication 2020). Further accounts gathered during this project are detailed in Figure 33 below.

‘I am a marine biologist who regularly carries out surveys found on rocky shore and estuary sites. I have twice now been injured by Pacific oysters while turning boulders. On the first occasion I cut the palm of my hand quite badly, requiring stitches. I was not wearing gloves, which we have since added to our safe working practice, although they inhabit one’s ability to identify species by touch. The second time, I slipped while crossing a Pacific oyster reef and slashed my bare arm, although my gloves protected my hands. The increasing presence of Pacific oysters on the shore has definitely made surveying more difficult and dangerous.’

Christine Wood: Marine Biological Association, Plymouth.

‘The local parish/Harbour have many stories of people cutting their feet jumping out of boats and walking along the foreshore in addition to injured paws and vet visits from people using the area to walk their dogs.’

South Devon AONB Estuaries Partnership, south Devon.

Figure 33: Accounts of human impacts from Pacific oysters.

Inflatable dinghies and stand-up paddle boards (SUPS) are also particularly vulnerable. Within the South Devon AONB there have been reports of inflatable boats being punctured or scratched by Pacific oysters.

Slipways and other artificial concrete structures are particularly attractive to Pacific oyster spat (for example in the Fowey estuary) and where oyster colonisation is not kept under control, they can rapidly become unusable. Some areas in the south west have slipway cleaning operators who try to remove the Pacific oysters.

Around the Yealm estuary in south Devon, warning signs (Appendix 1) have been erected to make the general public aware of the hazard and to strongly advise wearing suitable footwear. Signs have also been put up at Stoke Gabriel on the Dart estuary funded by the local boating club. These signs were designed and funded by the South Devon AONB Estuaries Partnership.

Image 8: Pacific oyster warning sign – Yealm estuary (Appendix 1) ©Nigel Mortimer

4. Discussion: Pacific oyster surveys undertaken by volunteers

4.1 Ascertain the existing distribution and population density of Pacific oysters around the coast of Cornwall and south Devon and identify Pacific oyster hotspots, focusing on MPAs.

This project has contributed to our knowledge of the current population density of Pacific oysters within MPAs in Devon and Cornwall. It has also identified a number of hotspots where Pacific oyster settlement is a cause for concern, and other areas where they may become an issue in the near future.

Pacific oysters have been recorded during this study from St. Ives Bay and Newlyn in west Cornwall, to the Salcombe and Kingsbridge estuaries in south Devon. They are present in every estuary to some degree along this stretch of the Cornwall and Devon coasts, and have also been recorded on the open coast.

4.2 Pacific oyster hotspots and reefs

In some survey areas Pacific oysters were extremely dense and rated Superabundant on the SACFOR scale, with densities of more than 100 oysters per m^2 recorded at one point at least, or more widely along a section of shore. This is the highest density category and has been used to identify Pacific oyster hotspots. At this level Pacific oysters may be causing the designated features of MPAs to be in unfavourable condition. Hotspots were found at the following locations during the study:

- Fal estuary – Restronguet Creek, Loe Beach, Tregothnan Park (Deer Park), south of St Just Pool
- Fowey estuary – Mixtow Pill, Pont Pill
- Plymouth Sound – The Cove near Wilcove
- Yealm estuary – Machine Beach, Newton Ferrers, Noss Mayo

The highest density was found at The Cove, Wilcove near Torpoint in the Plymouth Sound and Estuaries SAC, with 396 Pacific oysters per m^2.

As the density of Pacific oysters increases, they begin to form reefs as they cement together. This can lead to a change in the community structure and habitats that are present as they begin to cover the shore. Project officers noted that at all of the above hotspot locations Pacific oysters were forming or had started to form a reef (Mortimer. N, personal communication 2020 & Slater. M, personal communication 2020).

In addition to the above locations, they also noted that reefs were present or had started to form at these locations:

- Fal estuary – Channals Creek
- Helford estuary – the beginnings of reef formation at the entrance to Port Navas Creek on both sides, Porth Navas, around Helford Point and Treath
- Salcombe estuary – in intertidal seagrass *Zostera noltii* to the west of Gerston Point, at the entrance to Collapit Creek, on the northern shore

A previous survey in the Yealm estuary for Natural England (Curtis 2018) defined reefs as areas where there was 100% cover, or more, of Pacific oysters. It should be noted that the locations above suggested by project officers were based on their subjective opinion, and not based on this definition. It is clear however that many of their suggestions align with what was found in the quadrat surveys.

A recent study by Hooper (2020) also identified reefs at Empercombe and Beggar's Island near Plymouth.

This work highlights that there are hotspots for Pacific oysters that have the potential to damage designated features of MPAs, in South Devon and Cornwall, if management is not put in place to control Pacific oyster populations.

4.3 Additional areas with high levels of Pacific oysters

In addition to the hotspots above, there were several areas where Pacific oysters were rated as Abundant on the SACFOR scale, with 10–99 oysters per m^2. At this level Pacific oysters may be causing the designated features of MPAs to be in unfavourable condition. During the study, Pacific oysters were found to be Abundant at the following locations:

- Fal estuary – Greatwood Quay, Restronguet Creek, to the east and west of Loe Beach at Feock, west side of Channals Creek, Turnaware Point, Tregothnan Park, St Just Pool, Messack Point to Messack House and further up into St Just Creek, near Halwartha
- Par Beach
- Looe
- Whitsand Bay – near Freathy
- Plymouth – near Churchtown Farm Nature Reserve, Beggars Island to Juniper Point, Cawsand, Mount Batten
- Yealm – Passage Wood, Clitters Wood, between Court Wood and Newton Ferrers Harbour Office
- Exe estuary – Cockwood

Given the number of locations where Pacific oysters have been found to be Abundant or Superabundant in the Fal and Helford SAC and Plymouth Sound and Estuaries SAC (and their other overlapping MPAs) we recommended that targeted management of Pacific oysters is initially focused on these sites. Both of these MPAs have already been assessed as being in unfavourable condition due to pressures which include the presence of Pacific oysters. They will therefore require further management action to address the current impact of Pacific oysters in these sites.

4.4 Areas with notable levels of Pacific oysters

The SACFOR category of Common, 1-9 Pacific oysters per m^2, has been used in this report to identify notable areas of Pacific oysters. At this level there is the potential that the presence of Pacific oysters is already causing changes to habitats and communities, and they are approaching levels that may cause the designated features of MPAs to be in unfavourable condition.

All of the estuaries surveyed had areas where there were notable levels of Pacific oysters, as did Mounts Bay MCZ and Whitsand and Looe Bay MCZ. There were only a few very small sections of shore that were recorded as having no oysters at all, however, this is not surprising, as this project focused on survey locations where Pacific oysters were known to be present.

It is recommended that regular monitoring is undertaken in these sites with notable levels of Pacific oysters, to identify if the populations are increasing. If sufficient resources are available, targeted controlled management should also be put in place to remove oysters before they reach levels that will lead to designated features becoming unfavourable.

It was beyond the remit of this study to investigate why Pacific oysters are more prevalent in certain areas. However, this is likely to be due to various environmental conditions such as substrate type, currents, and other environmental variables.

Whilst reviewing the data from this project, walkover surveys appear to have routinely underestimated the densities of Pacific oysters by one category on the SACFOR scale when compared to the quadrat surveys (note this has not been statistically analysed). It is recommended that quadrat surveys are used where an accurate density recording is required (this may include control sites). Walkover surveys however are still valuable as they can provide a quick means of identifying where there are higher densities of Pacific oysters and therefore where to focus further work.

4.5 Determining the density at which Pacific oysters impact MPA features

This study has highlighted the complexities surrounding the determination of exact densities at which Pacific oysters affect MPA features. It is likely that this will vary between features but also between sites, depending on local conditions.

The precise densities at which Pacific oysters begin to affect designated features (habitats and species) of MPAs are likely to be dependent on several factors, including: the nature of the feature concerned; the individual attributes which describe the integrity of the feature; the extent of the feature affected; as well as other pressures. Recent Condition Assessments in Plymouth Sound and Estuaries SAC, Fal and Helford SAC, and the Thanet Coast SAC in Kent have assessed both intertidal rock and sediment features as being in unfavourable condition, where Pacific oyster densities of 10-99 per m^2 (Abundant on the SACFOR scale) were seen.

This discussion on the potential impacts of Pacific oysters in MPAs, utilises this approach. However, it should be noted that the development of this report has led to further discussions regarding the levels at which Pacific oysters may impact different habitats and species; and these are detailed at the end of this section (Table 6).

One attribute of a feature may be affected at a different density threshold to another attribute. Community composition is often assessed looking at the presence of previously recorded biotopes and assessing whether any change has occurred.

There are currently no British biotopes described that include Pacific oysters as one of the predominant, component, or characterising species. It may be necessary to address this, with Pacific oysters now characterising biotopes in many sites. Further research into the density thresholds at which Pacific oysters begin to cause feature attributes to fail to meet their condition targets is needed.

'Reduce the spread of invasive, non-native species' is a secondary attribute target (see Section 2) and therefore, although this target is unlikely to be met (unless robust and targeted control of Pacific oysters continues), on its own it will not cause a feature to fail overall.

'Maintain the community composition of component species', however, is a principal attribute target, and if community composition is considered to have been altered, this alone will cause a feature to fail its Condition Assessment.

Community composition changes may be subtle and not immediately apparent, particularly on intertidal rock, apart from the obvious presence of Pacific oysters within a described biotope. There is still limited understanding of the impacts of oysters at varying densities and detailed studies are required to detect, describe, and quantify any changes to community composition.

A qualitative visual assessment of an area of intertidal reef may reveal rocky shore species, for example limpets, barnacles, sponges, and seaweeds, to be present in areas with significant Pacific oyster settlement. These species may inhabit the hard-upper valve of the oyster much as they would the surrounding hard surface of the rock. It is unclear however, due to the limited evidence in the literature, whether some species may be disadvantaged, leading to opportunistic gains by other species. Community structure may have undergone subtle changes and further studies are urgently needed to ascertain the impacts to intertidal rock habitats, if any, at varying levels of Pacific oyster abundance.

For sediment communities the changes are more obvious. Pacific oysters can be seen to smother sediments, changing habitat types from sediment to biogenic reef and disturbing or blocking the sediment surface that may be used as foraging habitat by birds and fish. Species diversity and biomass may increase in areas where Pacific oysters have formed reefs (Herbert and others 2018), however, prey species associated with Pacific oyster reefs may not be as accessible to some bird and fish species, and infaunal invertebrate assemblages may not survive smothering by biogenic reefs. Even if species diversity or abundance increases within a site as a result of colonisation of Pacific oyster reefs by other species, the wider biodiversity (across MPAs) must be considered. Some sites may protect rare species or habitats and the loss or degradation of these species or habitats could be significant on a national scale.

In the absence of sufficient evidence, density thresholds at which features are impacted, have been assigned. This is a judgement based on best available evidence and may be subject to change as further evidence becomes available. Intertidal rock has already been assessed as unfavourable in several MPAs when Pacific oysters are Abundant (10 -99m^2). At this threshold, biotopes are dominated by oysters. Sediment habitats are physically changed at lower oyster densities, with oysters engineering a new structurally complex habitat and causing a change from a soft to hard substrate, especially when reefing occurs. As such, biotopes, species, and habitats are likely to be significantly changed at Pacific oyster density thresholds of 1 – 9 m^2 (Common on the SACFOR scale).

It will be extremely valuable to understand the specific abundances at which Pacific oysters begin to affect different feature attributes and lead to changes in community composition and biotope type within MPAs. While sufficient evidence is lacking, we recommend that the thresholds listed in Table 5 are applied, which consider the varying sensitivities of different MPA features. It should be noted that individual sites and biotopes may have different characteristics and that the thresholds listed below may not be appropriate in all situations. Thresholds may change as evidence and understanding develops.

Table 5: Abundance thresholds at which Pacific oysters may begin to impact intertidal habitats and cause condition targets to fail.

Feature	Lowest abundance threshold at which feature likely to be affected (SACFOR scale)	Rationale	Confidence	Further evidence required
Intertidal rock	Abundant (10 – 99/m^2)	The hard-upper valves of Pacific oysters are likely to replicate the physical nature of the rock, and as such, may be colonised by native species in a similar manner. Biotopes are altered, even at lower	Low	Studies comparing community composition of intertidal rock communities in areas with varying Pacific oyster abundances and areas with no settlement, where other variables (e.g. physical characteristics/

		abundances, however, it is not yet clear what impacts this may have on community structure. At an ‘abundant’ threshold of settlement, Pacific oysters dominate this feature.		exposure) are accounted for.
Intertidal sediment	Common (1 – 9/m^2)	Even at lower densities of Pacific oyster settlement, the physical nature of sediment habitat is altered. This habitat is changed to another habitat type and is likely to show a change in ecological function.	Low / Med	More research into ecological changes at varying thresholds, looking at different sediment types.
Seagrass beds	Occasional (0.1-0.9/m^2)	Seagrass is a sensitive habitat and Pacific oyster reefs forming within seagrass beds may result in a reduction or loss of this feature.	Low/ Med	We would not recommend studies into effects of Pacific oyster settlement in seagrass beds; rather the prompt removal of Pacific oysters before reefing can occur.

4.6 Recommended actions for MPA survey sites

The table below summarises the maximum average Pacific oyster abundance (on the SACFOR scale) for each MPA, calculated from quadrat survey data (unless stated otherwise), along with recommended actions.

Table 6: Pacific oyster densities recorded in MPAs using quadrats (walkover information in brackets).

Marine Protected Area	Maximum average density from quadrats for a section of shore (SACFOR)	Maximum density based on a single quadrat (SACFOR)	Recommendation
Mounts Bay MCZ	(Common - walkover)	N/A	Monitor and manage
Helford MCZ	Common	Common	Monitor and manage
Fal and Helford SAC	Abundant	Superabundant	Manage Pacific oysters
Lower Fal and Helford Intertidal SSSI	Common	Abundant	Manage Pacific oysters
Rosemullion SSSI	N/A	N/A	Initial survey
Malpas Estuary SSSI	N/A	N/A	Initial survey
Upper Fal Estuary and Woods SSSI	Abundant	Superabundant	Manage Pacific oysters
Upper Fowey and Pont Pill MCZ	Abundant adjacent to site boundary at Pont Pill (Superabundant elsewhere in estuary)	Superabundant adjacent to site boundary	Manage Pacific oysters
Whitsand and Looe Bay MCZ	Abundant adjacent to site boundary at Looe. (Abundant - walkover)	Abundant adjacent to site boundary at Looe	Manage Pacific oysters
Plymouth Sound and Estuaries SAC	Superabundant	Superabundant	Manage Pacific oysters

Marine Protected Area	Maximum average density from quadrats for a section of shore (SACFOR)	Maximum density based on a single quadrat (SACFOR)	Recommendation
Tamar Estuaries Complex SPA	Superabundant	Superabundant	Manage Pacific oysters
Lynher Estuary SSSI	Common 450m from site boundary	Abundant 450m from site boundary	Initial survey
Plymouth Sound Shores and Cliffs SSSI	Abundant at Cawsand 350m from site boundary. (Abundant - walkovers adjacent to site boundary at Mount Batten)	Abundant at Cawsand 350m from site boundary	Initial survey
St. John's Lake SSSI	(Frequent - walkovers very small section south west corner. None - walkovers 180m from site boundary at Torpoint)	N/A	Initial survey (given proximity of reef at Empercombe to the SSSI seagrass beds)
Tamar-Tavy Estuary SSSI	(Nearest survey point north of Hearn Point approximately 1km away with no Pacific oysters)	N/A	Initial survey
Wembury Point SSSI	Abundant	Superabundant	Manage Pacific oysters
Yealm Estuary SSSI	Abundant	Abundant. (Superabundant adjacent to site boundary at Court Wood)	Manage Pacific oysters
Tamar Estuaries Sites MCZ	(Nearest survey point north of Hearn Point approximately 1km	N/A	Initial survey

Marine Protected Area	Maximum average density from quadrats for a section of shore (SACFOR)	Maximum density based on a single quadrat (SACFOR)	Recommendation
	away with no Pacific oysters)		
Start Point to Plymouth Sound and Eddystone SAC	Frequent (extremely small section at entrance to Erme Estuary)	N/A	Initial survey (as reefs mostly subtidal)
Erme Estuary MCZ	(Common – walkover)	N/A	Monitor and manage
Erme Estuary SSSI	(Common – walkover)	N/A	Monitor and manage
Devon Avon MCZ	N/A	N/A	Initial survey
Salcombe to Kingsbridge Estuary SSSI	Common	N/A	Monitor and manage Pacific oysters
Dart Estuary MCZ	(Features have Recover GMA due to Pacific oysters)	N/A	Manage Pacific oysters
Exe Estuary SPA	Abundant (small section at Cockwood)	Abundant (small section at Cockwood)	Manage Pacific oysters at Cockwood and initial survey for rest of site
Exe Estuary SSSI	Abundant (small section at Cockwood)	Abundant (small section at Cockwood)	Manage Pacific oysters at Cockwood and initial survey for rest of site
Dawlish Warren SSSI	Abundant 200m from site boundary at Cockwood	Abundant 200m from site boundary at Cockwood	Initial survey

4.7 Pacific oysters outside surveyed areas

It is likely that other locations with significant Pacific oyster settlement exist both within and outside of the MPAs surveyed as part of this study. These areas may be unknown, either because they have not yet been visited and surveyed, or because they are relatively inaccessible. These other potential locations could act as source populations for the spread of Pacific oysters both within and into MPAs.

It was beyond the scope of this project to identify areas such as these. Cefas is currently undertaking modelling work to identify how feral Pacific oyster's populations are affected by external recruitment from farmed and other feral populations. We recommend that the outcomes of the Cefas study are reviewed and used to identify appropriate management approaches, irrespective of whether they are within a MPA, to prevent further recruitment from contributing to unfavourable condition of MPAs. Outside sources could also impact the effectiveness of management work being undertaken in MPAs.

Some areas may be relatively inaccessible by volunteer groups either due to a lack of access routes, or the requirement to work in more difficult environments such as intertidal mud. These areas could be surveyed remotely, using technological methods such as drone footage, to see whether there was validity in further investigation.

4.8 Record other Invasive Non-Native Species

Pacific oysters are not the only invasive non-native invasive species (INNS) that have been recorded on Devon and Cornwall shores. For example, the American slipper limpet *Crepidula fornicata* and the alga *Gracilaria multipartita* have previously been recorded within the Plymouth Sound and Estuaries SAC. The Tamar Estuary Biosecurity Plan lists 16 non-native species which are thought to have a significant presence in the area with an additional 29 species also known to occur here (Wood and others 2018). At least 25 non-native species have been recorded around the Fal estuary (Natural England 2017h) and there are significant populations of American slipper limpet *Crepidula fornicata* in The Bag in the Salcombe to Kingsbridge estuary SSSI (Mortimer. N, personal communication 2020). We had hoped to improve our current understanding of the distribution of other INNS within the region, with volunteers asked to record other INNS where possible. Although the INNS workshop that was delivered for volunteers at the beginning of the project was interesting and informative and perhaps inspired volunteers in their involvement in this project, little data were received on other INNS. This is thought to be due to the prime focus being the recording and culling of oysters. Volunteers were usually surveying within strict time limits due to tides, and priority was most likely given to the survey methods and management of Pacific oysters.

On reflection, it is likely that recording of other INNS may have been too time consuming an activity that was not particularly compatible with the main project focus. Volunteers have their eyes trained in to detect Pacific oysters and looking out for other INNS may have been distracting. The training session was certainly worthwhile and aided volunteers with the identification distinction between Pacific oysters and native oysters and provided them with useful background knowledge on species invasions. Although the recording of other INNS would have been useful, it was not an essential aspect of this project. A future focus that increased quadrat surveys could consider this, perhaps as part of a local biosecurity action group, subject to available funding.

4.9 Monitor settlement rates

At the beginning of the project, one of the aims was to monitor the re-settlement rate of juvenile Pacific oysters after culling. Unfortunately, for a number of reasons including staff changes and earlier recommendations on culling seasons (to avoid spawning times), survey work did not commence until midway through year one. This reduced the time available to monitor settlement rates within the two-year scope of the project.

Although no systematic settlement surveys could be carried out in the time available, small Pacific oysters that looked like new spat were recorded when encountered. It has not been possible to ascertain whether these were indeed new spat following culling as growth rates can vary according to local environmental and physical conditions and as such it can be difficult to estimate the exact age of specimens.

Significant numbers of small juvenile Pacific oysters were recorded between November 2019 and May 2020 within the Fal estuary and this may be a useful area to target future studies. Robust methodology should be devised to monitor settlement rates, ideally over a longer term than 2 years, as mass spawning events can be sporadic and influenced by environmental conditions. Evidence collected as part of this project, such as information on where recent spat settlement has occurred, will be useful in informing future studies.

Image 9: Small Pacific oyster within the Fal Estuary ©Matt slater

Image 10: Small Pacific oyster within the Fal Estuary ©Matt slater

4.10 Risk of Pacific oysters to seagrass beds

An unexpected result of this study was that it highlighted the risk of Pacific oysters to seagrass beds within the region. During walkover surveys, Pacific oysters were found within the intertidal seagrass beds, which are a designated feature of the Salcombe to Kingsbridge Estuary SSSI. The South Devon AONB project officer noted that Pacific oysters here had begun to reef, with small clumps forming in places. Pacific oysters therefore have the potential to pose a threat to seagrass beds. When Pacific oysters form reefs, they physically change their environment and may cause changes in local hydrodynamics. They may also cause a build-up of sulphide in the sediment, which may be toxic to seagrass (Kelly & Volpe 2007), add nutrients, and change sediment characteristics such as silt:sand ratios (Wagner et al. 2012). Seagrass *Zostera marina* density has been shown to decrease with increasing oyster density (Tallis et al. 2009; Wagner et al. 2012) and the community composition of associated species may change (Kelly et al. 2008). Pacific oysters, if beginning to form reefs, may smother seagrass, potentially inhibiting seagrass density, shoot length, growth, and other condition attributes.

This study identified reefs at The Cove, Wilcove, near Plymouth, and Hooper (2020) also identified reefs at Empercombe. The reef at Empercombe (Hooper 2020) within Plymouth Sound and Estuaries SAC, St Johns Lake SSSI and Tamar Estuaries Complex SPA, lies close - approximately 450m - to the intertidal seagrass *Zostera noltii* in St John's Lake. The reef at The Cove, Wilcove, is approximately 400m from the seagrass bed in Cangapool which lies just outside the Plymouth Sound and Estuaries SAC boundary.

It is recommended that these SSSI and SAC features, and SPA supporting habitats, are monitored regularly for Pacific oyster settlement so that effective management action can be taken quickly if required. This could include targeted removal of Pacific oysters which is discussed in the next section on culling.

It is also recommended that potential impacts to seagrass beds within the region are further investigated, to improve the understanding of locations of seagrass beds that are currently impacted or have potential to be impacted. This could be carried out initially as a desk study, looking at the proximity of seagrass beds to areas known to have high densities of Pacific oysters, and using invasive non-native species data collected from seagrass monitoring surveys.

5. Pacific oyster culling trials

5.1 Aims and objectives:

The project's aims for Pacific oyster surveys were to:

- Undertake population control methods to reduce feral populations and reduce population expansion
- Assess whether control of Pacific oysters using volunteer effort can be effective in reducing Pacific oyster density over a two-year period.

These aims would be achieved by:

- Training volunteer groups to carry out population control on feral oysters around Cornwall and south Devon
- Undertaking data analysis to determine the impact of reducing populations

5.2 Control Methodology

5.2.1 Population control – culling of Pacific oysters

Removal of Pacific oysters was carried out by volunteers during survey events in both Cornwall and South Devon. A majority of the cull surveys were undertaken during or after walkover surveys; usually following the same transect.

The method of culling used in this study was based on the study in North East Kent by W. McKnight and I.J. Chudleigh (2012).

In McKnight and Chudleigh's study, Pacific oysters on hard substrates were culled by striking the upper valve with a hammer or heavy object. This displaced the upper shell leaving the lower shell in place. The exposed tissue was then consumed by gulls and other marine life. Oysters directly attached to hard structures such as rocky reefs cannot be fully removed as the lower shell is cemented to the substrate. Prising off this lower shell can damage the rock and is time consuming. There are also issues regarding the disposal of the oyster once removed.

In some soft sediment areas, Pacific oysters were removed by hand where possible. This method was previously trialled in Kent where it proved to be the most effective and time efficient method of controlling Pacific oyster numbers in sediment habitats.

5.2.2 Ethical considerations

Invasive species control and eradication takes place throughout the world to protect threatened native species and habitats (for example rats or mice on offshore islands that are important for ground-nesting native birds). In this case the benefits of removing this invasive species was necessary to reduce the potential impact to many protected features and the biotopes that they are made up of. The killing of bivalve molluscs may not equate in some minds to the killing of higher or more physiologically complex animals, however, it is likely that some will view the smashing of live shellfish with a hammer as a cruel practice.

During this project a small number of volunteers were reluctant to undertake this activity for personal, ethical reasons. At the start of this project it was agreed that it was important that individuals did not feel pressured to undertake an activity they were not entirely comfortable with. In this project, volunteers who were keen to assist with what they considered important conservation work, had the option to take part solely in the monitoring aspect of the project (rather than culling), thereby providing useful data on the spread of Pacific oysters in the region.

A significant number of volunteers, though apparently having no ethical objection to the culling of Pacific oysters, considered the practice rather wasteful, as a potential resource was being destroyed and left *in situ*, instead of being put to good use. This issue has been considered further as part of this project with potential alternative uses explored in section 11.

It is well known that the total eradication of this species is not possible, and this was made clear to participants at the outset. It was explained however that monitoring, and control programmes could control the population of Pacific oysters in areas that have not reefed or are showing early signs of colonisation.

Most volunteers in this project considered control necessary to protect native communities and habitats and therefore a worthwhile action to take. Some volunteers received negative comments while undertaking Pacific oyster control and suggested that branded vests, signage, or hand-outs to inform the general public may be useful in future. The sight of a group of people using hammers to smash organisms on the shore can initially appear quite shocking. Hand-outs were produced addressing frequently asked questions and giving further information on the project (see Appendix 2). These were available for use by volunteers on the shore and used on many occasions. However, it was reported that not all groups had these to hand during all culling events.

Image 11: Cornwall Wildlife Trust volunteers during a quadrat survey ©Matt Slater

6. Results: Pacific oyster control

6.1 Numbers of Pacific oysters removed

As part of this project Pacific oyster culls were carried out from Bude in north Cornwall to the Dart estuary in south Devon. Cull locations, years and total numbers culled at each location are shown in Table 14 below. At some locations several culls were completed during a year.

At least 176,757 Pacific oysters were culled as part of this project. The largest numbers of Pacific oysters were culled by volunteers in the Fal estuary with a total of 85,044 individuals. This was followed by the Fowey estuary with 35,835 Pacific oysters culled and the Helford estuary with a total of 29,095 Pacific oysters culled. These numbers may in part be due to the very high density of Pacific oysters within these areas but may also reflect the numbers of volunteers that were engaged in this area.

It was not possible to carry out further analysis on how many oysters could be removed per volunteer hour due to gaps in the data. It is also likely that the number of volunteer hours required to clear a section of shore of Pacific oysters will be dependent on the density of the oysters at the start of the cull, the type of habitats present and terrain to be covered.

Table 7: Cull locations, years and number of Pacific oysters culled in South Devon and south Cornwall.

Area	Location	Years culled	Total no. Pacific oysters culled
Gwelva, Bude		2018 & 2019	**963**
Carbis Bay, St Ives		2019	**165**
Mount's Bay	Chyandour	2019	1634
	Long Rock, Penzance	2018 & 2019	459
	Great Hogus	2018	10
		Total	**2103**
Helford Estuary	Gillian Creek east	2018	1442
	Gillan Creek west	2017, 2018, 2019	693
	Treath	2016, 2018, 2019, 2020	5978
	Port Navas Creek to Calmanscac	2016, 2018, 2019, 2020	14,862
	Pedn Billy Point	2015, 2017, 2018, 2020	1614
	Bar Beach	2015, 2017, 2018, 2020	2549
	Ferryboat Beach	2017, 2018, 2019	1120
	Trebah Beach to Grebe Beach	2015, 2016, 2017, 2018, 2020	837
		Total	**29,095**
Fal Estuary	Maenporth Beach	2018	82

	Falmouth Harbour	2020	859
	Prince of Wales Pier, Falmouth	2018	229
	Greenbank	2018 & 2020	397
	Flushing	2019	530
	Trefusis	2019	2725
	Falmouth Water Sports Centre	2018 & 2019	505
	Mylor Quay and Mylor Creek	2019	6
	Greatwood Quay and House	2018 & 2019	4522
	Weir Point Beach	2020	63
	Restronguet Point	2019	9293
	Loe Beach, Feock	2020	12,637
	Channals Creek, Trelissick	2019	2273
	Turnaware Point	2019	6101
	Messack Creek	2019	23,928
	St Just Creek	2019	13,570
	St Just Pool	2019	6478
	Lowlands beach	2018	846
		Total	**85,044**
Portmellon to Mevagissey		2019	**132**
Par Beach	West Rock Groyne	2018 & 2020	**3249**

Fowey Estuary	Readymoney cove	during some Shoresearch surveys, dates unknown	n/a
	Albert Quay	2018	871
	Golant Sailing Clun to RNLI steps	2019	1174
	Whitehouse to Town Quay	2020	1370
	Town Quay to RNLI steps	2020	340
	Caffamill	2019	1637
	Grid Irons	2019	3575
	Pont Pill	2018 & 2019	17,894
	Polruan	2020	45
	Prime cellars	2020	8929
		Total	**35,835**
Portholland		2019	12
Looe	Looe Harbour walls	2018 & 2019	2001
Whitsand Bay	Furthest NW end of Whitsand Bay	2018	485
	NW end of Whitsand Bay	2018	732
	Tregantle	2019	350
	Sharrow	2019	2384
	Polhawn end of Whitsand Bay	2019	248
	Furthest SW end of Whitsand Bay	2018	654

		Total	**4853**
Plymouth Sound and Estuaries SAC (excluding Yealm estuary)	Cawsand Beach	2019	185
	Kingsand Beach	2019	1736
	Sandways Beach	2019	1171
	North Ballast Pound	2020	314
	Wilcove, Torpoint	2019	52
	Churchtown Farm Community Nature Reserve to Passage Point ferry	2020	215
	Wearde Quay	2020	25
		Total	**3698**
Yealm Estuary	Shore by the Yealm Harbour Office	2019	2500
	Noss Mayo	2017	unknown
		Total	**2500**
Erme Estuary	West side	2019 & 2020	1196
	East side	2019	301
		Total	**1497**
Salcombe and Kingsbridge Estuaries	North Sands to Woodville Rocks	2019	300
	Salcombe Harbour Hotel to Lifeboat Slipway	2019	676
	Snapes Point	2019 & 2020	2251

	Ilton Creek off Blanksmill Creek to Lincombe Creek	2019	58
	Northern shore of Blanksmill Creek and around Rowden Point to the mouth of Collapit Creek	2019	185
	West Charleton Marsh to Curlew Drive	2020	668
	Frogmore Creek	2019	107
	Yalton Bay to East Portlemouth ferry	2020	500
	East Portlemouth ferry jetty to Limebury Point	2020	296
		Total	**5041**
Dart Estuary	Duncannon to Stoke Gabriel	2019	**569**
Total number of Pacific oysters culled during the project			**176,757**

6.2 Helford Marine Group

No known walkover surveys were undertaken in the Helford estuary and oyster density was only recorded in three quadrats at St Anthony-in-Meneage in 2017. However, between 2015 and 2020 the Helford Marine Group undertook a series of Pacific oyster culls around the estuary where they recorded the number of Pacific oysters removed and the number of volunteers involved. A total of 29095 Pacific oysters were culled from the Helford estuary between 2015 and 2020.

The largest volunteer effort was focused on the area of shore at Calmansac (Figure 34: Section A). A total of 44.9 hours was spent culling Pacific oysters at this location between 2016 and 2020. 39 volunteers were involved in the cull over this period which resulted in the removal of 14862 Pacific oysters.

In Port Navas Creek (Figure 34: Section B) 1614 Pacific oysters were culled between 2018 and 2020 over 7 hours by a total of 13 volunteers throughout this period.

To the east of Port Navas Creek at The Bar (Figure 34: Section C) 2549 Pacific oysters were culled between 2015 and 2020 over 7.5 hours by a total of 22 volunteers throughout this period.

At Passage Cove and eastwards to the headland (Figure 34: Section D) 1120 Pacific oysters were culled between 2017 and 2020 over 11.65 hours by a total of 13 volunteers throughout this period.

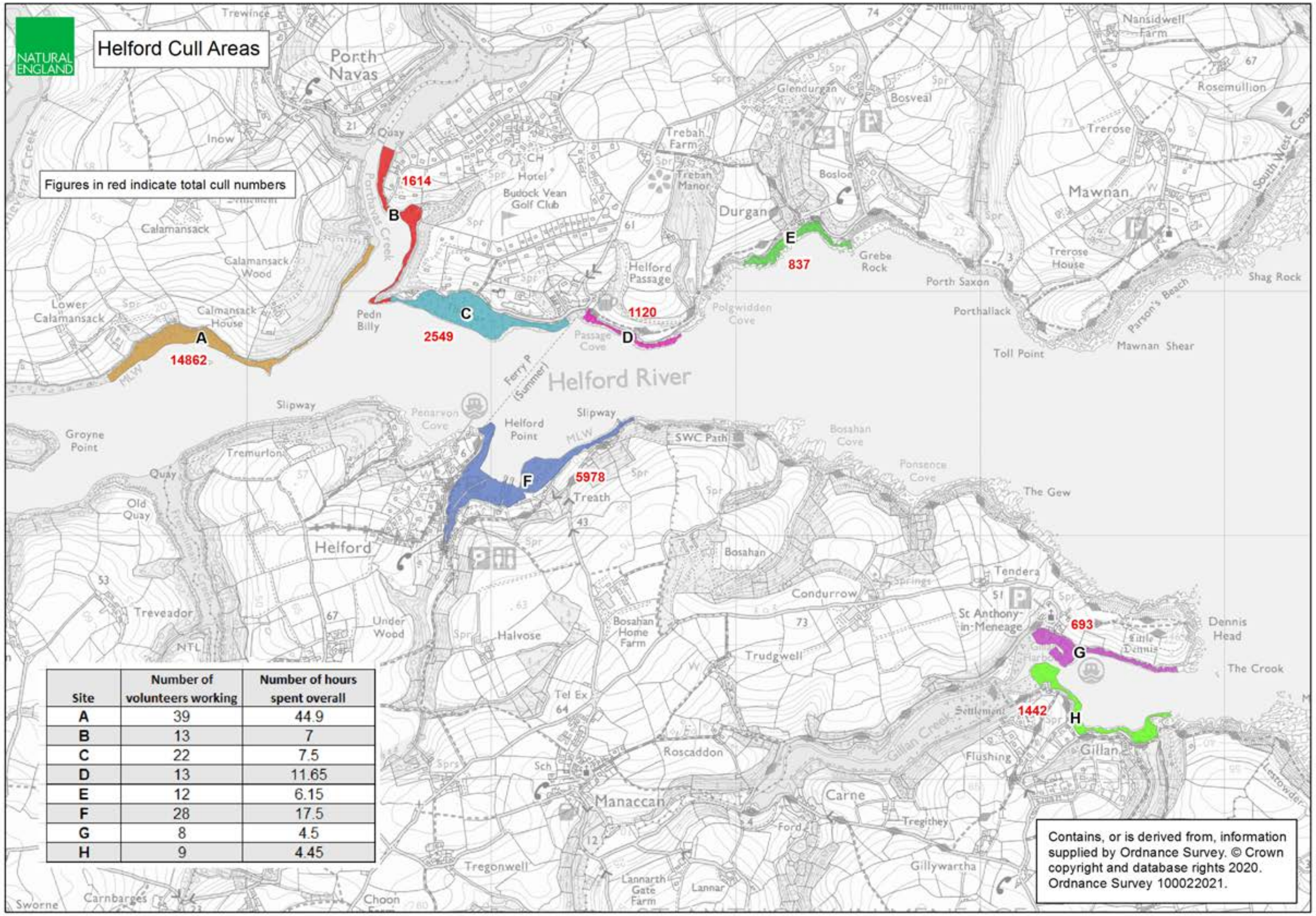
At Durgan (Figure 34: Section E) 836 Pacific oysters were culled between 2015 and 2020 over 6.15 hours using 12 volunteers throughout this period.

At Helford, between Helford point and the slipway to the east of Treath (Figure 34: Section F), 5978 Pacific oysters were culled between 2016 and 2020 over 17.5 hours by a total of 28 volunteers over this period.

At St Anthony-in-Meneage and eastwards to Dennis Head 693 Pacific oysters were culled between 2017 and 2019 over 4.5 hours by a total of 8 volunteers over this period.

Finally, from the mouth of Gillan Creek to Gillan 1442 Pacific oysters were culled in 2018 over 4.45 hours by total of 9 volunteers over this period.

It was not possible to calculate how many oysters could be removed per volunteer hour as it is not certain that all volunteers participated in every session over the entire cull period.



Site	Number of volunteers working	Number of hours spent overall
A	39	44.9
B	13	7
C	22	7.5
D	13	11.65
E	12	6.15
F	28	17.5
G	8	4.5
H	9	4.45

Figure 34: Culled areas and volunteer effort within the Helford estuary (Figures in red indicate total Pacific oysters culled)

6.3 Hand collection and incineration of Pacific oysters

Since 2016, following the discovery of large quantities of Pacific oysters on the shore at Port Navas and in other classified shellfish areas of the Helford estuary, the Helford voluntary Marine Conservation Group (HVMCG) have continued to liaise with the Duchy of Cornwall and Natural England for permission to continue removing Pacific oysters from the intertidal areas.

The largest concentrations of feral Pacific oysters are in Port Navas creek and around Calamansac Point. There are currently still large numbers of loose oysters in the area which haven't been removed. With concerns surrounding these remaining oysters breeding, the incoming tenant to the farm was able to establish a small market for the feral Pacific oysters and permission was secured to reinstate the water quality classifications so they could be sold.

HVMCG has been able to hand collect these oysters, store them in bags and leave them on the shore for collection. These oysters have been collected by Duchy Oyster Farm and are shipped to their Rossmore Oysters depuration unit in Sussex where they are purified and marketed.

Image 12: Pacific oysters awaiting collection at Port Navas Depot ©Sue Scott

In 2020, as a result of the coronavirus pandemic, Pacific oysters hand collected by HVMCG could not be sold during the summer months. There was concern that leaving these oysters *in situ* would result in a possible spawning event and therefore negate all of previous work done in this area. Within the project budget there were funds for the removal, transportation, and disposal of Pacific oysters by Peakes (GB) Limited, a waste removal company based in Liskeard. HVMCG collected and stored 921kg of Pacific oysters prior to collection by Peakes. The oysters were disposed of via incineration in July 2020.

6.4 Pacific oyster live removal trial – St Just Creek and Channals Creek

As the project progressed, it became evident that Pacific oysters were starting to colonise a small area of St Just Creek in Roseland. An idea developed between Natural England, Cornwall Wildlife Trust, and local entrepreneur Ewen Abram-Moore of ReOstra, that the live removal of these oysters could be trialled.

Using volunteer effort, one tonne of Pacific oysters was to be removed from the sediment by hand and stored in oyster sacks. They would be transported to the slipway off the shore by wheelbarrow and taken off site by a large vehicle. The oyster meat and shell were to be separated, dried and heat treated; then crushed for the purpose of use as a soil conditioner.

Some of the crushed oyster shell was going to be sent for nutrient testing at Wheal Jane Laboratory whilst the excess was to be stored for future use. Due to COVID 19 this did not go ahead, and it was not possible to carry out this work as a collaborative effort at the planned time. ReOStra however, have been collecting feral Pacific oysters under licence in 2020 to allow for a smaller scale trial.

In autumn 2020, Cornwall Wildlife Trust volunteers, led by Matt Slater, were able to access the shore and clear unmarketable shaped reef-forming oysters from mixed sediment at Channals Creek. This was aided by the National Trust, who provided a vehicle to facilitate removal of bags from the shore. Twelve volunteers were able to retrieve half a tonne of oysters in two hours, using net bags provided by Corncockle. Volunteers were advised to put a maximum of 50 oysters in each bag (approximately 10kg when half full) to avoid over lifting. Further information is given in Fig 5 below:

Comments from Matt Slater, Cornwall Wildlife Trust, following removal of unmarketable Pacific oysters by volunteers at Channals Creek:

‘’It actually went very well. The oyster bags were removed by the National Trust who had a small pick up (John Deere Gator) and were able to get down to the shore. They have been taken by Ewan Abrams- Moore and will be turned into soil conditioner. We only took unmarketable shaped oysters and we were able to effectively break up the areas where oysters are starting to form reefs. As it's within the shellfish area we have notified local oyster men and encouraged them to come and remove the remaining oysters. We gained landowners permission and informed Cornwall IFCA. Ewan is keen to do more days like this and in areas where you can't get a vehicle down we will leave bags of oysters on the upper shore and he will collect using his small boat’’.

‘’Regarding equipment you need small hammers to remove small rocks from the clumps before bagging. We found that it was actually very easy to collect them up in that area (as it would also be at St Just Creek). It may be more difficult in dangerously muddy areas but in this case it was fine and we fully risk assessed the activity and carried out dynamic risk assessing on the day. It was a very encouraging day and great to see the shells being removed – as breaking them and leaving them is not the answer as you know as the shell becomes a great surface for more oysters to settle, helping the reef to build up‘’

Figure 35: Matt Slater's account of a trial removal of unmarketable Pacific oysters from sediment at Channals Creek – November 2020

6.5 Pacific oyster and seagrass

A visit to investigate the level of Pacific oyster spread within dwarf seagrass beds on the Salcombe and Kingsbridge estuary was undertaken by South Devon AONB and Natural England on 27th February 2020. The site is soft sediment mudflat that can only be accessed via boat or with access permission from landowners.

A local project - ‘'Till the Coast is Clear' - provided boat transport to the site. A significant population of Pacific oysters was found within and adjacent to the estuary's very extensive and otherwise healthy meadows of the dwarf seagrass, *Zostera noltii*. Closer inspection revealed a mix of solitary Pacific oysters settling on native cockle shell debris. Clumps of Pacific oysters were growing on top of one another; indicating the start of reefing. It is very difficult to cull oysters on soft sediment. A burial method was used, where the Pacific oysters that were **not** directly in the seagrass were pushed down approximately 15cm into the sediment. This was done using either a large pole or by foot, taking care to avoid trampling on the seagrass.

It should be noted that this method is not necessarily recommended to cull Pacific oysters on soft sediments. Even if it is successful in killing the oysters, the hard shell would remain in situ, potentially changing the habitat to a different habitat type if significant numbers were present. Sediment erosion could expose the hard shells in the future and these shells could subsequently act as settlement habitat for further Pacific oyster spat. Mudflats in this location are considered to be fairly stable (Mortimer. N, personal communication Nov 2020), and therefore risk of shells becoming exposed may be low at this site. This method requires further consideration and also assessment on a site-specific basis, weighing up the risks of damage by boat scour and excessive trampling, and those associated with leaving hard shells in situ within the sediment habitat. A previous event on the Helford estuary, where a large number of Pacific oysters were mechanically pushed into the sediment, was not considered successful as live oysters started to appear on the site a few weeks later (Scott. S, personal communication 2020). It is possible that these oysters were not buried to a sufficient depth and therefore were able to survive.

The South Devon AONB Project Officer was able to reassess the area in June 2020, accessing the site via kayak. The culled area appeared significantly different to when the site was visited in February, with Pacific oysters appearing to have remained buried (Mortimer. N, Personal communication 2020).

South Devon AONB is investigating the feasibility of asking volunteers to further help in surveying and managing these Pacific oysters on sediment. Salcombe to Kingsbridge Estuary SSSI supports some of the best examples of seagrass meadows in the UK and there are significant concerns, that if left unchecked, this mudflat population of Pacific oysters could continue to expand and physically displace the seagrass and some of its considerable natural capital.

Image 13: Alternative method of culling: burial method ©Adele Morgan

7.Statistical analysis of quadrat data

The following statistical analysis was carried out independently by Natural England's internal Statistics and Modelling service, who were asked to investigate if there was a suitable method of analysis which could establish if culling was an effective management intervention to limit the spread of Pacific oysters. Significant support and advice was received from Professor Rick Stafford at the University of Bournemouth to develop the mixed models.

This section provides a summary of the modelling work, but more detailed descriptions of the data cleaning, processing procedures and results can be found in Appendix 6.

The objectives of this work were to:

- Merge and clean the various datasets.
- Review the data to see if it was possible to develop a technique for analysis.
- Use statistically robust methods to assess whether culling was an effective intervention in the management of the non-native Pacific oyster.

7.1 Model Methodology

7.1.1 Data preparation

Raw data were provided from the quadrat surveys, walkover surveys and the subsequent Pacific oyster culls. After reviewing the data available and survey conditions for each data type, it was decided that the quadrat surveys provided the best information for quantitative analysis as there were examples of repeat surveys with a range of treatments – some with and some without culls that could be compared. The walkover and cull data were less easy to use for this analysis due to uncertainty in geographical extent and inconsistencies in the collection method. However, the walkover data could be used to indicate where a cull had occurred as walkover surveys were carried out before culls, and culls followed the extent of the walkover surveys (but covered the full width of the beach). Details of the review of methods and data is in Appendix 6.

A significant process was undertaken to clean erroneous data points in the quadrat and walkover data (described in Appendix 6). Every effort was made to correct errors across the datasets, but more focus was placed on sites that were selected for analysis, so there are some remaining errors in other areas.

Mapping the corrected data enabled an understanding of the extent of each of the walkover surveys in relation to quadrat points and therefore identified where a cull should have occurred. As repeat quadrat surveys did not always cover the exact same stretch of beach, a detailed inspection of the data was carried in QGIS and polygons were used to manually group areas of data which had repeat quadrat points that were directly overlapping and comparable. These sites were then subdivided according to whether or not they were covered by cull lines. The polygons were given a unique code (e.g. TURS_3A_PC) which represented the location (e.g., TURS); each unique set of survey dates (e.g., group 3), and additional polygons with the same set of dates in other sections of the beach were further subdivided (e.g. 3B, 3C); and finally polygons were divided according to their treatment and whether the area had been culled, not culled, potentially (some walkover points present though no line) or partially culled, or culled before the surveys (C, NC, PC,CB).

This created a final dataset with 14 individual analysis groups within 6 overall locations in the Fal Estuary (Turnaware, St Just, St Just Creek, Restronguet Creek) and Plymouth Sound and Estuaries (Newton Ferrers, and Noss Mayo), that could be used for quantitative analysis. These final analysis groups represent sets of repeat survey areas covering the same geographical area with the same unique years of survey, interval, and treatment across time. Analysis groups in the same sites with different years of survey were not grouped, and analysis groups with the same survey periods/years but in different sites were also not grouped. This decision was made as the impact of environmental conditions are likely to vary between sites and between years and would affect population growth rates and are unaccounted for in this analysis. It is expected that the individual analysis groups selected have experienced the same environmental conditions, with some small variations in exposure. A fifteenth site is also included in the individual model analysis but this group (YEALMNF_7) only has one year of survey, but one area was culled before and one area was not. This area was therefore treated differently and not included in the mixed models but was modelled individually.

7.1.2 Modelling method

Two different approaches were taken to assess whether culling was an effective intervention in the growth of Pacific oysters. First a dataset with the 14 repeat analysis groups was used in a mixed model (also called a nested or hierarchical model) to assess the overall effectiveness of culling. Second, individual models were used for each of the 14 analysis groups to measure the trend and calculate growth rates between first and last survey. A different model was used for the 15th non repeat analysis group to test the difference in means between the area culled and the area not culled.

To decide which models to use, the distribution of the count data was explored for the whole dataset and for each individual analysis group. Although the data appeared to be of a Poisson distribution each group was tested with potentially relevant models (linear models (LMs) or generalized linear models (GLMs) with normal, Poisson, negative binomial, and quasi Poisson distributions for over dispersed data). The models were consistently best with a negative binomial distribution due to the high number of zeros in the count data, so both modelling approaches were done using generalized linear model frameworks. The best models were selected by comparing the AIC (Akaike's Information Criterion), plots to show the heteroskedasticity (fitted residuals) for the mixed models, goodness of fit diagnostics, and model dispersion factor. Analysis work was completed in R Studio (R,2020).

Generalized linear mixed model (GLMM) for the whole data set

To test the overall effect of culling across all sites, we used GLMMs with the ***lme4*** package in R, to determine differences in Pacific oyster density (number per 0.25M quadrat) with time as a continuous, fixed explanatory variable. These models allow for a nested approach so that the difference between locations and treatments could be interrogated. The data was classed by the following categories to facilitate these models:

- LOC_group: The 6 sites containing the analysis groups.
- Model_group: The 14 individual analysis groups within sites with unique repeat dates, interval, and treatment.

- Group_status: The culling treatment for the model group, which was either culled(C), partially culled (PC), not (NC), culled before (CB). NC was relabelled as A_NC so that it was first alphabetically, and the model would treat this as the first variable so other categories would be tested against it.

The best model included LOC_group and Group_status as fixed factors, model_group as a random factor, and included a three way interaction between the fixed factors so that the model would assess the difference for each treatment, within each location. The structure of the final model was:

- **Live_POs_A ~ DAY*GROUP_STATUS*LOC_GROUP +(1|Modelgroup), family=negative.binomial (theta = 1.25)**

As mixed models don't easily generate significance terms, the best model with the interaction was compared to a GLMM with the fixed effect but without the interaction term (i.e. initially dropping the three-way interaction and keeping the two-way interactions only). This was done with the ***ANOVA*** function in R to generate the significance of the interaction, using methods similar to Howlett et al (2016).

Generalized linear models (GLM) for individual analysis group

Whilst the mixed model provides the most robust test of the effect of culling overall, they are difficult to interpret at the individual site level. Therefore, each individual analysis group was tested in an individual GLM regression model using the package ***MASS*** for negative binomial GLMs in R, to determine differences in Pacific oyster density (number per 0.25M quadrat), with time as a continuous, fixed explanatory variable. For each analysis group, the best model was used to measure and test the difference in posterior means between repeat surveys, calculate confidence intervals, and measure the change in densities between repeat surveys.

Survey years and interval periods differed between analysis groups (for example some covered two consecutive years, whilst others had 2 surveys within a 3-year period), which made them hard to compare. Therefore, these individual models enabled a further step to calculate annual population growth rates (percent of population increase or decrease per year) for each analysis group to allow comparison between sites that were culled, partially culled, culled before or not culled. To do this, the ***predict*** package in R was used to convert the model slope (trend between years) to a percentage, and the total percentage was simply divided by the interval period (slope % / Interval time in years).

This method is a robust population modelling approach, but these rates represent two different things depending on the treatment of the sites. Where there has been no intervention of the site in between surveys (i.e., not culled, or culled before), these rates represent the true population growth rates between surveys. However, for sites that have interventions between surveys (culled or partially culled), these cannot represent a true rate of change because we don’t know what the population was like at the point of cull in this particular area, and this would not be a straight line relationship. The population would be reduced by the number removed during the cull, then there would be a period of regrowth leading to the population present during the final survey shown in the plots. So, rates for culled sites only represent the percentage of difference in the population at the first and last survey before and after the cull events. This still allows us to understand whether there has been a growth or not but does not provide an accurate growth rate. The aim was therefore to see whether there was an increase or decrease between repeat surveys where we know there had been culling activities or not.

7.1.3 Caveats and assumptions

Natural England has analysed the survey data using the best available techniques, though caution has been applied in how the data was used due to a number of uncertainties in the data discussed in Appendix 6. The analysis technique was considered retrospectively to surveys and the following factors could not be accounted for:

- Quadrat positioning was not fully representative of the whole beach, and the number of quadrats varied between sample areas and years.
- Whilst groups with smaller numbers were joined with others to make final analysis groups, some still had lower than an ideal number of samples.
- Few areas had more than two survey years due to the length of the project to date, and it would be preferable to have more than two years of surveys for this kind of analysis.

Whilst we are confident the modelling approach is robust enough to test population growth, the precision in the growth rates calculated would be affected by sample size. Smaller sample sizes affect statistical significance (z test) and model fit and can cause over dispersion which is discussed further below. We highlight the numbers of samples in each analysis in Appendix 6, and any uncertainties in model results are highlighted in the results and discussed.

For the individual models, no assumptions have been made about the trends before or after the time series for each analysis, as this analysis can only represent the time period of surveys in each analysis groups. Extrapolation at this stage would probably not be very accurate with the small sample sizes, short project timescale, and differences between sites. However, this is not an issue for the mixed model, as it uses all the data together. The only concern for the mixed models is where there are fewer examples of a treatment, which is discussed more in the results below.

We have not been able to include environmental data as a variable within the models within the timeframe which would affect growth rates between sites and years surveyed especially as intervals between each time series differ. For example, it is known from literature that Pacific oysters need sea temperatures to reach a certain threshold before they spawn. Although one year with no spawning will not cause a decline it may slow growth the following year. However, similar to where culls would have occurred, the beginning and end points which are modelled would be the same regardless as the end point would be affected by in-between spawning conditions.

Thirdly, an assumption is made that the walkover lines all represent areas where a cull has taken place afterwards, unless the Cornwall Wildlife Trust log specifically identified the survey had not been followed up by a cull. Whilst walkover surveys had a limit of 4 metres transect width (2m either side of the survey line) the culls following these were unrestricted and the true extent unknown. Whilst the intention was to destroy every Pacific oyster found, the reality is this will not have been possible, and cull success will be affected by tide, volunteer numbers, size of pacific oysters and weather. All these issues would affect the subsequent final population growth or decline rates.

Whilst many walkover surveys were clearly mapped, the error checks to line up start and end points revealed erroneous points. Those which could not be fixed were removed. Some re-groupings were made (splitting remaining surveys in two etc.) where single start and end points were evident (even prior to removing erroneous points). For these a cull was assumed but the full cull extent is less clear, and they may not have completely covered the area of quadrat surveys. The walkover points and lines were re-mapped in R which highlighted walkover lines not previously identified in QGIS. This is because R reads start and end points horizontally and GIS reads them vertically which essentially highlighted where there were differences/errors in start and end points on each line. However, using maps in both QGIS and R helped identify where culls occurred, and where there were slight differences between them, we considered both areas as culled. Both maps are provided in Appendix 6.

A further consideration is that informal removal of Pacific oysters by others may have occurred during the period of this project that we are not aware of. This information therefore would not be presented in the results and plots below. However, where we are aware that removal of oysters has occurred, for example by members of the public at Newton Ferrers, this has been highlighted.

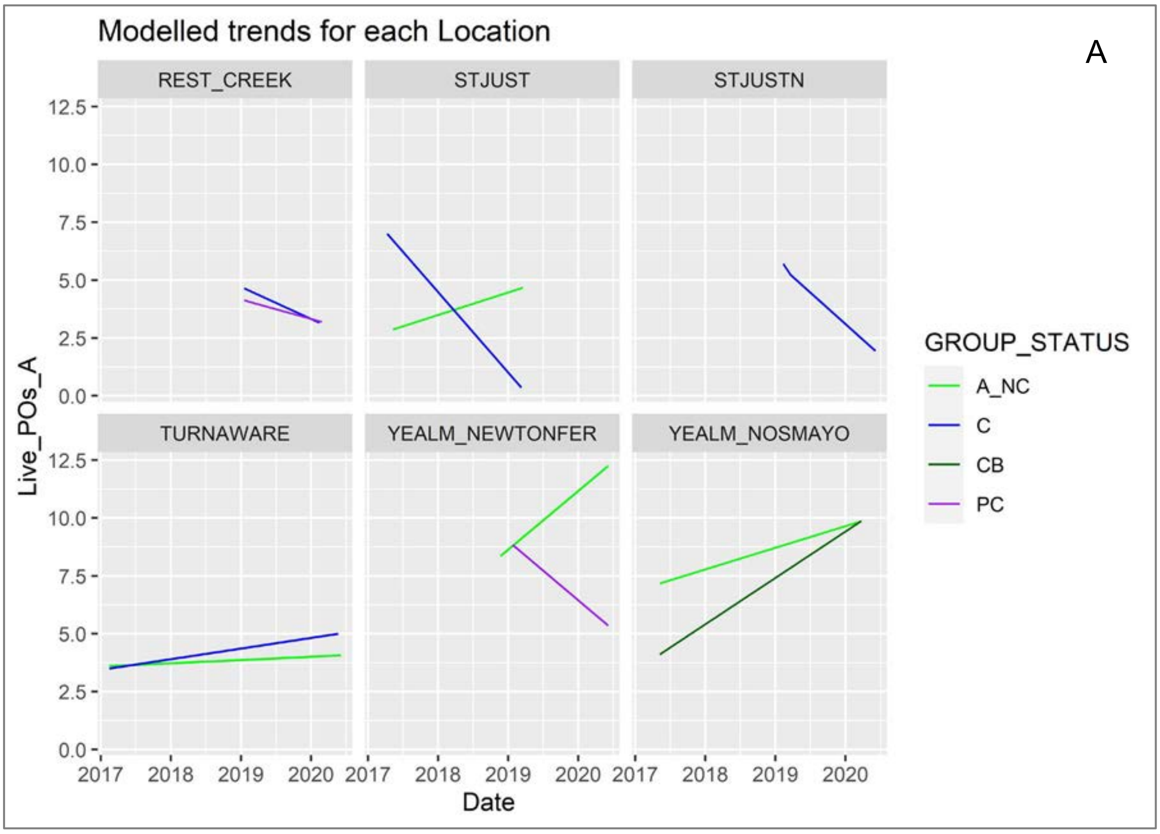
8. Model Results

8.1 GLMM results

All models showed that there is a significant difference in posterior mean between non culled model groups, and model groups that were culled and partially culled.

However, the best model also included a three-way interaction term between the effect of time, group status and location. The Anova function demonstrated that this interaction term was significant (p=<0.001), which effectively means that whilst cull and partial cull have an effect on oyster density overall, there is a difference in the effect of treatments at each location (and one site seems to increase regardless of a cull).

The interaction plots below in Figure 36 generated from the best model, demonstrate the true trends calculated by the model and show the results for A) Overall results for each group status in each location where they are found; and B) Results for each individual model group coloured by their group status. Figure 36 (A) summarises overall trends for each group treatment at each location. So, if there is more than one example of a treatment, the trends are combined. It demonstrates that in all locations, groups which were not culled (or only culled before the surveys) have an increasing density over time; and in most locations groups that were culled or partially culled have a decreasing density over time, except at Turnaware. Figure 36 (B) reflects the same information, but shows the trends calculated for each model group. These also demonstrate that partial and full culls reduced oyster density at the locations they occurred, except at Turnaware where the populations increased despite the cull. There is a steady increase for sites not culled, and a steeper increase for the one example where a site was culled before the survey. The trend lines on the plots in Figure 36 are coloured by the group treatment (Codes: A_NC = Not Culled, C = Culled, CB = Culled Before, PC = Partially culled)



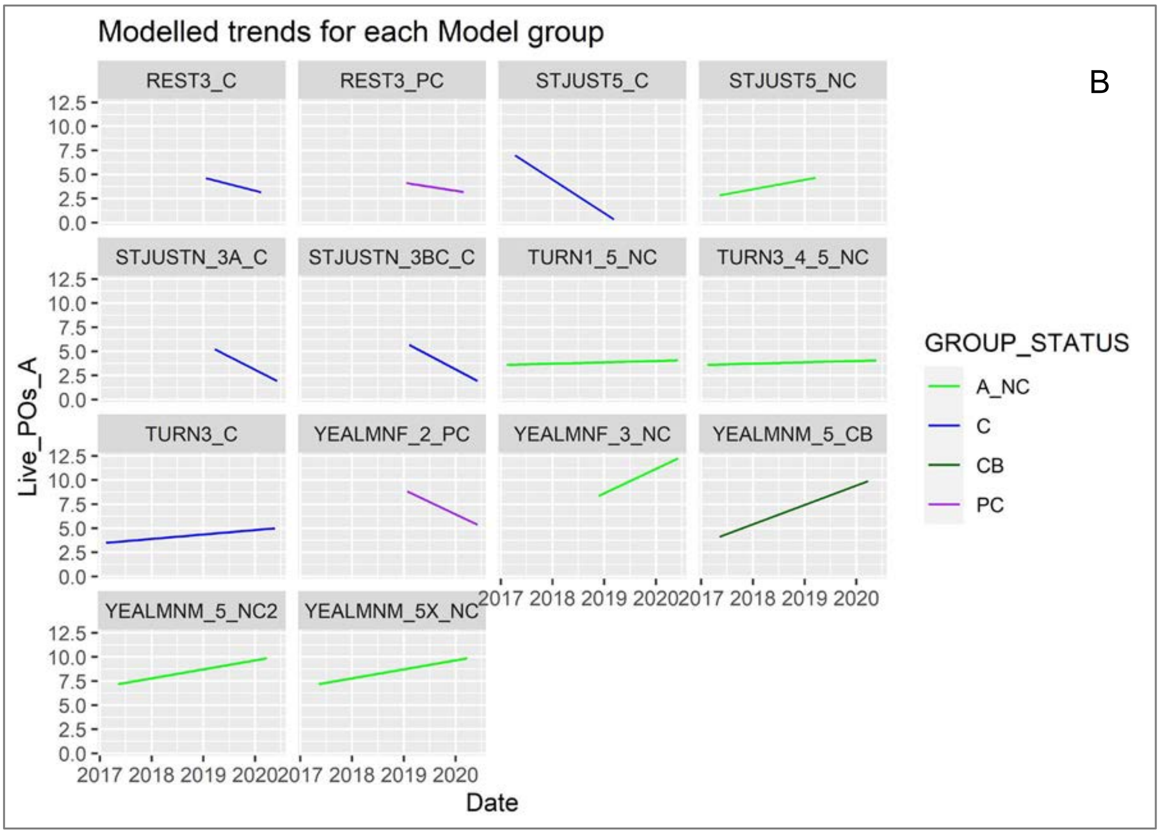
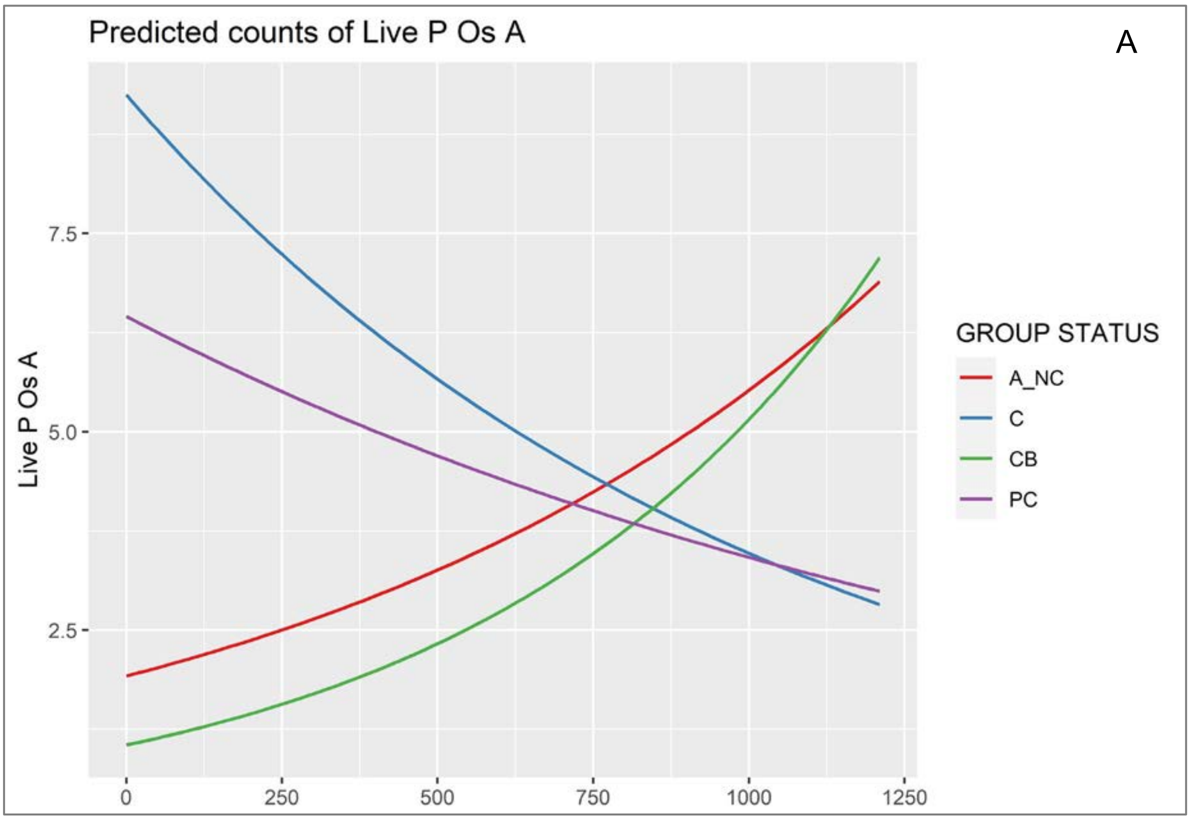


Figure 36: Plots to show the true trends from the best model (without prediction)

Hierarchal models are useful for summarising results in different ways, and like bayesian methods, can use existing data to predict trends further. So, the following plots in Figure 37 also show results from the best model, but these plots are generated by ***sjPlot*** in R which computes and visualises predicted values and interactions for mixed models. Because the best model included an interaction term between group treatment and location, the plots visualise how trends differ between these factors, and extrapolate relationships for all treatments across all sites, and across the timeline of all the surveys. While this helps to fill gaps in evidence, some caution is needed where there are fewer data for certain categories. We can see from the plots in Figure 36 that for each of the six locations, there were only one or two kinds of treatments. For example, at Restronguet creek, the two analysis groups were “Partially culled”, and “Culled”; whereas in St Just the analysis groups were “Not culled” and “Culled”. We also see that there is only one example of an analysis group classed as “Culled before” (CB), so particular caution is needed in interpreting predictive results for this category.

The plots below show extrapolated trends for A) Overall growth for each Group status across all the sites; B) Overall Pacific oyster growth at each location (combining all treatments); C) Overall Pacific oyster growth for each group status at each location. The predictive plots in Figure 37 show similar relationships to the true trends previously presented in Figure 36 as well as Figure 37 but also additional information regarding overall trends. Figure 37 (A) shows an overall reduction in Pacific oyster density in areas that were culled and partially culled, in contrast to increasing densities for areas not culled or culled before. However, Figure 37 (B) also demonstrates that despite the effectiveness of culls where they occur, overall, the densities of Pacific oysters at each location are still increasing. The exception is at St Just Creek (STJUSTN) where there appears to be a downward trend. Figure 37 (C) shows the predictive trends for all treatments across all locations, and again shows downward trends for culled and partially culled sites except at Turnaware, and increasing densities for sites culled before, or not culled – except St Just Creek. To note, the peculiarities at St Just may be an artefact of the model, and due to the fact that this location only has quadrat data from areas that were culled, and no data from areas not culled or culled before. It is also possible the growth appears to decline because St Just is an area reaching a carrying capacity.

The trend lines on the plots in Figure 37 are also coloured by the group treatment. Colours generated by ***sjPlot*** differ, but the codes are the same (Codes: A_NC = Not Culled, C = Culled, CB = Culled Before, PC = Partially culled).



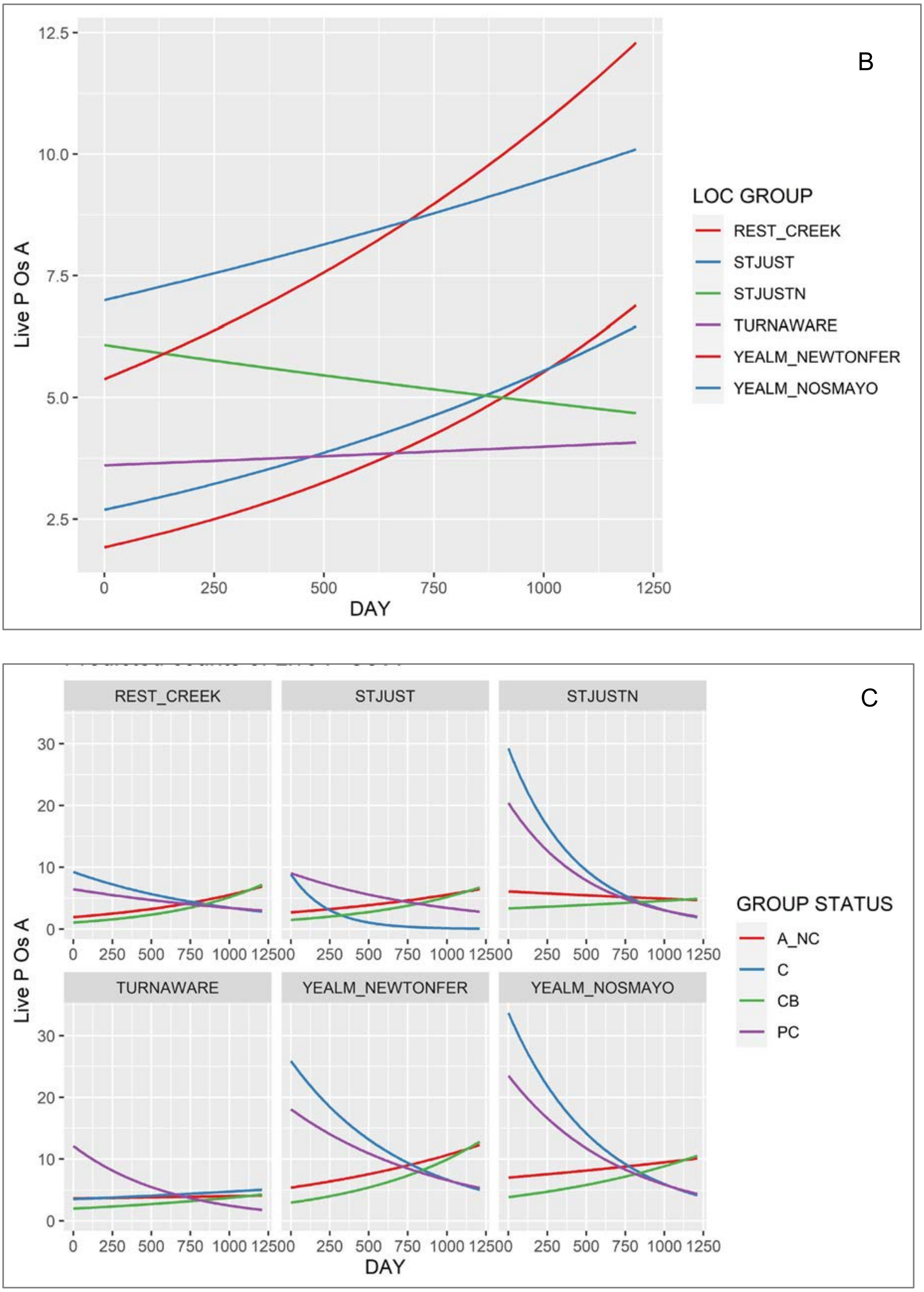


Figure 37: Plots to show the extrapolated trends from the best mixed model

8.2 Individual GLM results

The individual models reflect the same relationships presented by the mixed model, where most sites culled or partially culled have reduced densities at the second survey (except at Turnaware), and sites that were not culled (or culled before) have increasing densities (except at Turnaware where one site stayed almost the same). The 15th individual model assessed the difference in a site where one area was culled two years before the survey and one was not, and this showed no difference between densities at the two areas. The table below provides a summary of the results from all the individual models for each analysis group to allow comparison between models. Key information presented is:

- **The annual growth rate** (percentage per year): This is the most important parameter to compare between sites. This shows if trends have increased or declined for the group. Increasing growth rates are highlighted in red, decreasing growth rates in green. These trends are likely to be true, but precision will be less accurate if the model does not fit as well, so it's important to review the goodness of fit measures provided, these are highlighted where they exceed thresholds.

- **P_value**: The model test of significance (z-test for GLMs) testing if there is a significant difference between the intercept (first survey) and coefficient (second survey). Whilst these are important to consider, p values can be affected by certain conditions and in this case low sample sizes, as smaller sample sizes will lead to less significance regardless (hence only highlighting p values more than 0.1).

- **Chisq**: Goodness of fit measure representing the **Chi square test of deviance** which provides a statistical measure describing how likely the model is to be true given the data. These are highlighted where a p value less than 0.05 indicates a poor fit for the model and some caution is advised.

- **PDE**: Goodness of fit measure representing the **Percent of deviance explained** for these GLM models, where 0 is worst and 100% is best (but not ever achieved).

- **ODP** = **Over dispersion parameter** which should be 1.1 or less. Where models are over this they are highlighted, and some caution is required.

More detailed results are provided in Appendix 6 including plotted model results, tabulated results showing model diagnostics, and maps for each of the six locations and each of the 15 analysis areas to show the quadrat points in relation to the cull lines.

The results for the 15th model in the table below are slightly different. They show the difference in posterior mean between the area culled before (15 A), and the area not culled before (15 B). The model which compared the results demonstrated no difference between the means (p = 1, i.e. 100% probability they are the same).

Table 8: Overview of individual model results (Cull Codes: NC=Not Culled, CB = Culled Before, PC=Partially Culled, C=Fully Culled).

Model group Cull_Code	Survey Dates	Cull Dates	Annual growth in %	P value	Chisq	PDE	ODP
Site 1: Turnaware (Fal Estuary)							
1.TURN1_5_NC	15/02/17 05/06/19 21/05/20 04/06/20	NOT CULLED	+7.99	0.29	0.25	2.22	1.13
2.TURN3_4_5_NC	15/02/17 05/06/19 21/05/20	NOT CULLED	-0.61	0.92	0.3	0.01	1.08
3. TURN3_C	15/02/17 21/05/20	05/06/19	+9.2	0.27	0.07	6.17	1.7
Site 2: St Just (Fal Estuary)							
4. STJUST5_C	12/04/17 11/03/19	12/04/17	-49.72	0.01	0.48	55.72	0.98
5. STJUST5_NC	11/05/17 11/03/19 19/03/19	NOT CULLED	+20.94	0.01	0.14	4.17	1.13
Site 3: St Just North Creek (Fal Estuary)							
6. STJUSTN_3A_C	21/03/19 04/06/20	21/03/19 27/11/19	-41.51	0	0.11	9.56	1.22
7. STJUSTN_3BC_C	11/02/19 18/02/19 04/06/20	21/03/19 14/10/19 27/11/19	-54.64	0	0.09	45.81	1.22
Site 4: Restronguet (Fal Estuary)							
8. REST3_C	18/01/19 23/01/19 13/02/20	07/12/18 08/04/19 18/04/19 20/04/19 21/04/19	-29.5	0.02	0.13	5.45	1.19

9. REST3_PC	18/01/19 20/02/19 13/02/20	08/04/19	-22.32	0.14	0.38	3.2	1.05
Site 5: Noss Mayo (Yealm Estuary)							
10. YEALMNM_5_CB	10/05/17 23/03/20	01/02/17 (before)	+20.34	0.02	0.17	15.64	1.23
11. YEALMNM_5_NC	10/05/17 23/03/20	NOT CULLED	+6.77	0.42	0.11	0.86	1.22
12. YEALMNM_5X_NC	10/05/17 23/03/20	NOT CULLED	+13.52	0.11	0.15	5.33	1.23
Site 6: Newton Ferrers (Yealm Estuary)							
13. YEALMNF_2_PC	24/01/19 04/06/20	Private oyster removal	-28.97	0.06	0.34	12.29	1.09
14. YEALMNF_3_NC	22/11/18 04/06/20	NOT CULLED	+20.77	0.14	0.32	6.67	1.1
Model group_Cull Code	Survey Dates	Cull Dates	Posterior mean	P value	Chisq	PDE	ODP
15 A. YEALMNF_7_CB	04/06/20	22/11/18 (before)	2.158				
15 B. YEALMNF_7_NC	04/06/20	NOT CULLED	2.160	1	0.32	0	1.05

9 Discussion: Models

The mixed model clearly shows that culling and partial culling are effective interventions in the management of Pacific oysters at the locations where they occur for an amount of time. Nearly all sites that have been culled or partially culled have a reducing trend line, with the exception of Turnaware in the Fal estuary. All sites not culled or only culled before the surveys show an increasing trend line over time. However, the models also showed a significant interaction between the location and group status, which means there are differences in the trends between the six locations. Also, despite the majority of individual culls causing a decline at the locations they occur, the overriding trend in most locations still seems to be an increase in Pacific oysters, so the effect of the culls are limited to where they occur and are only temporary. The resolution of culls to date is not enough to reduce the population overall (i.e. all areas would need to be culled). The same relationship is reflected in the individual models. Whilst we acknowledge there may be limitations in how accurately we can calculate precise population growth rates with these data, we are confident that the strong trends and growth rates highlighted by the models for the non-culled sites are true. For the non-culled sites, nearly all sites (except

Turnaware) have an increasing growth rate, and there seems to be some consistency in the annual population growth rates which vary between 10% to 20%. For sites that are culled, we cannot calculate accurate annual reduction rates, but we can see the percentage in change between first and last surveys, and we consistently see that surveys after culls have a smaller population than before (except Turnaware).

Whilst there is a clear overall effect from culls in reducing densities where they occur, there are variations in the rates of reduction and therefore the effect of culls in each location. One likely contribution to the variation in reduction from culls is the interval period between surveys and culls. The interval time between surveys and culls are inconsistent and unaccounted for in the models. Some sites have small interval periods of only a year between surveys and culls, whereas others have two or three years. The longer the interval period between culls and surveys, the longer the recovery time will have been so this may appear as a smaller rate in reduction whereas in reality the population reduced and then regrew. Most models showing an effect from the cull in reducing densities have an interval of around a year, however one site (STJUST5_C) where there was a decline in densities (-49.72% pa) did have an interval of two years between the cull and the next survey. However, for the 15th model which compared a survey where one area was culled two years before the survey and one area was not, the model showed that after two years the effect of the cull was no longer evident as the means for both areas were almost identical.

It also seems clear that those sites with multiple cull lines on the plots see the steepest declines over time, and those with partial culls potentially slow population growth rates but not to the same extent. Cull lines close together don’t always represent repeat temporal culls in the same place though often they overlap, but represent multiple culls covering multiple spatial areas along a beach length.

A key exception is the site (TURN3_C) at Turnaware which had a population increase of +9.2% per annum despite a small cull covering this area. The interval between the surveys was three years, so it’s possible that the cull did reduce numbers but overall, there was still growth since the first survey. However, Cornwall Wildlife Trust (Matt Slater pers comms) have since acknowledged that the cull was undertaken when the tide was higher than during the surveys, so lower areas of the shore were not culled. The following surveys took place during the low tide, when areas with high densities lower on the shore that had not been culled were revealed, although the areas higher on the shore that had been culled remained lower in density. Furthermore, the survey and cull area were very small and within a much larger area not culled. So, it is also possible that larval distribution from the surrounding area quickly replaced the oysters that were culled.

For unculled sites, and sites culled before, we mainly see increasing natural growth rates but there is also variation in these growth rates. Sites at Turnaware showed very low or no growth at all despite not being culled (TURN3_4_5_NC had a very insignificant (p=0.92) annual growth rate of -0.61 % per annum; TURN1_5_NC had an insignificant (p=0.29) annual growth rate of only +7.99% per annum). It may simply be that where natural growth rates are lower the sites may be approaching or have already reached a natural carrying capacity (where growth rate would slow and potentially even decline again) or there has been a reduction in growth for other reasons. A carrying capacity is likely to be reached when all possible spaces for colonisation are taken, and in some cases when the habitat has formed a reef. Where this is probably the case such as in Noss Mayo you can see in the plots that there are already quadrats with higher densities in the first surveys, whereas areas where growth rates are higher have fewer quadrats at higher densities in the first survey. When a site is reaching a carrying capacity, but one area is culled, it may seem the growth rate increases because that area has space for colonisation again. This is evident in Noss Mayo where one area (YEALMNM_5_CB) was culled prior to surveys and the annual population growth rate calculated here (+20.33% per annum) is much higher than the close neighbouring site which was not culled in advance of the surveys (YEALMNM_5_NC, +6.77% per annum).

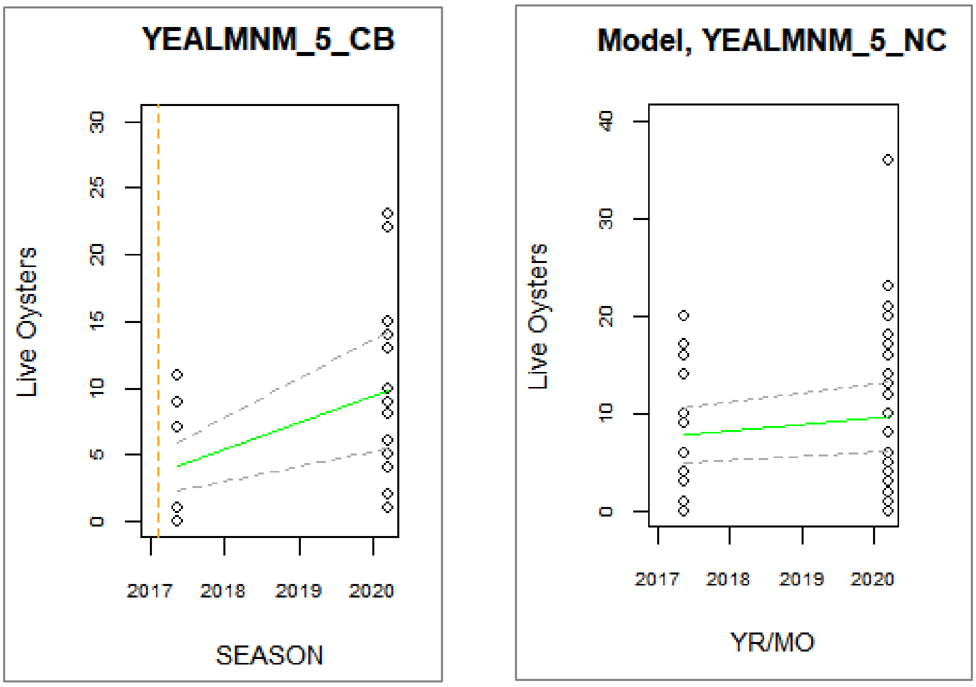


Figure 38: Plots to show the difference in growth rate between sites at Noss Mayo. (Orange line indicates the date of the partial cull prior to surveys)

One further anomaly was a site in Newton Ferrers in the Yealm (YEALMNF_2_NC) where no culls were recorded but the model showed a decline in annual population growth rates (- 28.97% per annum). However, it has since been confirmed by site officers, that there has been removal of oysters by members of the public at this site.

A hypothesis could be drawn from these conclusions that the consistency and full spatial coverage of culls is probably important to how successful they are in the long term. It is clear no culls have completely eliminated a population and the overall population is increasing regardless. Plus, there is a high natural population growth rate in competition to the culls, so lapses in culls spatially and temporally reduce their effects over time.

To increase confidence in these findings, it would be necessary to set up some controlled experiments. It would be important to consider populations at a catchment level and consider the supply of larvae due to connectivity with other sites. It would be interesting to focus all spatial and temporal effort intensely on one entire catchment, versus a few sites in each catchment which have been done to date. A further approach may be to introduce a BACI (Before -After –Control-Impact) research design to evenly study multiple areas during a set timeframe where several areas are culled, and several are not. A key issue is undoubtedly the supply of larvae, and it may be valuable to conduct eDNA surveys around the south coast to establish whether larvae are simply everywhere, or only concentrated around current Pacific oyster beds.

There were inevitably errors in the data (which would be expected from citizen science data that has gone through various data management stages), and the methods made it difficult to use walkover surveys and cull data quantitatively. Some small adjustments to the methods would help enable more analytical methods in the future. Quadrat surveys have more value than the walkover surveys for quantitative analysis, but it would be better if they were more representative of the beach profile. The quadrats are very close together at 5m, so perhaps if more effort was put into quadrats (rather than doing both walkover and quadrat surveys), and quadrats were spaced out more, much more coverage across the profile could be achieved. Surveys could still follow a line (or multiple lines) but quadrats could be randomly distributed to distances left and right of the line (to get replicates for each location). Pacific oysters may often be found in clumps, particularly in sediment habitats, and this would need to be considered in any future experimental design to ensure oysters are not missed in these instances. For walkover surveys, it is important to try to standardise the length of segments (e.g., along a 50 m tape measure length) rather than starting a new segment every 50 oysters. The true number of oysters should be counted, or larger numbers estimated within these segments (which is normally done using quadrats) and stick to within MHW and MLW to be able to calculate the area or mark on a map the area of survey). Ideally if cull numbers (and quadrat surveys) were also focussed within these same segments, and the segments were consistently applied, there would be much more potential to add the cull data into analysis, and more analysis potential overall.

It should also be noted that whilst not all data was used for statistical analysis, the final dataset following the cleaning process for this analysis was then used to estimate and map densities per m^2 for all areas, as shown in earlier chapters of the report so was still a valuable resource.

10. Discussion: Pacific oyster control

10.1 Undertake population control methods to reduce feral populations and reduce population expansion.

At the start of the project culling was only undertaken during winter months to avoid the risk of culling triggering emergency spawning during the warmer months. Therefore, during the first year of the project, surveys and culling were only carried out between September and May. Busy locations were also avoided during holiday periods. Later on, in the project it was decided that this methodology was overly precautionary, and that as long as oysters culled in the summer months were well away from the water's edge at the time of culling gametes were unlikely to survive if spawn were released from culled individuals. In practice however, survey activity was always reduced during summer months as volunteers were busier and in some cases, volunteers were concerned that culling during these times would result in potential negative publicity.

Surveys were only carried out on low spring tides so that volunteers could clear shorelines completely, right down to the lower shore. Following initial surveys, many volunteers noted that Pacific oysters were present predominantly on the mid-shore. Further control events could have taken place if these events weren't restricted to the lowest spring tides.

Due to these factors, the time available for Pacific oyster control was not as great as originally hoped.

Pacific oysters that have settled onto rocky substrates are difficult to fully remove. Their lower shell is attached to the rock and trying to remove this is a time-consuming activity and could possibly cause damage to the substrate. Previous work has shown that breaking the top shell is effective in culling these oysters. This was the most common method of population control used during this project.

Initially, volunteers used light weight tack hammers to carry out control work. This was soon deemed ineffective as they were not strong enough to crack the oyster shell and would also frequently break upon use. Volunteers subsequently started using alternative tools such as builder's hammers, steel bars and chisels. These proved much more effective especially in areas with significant densities of Pacific oysters. The lower shell of the oyster is left *in situ* and the exposed tissue is consumed by gulls and other marine species. For culling events where oysters were present on rock, using robust tools to break the top valve of the oyster was effective. This is in contrast to other methods that have been tried, such as drilling into the oyster where it has been observed that the oysters are able to survive and regrow their shells (Fenwick. D, personal communication 2017).

It is evident that Pacific oysters are able to settle and thrive on manmade structures and debris, including stone, concrete, harbour walls and iron work such as chains and old pontoon structures. Many estuaries contain significant amounts of hard debris and it could be beneficial to remove such items. One way to address this issue could be to undertake the removal and clean-up of this type of debris as part of Harbour Authority Biosecurity Plans and we recommend that this is investigated along with other options. Some of these structures are difficult as well as unsafe for volunteers to access and control may need to be undertaken via commercial contracts. As such, removal of abandoned structures and debris may be more cost effective in the longer term.

Vertical surfaces such as harbour walls were also difficult to access. Walls that abut deeper waters, for example in harbours, were problematic with boats obstructing survey sites and accessibility difficult at certain states of the tide. Using long instruments to scrape oysters may also risk them dropping into the water below allowing them to continue spawning. Again, specialist help may be required, perhaps in the form of commercial contracts, to survey and cull oysters on these structures at certain locations.

There were some minor complaints from local residents that culled Pacific oysters were more visible from the distance and therefore impacted on the overall appearance of the area. Volunteers however observed the process of shell degradation over a period of roughly 3 months, with a dulling of the colour (Mortimer. N, personal communication 2020). It is thought that these shells will not remain permanently and will eventually breakdown as part of a natural process. Improved communication and development of information resources for local residents and the general public may be beneficial to accompany any future work.

During surveys, volunteers from both Cornwall and South Devon noted that some individual Pacific oysters looked very similar to native oysters and vice versa. The policy applied was ‘if in doubt don’t cull it’ to avoid killing native oysters which are rare and protected.

Pacific oyster reefs can be found on intertidal areas of estuaries that can be difficult to access. These are often muddy areas which are only exposed during low tides and can be hazardous to reach. The removal of Pacific oysters from these areas could potentially be achieved by hand collection, dredging or mechanical removal. It is essential however that the sensitivity of these estuarine habitats is fully considered.

Hand collection has been shown to be an effective method of removing Pacific oysters from soft sediment, however it requires a high level of manual labour. Despite this, they can be removed from the sediment fairly easily, and with care, lead only to minor physical impact of the shore from trampling. Although there are benefits to this method, implications such as licencing, costs, logistics and disposal need to be taken into consideration.

Pacific oysters can only be removed for consumption within Classified Shellfish Areas. Licenses are also required for hand collection of shellfish within the Fal Fishery area. Very few groups were able to handpick Pacific oysters from soft sediment areas due to local sites being within Classified Shellfish Areas and the barrier of requiring a specific licence to operate there.

Removal via dredging and mechanical processes would allow greater quantities to be cleared within significantly shorter timescales. This however has been hindered by the costs associated with transportation, processing and disposal and potentially greater impacts on the underlying substrate and existing communities.

Fowey Harbour Authority, who have considered dredging to remove a local reef, have stressed that the amount of fuel and staff time it would take to deploy dredges may be prohibitive. Dredges would also have to be deployed at high tide in areas where there is a sufficient depth of water. Additional risks include the potential abrasion and physical damage to the sediment and associated infaunal communities, particularly within MPAs.

Diggers could be used in extreme cases to quickly remove oyster reefs but as with mechanical dredging this runs a serious risk of harming the underlying habitats. It also risks compaction of the sediment and heavy equipment may get stuck in the soft ground making this dangerous to operatives as well as an environmental risk.

Collected sacks of Pacific oysters need to be removed from the shore and removal sites can be some distance from a refuse collection point. Suitable vehicles could be used to remove sacks of oysters; however, this is dependent on the area and landowner permission amongst other logistical considerations. For areas that are difficult to access, an alternative would be to use an oyster barge that could be moored and left to dry out at low water, loaded up and then re-floated on the flood tide and taken to a suitable location for unloading and transfer of oysters to vehicles. This has been successfully carried out in the Yealm estuary by the Limosa Oyster farm.

A particular concern throughout the project is the settlement of Pacific oysters within seagrass beds. Seagrass beds are known to be important in carbon sequestration (Bedulli and others 2020), and projects are currently underway to restore seagrass beds across England, including Project Seagrass (2020) and the ReMEDIES Project (UK Government 2020). The discovery of Pacific oyster settlement within intertidal seagrass beds is extremely worrying and it has not been possible, at this stage, to propose an effective removal method. Anecdotal evidence from the Salcombe and Kingsbridge estuaries suggests that pushing oysters into the sediment to bury them may be effective in killing them. However previous mechanical burial of Pacific oysters on the Helford estuary was not deemed to be a success perhaps due to insufficient burial depth. Further consideration needs to be given to the potential impacts of this method before this could be recommended as a management method.

In summary teams of volunteers were able to successfully carry out culls of Pacific oysters on areas of intertidal rocky reef, using robust tools to smash the shell. This method is relatively straightforward and need not take place only on very low spring tides, with the majority of oysters present on the mid-shore.

Removal of Pacific oysters from sediment habitats is more complicated and not necessarily recommended for undertaking by volunteers. Difficulties and safety implications of access as well as unresolved problems around removal and disposal methods and cost implications have hindered progress. Methods of removal from soft sediment habitats require further investigation and habitat sensitivity needs to be considered when planning removal events.

Image 14: Pacific oysters on Dartmouth sea wall. ©Nigel Mortimer

Image 15: Flat-shaped Pacific oysters – Percuil ©Christine Townsend

10.2 Assess whether control of Pacific oysters using volunteer effort can be effective in reducing Pacific oyster density

Initially there were some challenges in using the project data including preparing the datasets received and designing an appropriate statistical analysis retrospectively. However, once these issues were resolved it was possible to carry out a statistical analysis to assess whether culling was effective in reducing Pacific oyster density. However, issues with data limited the amount that could contribute, but the analysis included data at fifteen sites within six locations in South Devon and Cornwall. These locations were: Restronguet, Turnaware, St Just Creek and St Just Pool on the Fal estuary; and Noss Mayo and Newton Ferrers in the Yealm estuary.

10.2.1 Natural Pacific oyster population growth rates

The analysis of quadrat data shows that where no culling interventions took place Pacific oyster populations are increasing naturally. There seems to be some consistency in the natural annual population growth rates which vary between 10% and 20% for most analysis groups. There are some exceptions to this, such as at Noss Mayo and Turnaware where growth rates were much less.

No culls were undertaken in the following sites:

- **St Just (Fal)** – At the southern end of the surveyed area no cull was undertaken between 2017 and 2019, and this area (Model 5) saw a significant increase in the total population of Pacific oysters of 38.32% or **+ 20.94% per annum** (P=0.01).

- **Noss Mayo (Yealm)** – No culls were undertaken on some sections of the shore at Noss Mayo towards the western end of Newton Creek (Models 11 and 12). An increase in Pacific oyster population was observed in both analysis groups between 2017 and 2020. The first had a total population growth rates of 19.43% or **+ 6.77% per annum** (P>0.42); and the second a total population growth rate of 38.79% or **+ 13.51% per annum** (P>0.11). Whilst there is a clear increase here, the model statistic is reported as not significant, though that could be for many different reasons. These models are neighbouring sites, but the quadrats for the later site where slightly higher- above the mean high-water line which is why they were analysed separately. It's not clear if this is the reason why the second site has a higher growth rate. These increases were in contrast to the western end of the beach with the same survey dates, but where a single training cull occurred in 2017 prior to both the surveys at this location (Model 10). In this case the population increase was greater with a total population increase of 58.37% or **+ 20.33% per annum** (P=0.02), perhaps because the preceding cull created space for additional growth.

- **Newton Ferrers (Yealm)** – No culls were carried out along a section of shore to the west of the end of Riverside Road (Model 14). There was an increase in Pacific oyster abundance with a total increase of 31.78% or **+ 20.71% per annum between** 2018 and 2020 (P=0.14) and although this was not statistically significant the model was a good fit so the trend likely.

- **Turnaware (Fal)** – Turnaware is an exception as several areas weren't culled but showed very low or no growth at all. Model 2 had a very insignificant (p=0.92) total growth of -2 % and annual growth rate of **- 0.61 % per annum**; and Model 1 had an insignificant (p=0.29) total growth of 26.06% and annual growth rate of only **+ 7.99% per annum**). It's not clear why there was limited growth here.

  It may simply be that where natural growth rates are lower, the sites may be approaching or have already reached a natural carrying capacity (where growth rate would slow and potentially even decline again) or there has been a reduction in growth for other reasons such as environmental factors. A carrying capacity is likely to be reached when all possible spaces for colonisation are taken, and in some cases when the habitat has formed a reef. Nonetheless, considering all the sites, the overall evidence shows that doing nothing leads to an increase in Pacific oyster abundance that can be at statistically significant levels. Natural growth rates are unlikely to reduce until all areas that could be colonised are, and to their full capacity.

10.2.2 Is culling an effective management intervention

Both modelling methods clearly show that culling and partial culling are effective interventions in the management of Pacific oysters at the locations where they occur, for an amount of time. Culls were undertaken at seven of the sites (5 fully and 2 partially culled). In six of the model analysis groups, where volunteer led culls occurred in between surveys, the pacific oyster population declined at these locations. The remaining site in Turnaware appeared to increase, but this is probably because an area of lower shore was missed as the cull occurred during a higher tide.

Areas with multiple culls in an area seem to see the steepest declines over time, and those with partial culls have potentially slowed population growth rates but not to the same extent. Where there are multiple cull lines in an area these don't necessarily represent repeat temporal culls in one place (though often they overlap). They usually represent culls covering multiple areas along a beach length to get more spatial coverage. This could suggest that full spatial coverage is probably important to how successful culls are in the long term, rather than only culling sections of a beach or Pacific oyster population.

However, it is clear no culls have entirely eliminated a population, and despite culls being effective in the locations they occur for an amount of time, overall, the populations are still increasing. The coverage of culls would need to be increased to further slow population growth or to eliminate whole areas, and there is a high natural population growth rate in competition to the culls, so lapses in culls spatially and temporally reduce their effects over time.

Culls were undertaken in these sites:

- **St Just Pool (Fal)** – At St Just Pool (Model 4) a cull was undertaken by volunteers in 2017 and the population of Pacific oysters on this section of the shore at the northern end was significantly reduced by a total of 94.96% or **- 49.72% per annum** (P=0.01) between 2017 and 2019. This is in contrast to a neighbouring area just to the south which was not culled (Model 5) where there was a population increase of **+ 20.91% per annum** (P=0.01) between surveys in 2017 and 2019 (Model 5).

- **St Just Creek North (Fal)** – The population of Pacific oysters at the eastern end of the area surveyed on the north shore of the creek, near to Messack House (Model 6), was significantly reduced by a total of 50.22% or **- 41.57% per annum** (P=0.001) between 2019 and 2020 following two culls in 2019. At Messack Point (Model 7) the oyster population was significantly reduced even further by a total of 71.58% or - **54.54% per annum** (P<0.001) between 2019 and 2020 following three culls in 2019.

- **Restronguet (Fal)** – At the back of Restronguet spit (Model 8) the Pacific oyster population was significantly reduced by a total of 31.56% or **- 29.5% per annum** (P=0.02) between 2019 and 2020 following one cull in 2018 and four culls in 2019. At two small sections at the northern end of the surveyed area (Model 9) the oyster population was reduced by a total of 24.78% or **- 22.38% per annum** between 2019 and 2020 following one cull in 2019. Whist this was above the statistical significance threshold (P=0.14) this may be partly due to small sample sizes.

This evidence shows that using volunteers to cull Pacific oysters can reduce their abundance at statistically significant levels.

Partial culls were undertaken at these sites:

- **Restronguet (Fal) –** An area behind Restronguet spit (Model 9) was partially culled in-between surveys in 2019 and 2020. There was a total decline in Pacific Oyster oysters of 24.78 % or **– 22.32 per annum** (P = 0.14). This is slightly less than a neighbouring site where a full cull was done, and which had an annual population decline of – 29.5 % per annum.

- **Newton Ferrers (Yealm)** – On a section of shore at the western end of Newton creek towards the harbour office (Model 13), where residents have removed pacific oysters, there was a significant reduction in the population of Pacific oysters by a total of 39.44% or **-28.97% per annum** (P=0.06). This is in contrast to a nearby site (Model 14), to the west of the end of Riverside Road West, with very similar conditions but not culled, which saw a total population increase or **+ 20.71% per annum**.

This evidence suggests that partial culls by volunteers and members of the public are likely to be less effective at reducing the abundance of Pacific oysters, but they reduce the natural population growth rates. This means the difference between years is less, which leads to less statistically significant changes.

The evidence from this project shows that culling is an effective intervention where they occur for a certain amount of time. Partial culls, where small sections of an area of shore were culled, were slightly less effective. This suggests that efforts to remove Pacific oysters need to be targeted and carried out along an entire length of shore rather than in a piecemeal fashion. Ideally culls would be repeated annually along a section of shore as this saw the biggest decreases in oyster population growth rates. In order to do this effectively volunteer efforts will need to be coordinated across a wide area such as a MPA or county. If no further action is taken Pacific oyster populations will continue to expand and their impact on intertidal marine habitats and species will increase, both within and outside of MPAs.

10.2.3 The benefit of long-term culling

It is strongly acknowledged that unless culls are carried out regularly and have significant spatial coverage, the effectiveness of culling may be negligible unless there are other interventions to prevent colonisation. As mentioned in the previous discussion section, potential sources of Pacific oyster recruitment may lie outside of the boundaries of MPAs. Management of these areas should be also addressed to ensure that they are not contributing to unfavourable condition of MPAs, and to ensure they are not affecting the effectiveness of control operations in these areas.

The short timescale of this project has obvious limitations, but longer-term work is likely to require a financial commitment. The overall expenditure on biosecurity in Great Britain is approximately £220m per year (House of Commons Environmental Audit Committee 2019). In 2019 for example Defra's eradication of Asian longhorn beetle in Kent cost approximately £2m (House of Commons Environmental Audit Committee 2019). We recommend that consideration is given to potential future funding for this work.

It is likely that funding the continuation of this work will have notable economic and environmental benefits in the longer term. For example, damage to seagrass beds could potentially reduce the carbon sequestration function of these important habitats. Loss of seagrass beds is also likely to have significant economic impacts on fisheries and coastal communities, with the removal of their well-documented functions as nursery habitat and in providing coastal protection by stabilising sediments. The economic impacts of damage to vessels from Pacific oyster settlement on pontoons and slipways and increasing human injury must also be considered. Future work should target specific problem areas and ideally a project coordinator should be employed to ensure consistency of approach.

10.2.4 The use of volunteers

It has been demonstrated here that volunteers can be highly motivated and willing to give up significant amounts of their time to help an environmental cause. A large proportion of the volunteers who gave feedback stated they would be happy to continue this work; indeed, many were adamant that the culling needed to continue in order to be effective. Volunteers enjoyed participating in what they generally viewed as a worthwhile project that could make a real difference on a local scale. One group leader made the comparison of Pacific oyster culling with scrub clearance or tree planting on land; where volunteers feel they are making a tangible difference and therefore find the activity rewarding. The dedication of volunteers and their enthusiasm for the project enabled collection of significant amounts of data that may otherwise have been extremely difficult to obtain.

The project engaged tens of volunteers from around the coast of Cornwall and south Devon. In these areas, a number of active environmental volunteer groups already existed, which was instrumental in enabling a project of this scale to start up within such a limited timescale. Many of the volunteers had in-depth knowledge of, or familiarity with their local coast, and some also had knowledge of intertidal species and habitats. However, without these pre-existing dedicated groups, and their strong relationships with project partner organisations, it would have been difficult to engage sufficient members of the public to carry out this project. There were some areas with no active volunteer groups at the start of the project, for example around the Dart estuary. In these areas recruiting volunteers proved difficult within the time frame of this project, however this appeared to be possible if given more time. More time and resources would need to be dedicated to engaging and recruiting volunteers and dedicated group leads in areas without pre-existing environmental groups, where Pacific oyster settlement is known to be significant. Although many volunteers acknowledged that the culling would need to continue into the longer term to be effective, it is not known at this stage whether volunteer groups could commit to a much longer term and more intensive project needed to prevent further Pacific oyster growth.

A two-pronged approach combining volunteer time and government intervention is likely to be a much more effective approach overall given the continuing increase of Pacific oysters despite all the effort to date. But now that Pacific oyster ‘hot spots’ have been identified, volunteer time could be targeted more efficiently in future, to tackle the worst affected areas. Although targeting sensitive areas with only very recent settlement should also be considered as at these sites it may be possible to keep on top of the problem, preventing Pacific oysters from becoming established in notable densities. Targeting effort to the most at-risk areas would need to be balanced with participants’ availability and willingness to travel to additional locations. Mechanisms by which group leaders could update on monitoring and control in their area, raise any issues and receive advice, for example, a monthly conference call, or social media discussion boards, are recommended in any future schemes. The Pacific oyster control project in Kent also recruited volunteers that were experienced to some degree and known to be committed to the project’s success (McKnight & Chudleigh 2015). This project was based on the guiding principles of ‘containment not eradication; a targeted response based on the monitoring and a long-term commitment’. These principles are also highly relevant to this project. Volunteers were aware that total eradication would not be possible and most stated that longer term monitoring and culling are essential to have any hope of improving the situation.

Citizen science is a growing area, with organisations and research institutions recognising its potential for acquiring data that would be difficult to obtain at scale or too expensive to acquire using contractors (Tullock and others 2013; Lee, Lee & Bell 2020). Citizen science is also an effective way to improve awareness of environmental issues, including the spread of non-native invasive species. Adequate training, dedicated volunteers, regular communication, and efficient project leadership are all essential for a successful citizen science project (Tulloch and others 2013; Lee, Lee & Bell 2020) and requires dedicated paid staff to bring it together effectively.

The non-native species training delivered by the Marine Biological Association was useful in giving background information on invasion pathways and the various alien invasive species that have colonised UK shores. Further training on the methodology and better communication between the project lead and volunteer groups may have improved the quality of data acquired. This aspect was unfortunately affected by project staff changes and there was a significant period of time where no project lead was in place. It is apparent that management of volunteers could be improved by more frequent contact and the ability to direct effort to where it is most needed.

Recording and validation of data could be improved, with a number of issues encountered surrounding data quality, particularly inconsistencies with GPS co-ordinates provided, which made some of the data unusable. It was also clear that there were some variations from the given methods in the data received and this in particular caused difficulties analysing the data collected from walkover surveys. These served to highlight that the walkover method was difficult to apply to all shores and group leaders agreed that a simplification in this aspect of the method would be sensible. In future, with regular contact with groups and feedback on data submitted these difficulties could be minimised.

With regard to Pacific oyster control undertaken by volunteers, it is clear that more robust tools need to be provided in future. Initial work was hampered somewhat by tools that were not of suitable quality which may have affected volunteer morale. Many of the volunteers found it difficult to remove the smell from clothes after carrying out control work. It is worth considering providing overalls for any future culling work.

Volunteer motivation is enhanced when participants feel they are making a difference. On shores where Pacific oysters are present in Superabundant densities, sites may not be visibly different, even after a large team of volunteers have put in significant amounts of time culling. Conversely, volunteers undertaking culling events where there is only sporadic settlement of Pacific oysters may lose motivation if it doesn’t seem as if there is much to do. Others may feel great satisfaction from having been able to clear an entire site from early colonisation by Pacific oysters. Certainly, managing volunteers’ expectations is important, whether this is being clear that culling large amounts of oysters may not have a significant impact unless work is continued in the longer term, or emphasising the benefit of keeping shores free of Pacific oysters where settlement has only recently started to occur.

It should be noted that this was an ambitious project, with a number of different groups with different levels of experience in scientific monitoring and different commitment capabilities. Overall, volunteer labour was an effective means by which to gather much needed data on the spread of Pacific oysters and information on culling efficiency. The commitment and enthusiasm of the volunteers and their strong interest in improving their local environment was key to this success. However, the level to date has simply not been enough to prevent the continual overall growth in the population of Pacific oysters.

Recommendations for future work with recruited volunteers include:

- Refining the methodology to minimise the scope for error
- Improving communication with group leads and participants through forums or social media platforms
- Offering reimbursement for expenses incurred
- Providing efficient tools and protective clothing
- Developing effective materials to inform members of the public that culling of an invasive species is taking place
- Targeting future efforts to optimise effectiveness of culling. Seeing tangible improvements is likely to increase volunteer motivation and commitment
- Funding for future volunteer coordination and management

10.3 Volunteer feedback

Volunteers who took part in the Pacific Oyster Project were sent a brief questionnaire to provide feedback on their experiences. Overall, volunteers felt that the project had been worthwhile, but emphasised that it would need to continue in order to be effective. Many thought that their efforts had made a noticeable difference locally. It was noted that there were some areas that weren't accessible, either because they weren't possible to physically reach (e.g. pontoon pilings, harbour walls) or the foreshore was privately owned, and permissions hadn't been given. This may have hindered the overall effectiveness of their efforts. In some areas Pacific oyster density was so large, volunteer morale decreased, which had an impact on survey and control effort. Removing Pacific oysters from soft sediments was generally thought to be more difficult and time-consuming.

One group leader stated: '*We made too big a deal about only surveying at low springs. The Pacific oysters were never close to the low waterline – always in a mid-tide band. We can survey at any decent low tide (not at neaps), so if we were serious and had the manpower, we could perform maybe 5 daily surveys at a time, as opposed to one survey every 2 weeks*'.

Several volunteers disliked the wastefulness of smashing oysters and many were keen that alternative uses are sought. Volunteers did not notice significant impacts on native wildlife although some noted that Pacific oysters had completely changed the intertidal landscape, and large areas had become dominated by this species, perhaps several volunteers disliked the wastefulness of smashing oysters and many were keen that alternative uses are sought limiting colonisation space for native species. Some noted that settlement on harbour infrastructure, slipways and beaches was having an impact on human activity, with some areas of foreshore becoming hazardous with the sharp shells of Pacific oysters potentially causing injury to humans and dogs. Damage to boats had been observed with rubber dinghies being especially vulnerable.

Almost all of the volunteers enjoyed meeting like-minded people, working outdoors on what they considered to be a worthwhile project and helping conserve the local environment. Most events were considered to be very well organised and successful in raising awareness of the issue locally. It was suggested that handouts, t-shirts, and high visibility jackets would have been useful, to inform members of the public who sometimes assumed volunteers were being destructive, not realising they were carrying out conservation work. Handouts were produced to provide information to members of the public and these were used by many groups. However, it appears from volunteer feedback that these may not have always been available, or perhaps not all groups were aware of them.

Equipment was not always very robust. Better hammers and overalls would have been useful, as clothes became ruined. Other suggestions for improvements for future projects included increased efforts to lift-share, more clarity on culling (when it was advised and when not), more consistency in reporting methods and consideration of the ethics of culling and the welfare of living organisms.

11. Alternative uses of wild Pacific oysters

11.1 Aims and objectives

The project’s aims for alternative uses were to:

- Identify pathways to promote alternative uses of removed Pacific oysters

These aims would be achieved by

- Liaising with stakeholders to identify pathways to promote economic use of collected Pacific oysters and investigate alternative uses

11.2 Pacific oyster alternative uses in the Southwest

On Tuesday 19th November 2019, an event was hosted by Tevi (Cornish for 'grow'), a business support programme for Cornwall and the Isles of Scilly that builds businesses and enhances the natural environment. The event brought together stakeholders and industry professionals to discuss the issues surrounding Pacific oysters and potential alternative uses, including how to remove barriers. Matt Slater (Cornwall Wildlife Trust) gave a talk on the impacts of Pacific oysters and the work going on around Cornwall to help monitor and control the species as part of this project. The session also included round table discussions on potential alternative uses of Pacific oysters. Groups were separated by two categories; food uses, and non-food uses. Many ideas arose from this workshop, all of which had significant limitations which are discussion in section 12.

Cornish entrepreneur Ewen Abram-Moore has been researching alternative replacements for unsustainable agricultural and horticultural resources since 2016. After becoming aware of the environmental issues of Pacific oysters, his research group ReOstra discovered that ground oyster shell was a suitable replacement for calcified seaweed which they had been previously testing as soil conditioner. ReOstra now intend to harvest (following guidelines and licensing protocols) Pacific oysters in critical areas of colonisation and process them to trial as a soil conditioner.

Several markets have been identified and the product has been tailored towards these markets. Initial trials have been very positive and ReOstra hope to be the first company in the UK to be actively using both oyster shell and flesh as viable products. Oysters are heat treated and then tumbled to ensure meat and shell separation. The shells are then crushed by hand to a size of 10mm to dust which is the preferred size for soil application. The dried meat can be minced down and potentially used as a poultry or fish feed. ReOstra is currently in the process of marketing the UK's first oyster shell soil conditioner, Shelly Soil Magic as Corncockle UK Ltd (see below).

Image 16: 'Shelly Soil Magic' – a soil conditioner made from recycled Pacific oyster shells. ©Ewen Abram-Moore

Corncockle UK is a limited company incorporated specifically to commercially address the perceived environmental problem of the population explosion of the Pacific oyster. 'Shelly Soil Magic' is a soil conditioner made from oyster shell waste that is treated and hand crushed in Feock, Cornwall. This product is not yet available on the market.

11.3 Commercial uses of oyster meat

As stated previously, shellfish including Pacific oysters are legally required to be processed before consumption as a result of the pathogens, biotoxins, heavy metals and organic pollutants that can become stored at enhanced concentrations in the oyster's tissues (FAO, 2008). Many of these harmful substances are introduced through agricultural runoff, sewage or are naturally present in the ocean (FAO, 2008).

Shellfish harvesting areas in the UK are closely monitored for these contaminants and are classified on an A-C scale which determines what treatment the oysters need for consumption (Herbert and others, 2012).

To be sold commercially, Oysters with B-C classification have to be purified in one or more of the following ways

- Re-laying: This involves removing and transplanting Pacific oysters from polluted waters into clean waters (Lees, Younger and Dore 2010). This is not a viable option for oysters in the south west as this relies on oysters from an area classified as B or C being relayed on a designated shellfish water that's rated A. Currently there are no such areas in the south west of England.

- Depuration: This involves removing Pacific oysters and transferring them into artificial tanks. Recirculating water is passed through ultraviolet sterilizers to remove the toxins.

- Heat treatment: This involves raising the temperature of Pacific oyster flesh to an approved level and maintaining it for a specified time.

The greatest UK market for oysters is for raw consumption (CEFAS, 2019). These oysters are generally bought by farmers and are grown in areas considered safe to be consumed without depuration. Oysters grown in B-C classified areas will need to be purified in order to be sold for consumption.

An alternative to selling fresh oysters would be to freeze, can or vacuum pack them and sell them onto retailers and supermarkets. These methods allow the shelf life of oysters to be extended. The FAO, 2005 stated that processed oyster products only represented a small part of the market globally. Raw consumption is still very common; especially in France and in the United States.

In the South West the promotion of Pacific oysters as a sustainable food source has been done actively through word of mouth, social media, small businesses and via the Cornwall Good Seafood Guide run by Cornwall Wildlife Trust.

When carrying out surveys in the Fal estuary and tributaries, volunteers from Cornwall Wildlife Trust did their best to not cull Pacific oysters that have commercial value (i.e. ones that are found on soft intertidal areas within shellfish waters). Via the CWT project officer, local oyster fishers were then informed about these so that they could collect them.

11.4 Commercial uses of oyster shells

The commercial use of Pacific oysters has been addressed all over the world and the potential uses of oyster shell have included agriculture (as soil conditioner), construction (as aggregate and alternative to concrete), water treatment, food supplementation, material production and aquaculture. Oyster shells can be ground to different grain sizes which determines the use of the product whether it be for wastewater treatment, soil conditioner or animal feed (Barros and others 2009). In this section, we explore some of the uses of Pacific oysters from around the world.

11.5 Plastic production

Calcium carbonate is utilised as an additive in the process of transforming PVC from a plastic resin into a final product (Boicko and others 2004). A study by Boicko and others (2004) showed that the use of calcium carbonate as an additive can both reduce production cost and improve the properties of PVC. An example of the applications of this is a surf bootie produced by Decathlon which consists of a thermoplastic elastomer mixed with 15% recycled oyster shells. The team collaborated with a company in Brittany that specialises in recycling oyster shells from the aquaculture industry. The shells are dried, crushed, milled, and then mixed with thermoplastic to create raw material pellets. These pellets are melted and injected into moulds to create the product shape. The formula was adjusted to ensure maximum shell powder in the composition of the bootie without affecting the adhesion properties (Decathlon no date; Living Circular 2016).

Limestone is used in a similar way in the production of neoprene in the manufacture of wetsuits and processed oyster shell could be utilised in the same way. A French wetsuit company released its new Green Line Bioprene neoprene wetsuit range in 2020. The wetsuits are based on powdered oyster shell in place of limestone, and natural rubbers, sugars, and oil in place of plastics (Boardsport Source 2020).

11.6 Construction materials

There are multiple studies which highlight the potential use of Pacific oyster shell within the construction industry. In 2019, oyster shells were combined with polymeric resin to create artificial stone. The results of this study confirmed the suitability of this material in construction with the production method adding value to oyster ‘waste’ whilst reducing the need to extract natural stone (Silva and others, 2019).

In another study, oyster shells were ground into a fine powder for use in asphalt as a replacement for virgin aggregate. The shell content in the asphalt was found to reduce moisture susceptibility and the material and improve the strength of the material (Ruiz and others 2020).

In Korea, crushed oyster shells were tested as a replacement for sand in cement mortar (Yoon 2003). The study found no significant reduction in the compressive strength with up to 40% shell content, demonstrating that recycled oyster shells can be an effective replacement for sand in development of construction materials.

Under appropriate heat treatment, calcium carbonate, an oyster shell’s main component, transforms to calcium oxide which can be used in cement production (Chilakala and others 2019).

11.7 Recycling waste oyster shells for eutrophication control

Eutrophication by definition is the ‘excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which causes a dense growth of plant life and death of animal life from lack of oxygen’ (Lexico 2020). This enrichment of nutrients, particularly phosphorus, can lead to toxic blooms of algae that interfere with oyster farming techniques and render the final product inedible (Kwon and others 2004).

Kwon (2004) investigated the potential of waste oyster shells to remove high levels of phosphorus from waste waters. Oysters were heat treated to convert the calcium carbonate in the shell to calcium oxide. Calcium oxide reacts with phosphates in water, altering the nutrient and creating an insoluble form of phosphorus that can be easily separated. Oyster shells that were heat treated to temperatures of 750 °C to 800°C for 1 h under a nitrogen atmosphere removed up to 68% of the phosphorus present in wastewater samples. Oyster shell use in wastewater treatment was shown to be an effective means of recycling which could greatly reduce eutrophication in coastal regions.

11.8 Agriculture

Lime is a product commonly used in agriculture as a soil conditioner, the primary active component being calcium carbonate. It has the effect of reducing soil acidity, benefiting soil structure, and improving degraded soil to increase the productivity of crops (Goulding 2016).

In farming villages in Thailand and the Philippines crushed oyster shell is used in agriculture as a soil conditioner, and ground up, dried, shells are also used as feed for waterfowl (geese) and other poultry species (Chilakala and others 2019). Hoon Lee and others (2008) have also demonstrated the effectiveness of oyster shell meal as a soil conditioner, with the shell material significantly increasing soil pH.

A study in Brazil (Pizzolante and others 2011) investigated the effect of replacement calcium sources on the performance and egg quality of chickens. Their study showed that chickens fed on a combination of coarse limestone and oyster shell had significantly improved external egg quality. Also known as oyster shell grit, this product is widely available to purchase.

A use for oyster material that requires minimal additional cost would be to utilize it as soil conditioner. Historically it was common practice for fish waste, seaweed and for bivalves to be put on to farmers fields as a source of nutrients, salt, and calcium.

The animal by-products order (1989) outlawed this practice and now it is illegal to put meat onto fields without heat treatment first. This adds considerably to the costs of processing oysters into soil conditioner. At the Tevi workshop this was discussed as a major hurdle and Environment Agency staff there said that it was very unlikely that this could be changed. However, it is hoped that lateral thinking could be applied as with careful management it is perfectly feasible to compost down oysters either crushed or whole to a point where the meat is decomposed sufficiently leaving a nutrient rich product.

By heat treating whole oysters the meat can be sterilized – this can be achieved by boiling (rendering) or steaming and meat removed from shell.

Cleaned oyster shells are then legally put onto land and used as soil conditioner. The shells are crushed into fine powder or to whatever grade is required.

This crushed shell product has a definite value, although value is hard to predict making it hard to say if it is worth more than the cost of collection and processing.

If sufficient heat-treated oyster meat is produced, then markets for that could also be investigated. It is rich in protein and has many potential uses – for example in animal feed, in protein powders, as aquaculture feed (as fish meal) and for human dietary supplements.

11.9 Water and air treatment

Oyster shells can be dried, crushed, and calcined (reduced, oxidised, or desiccated by exposing to strong heat) which allows them to be used in water and air purification processes - particularly phosphorus removal (Jung and others 2012). The shell material can be used to filter harmful chemicals from the water and air. Jung and others (2012) showed that treated oyster shells provided a greater surface area for absorption than commercial limestone. Hence, this offers a cheap alternative to industries looking to reduce their emissions - primarily sulphur dioxide and nitrogen oxides (Kwon and others 2004; Asaoka and others 2009; Jung and others 2012). In addition, crushed oyster shells can be used to treat eutrophic sediments and waters (Asaoka and others 2009). It provides an economically competitive alternative for treating these conditions, as well as having the potential to reduce emissions (Kwon and others 2004).

Oyster shells were calcined, hydrated, and foamed by adding cement and a foaming agent to produce oyster-shell foamed bricks (Chiou, Chen and Li 2014). These bricks were used to neutralise acidic rainwater - the calcium carbonate within calcined oyster shells mostly transforms into calcium oxide which functions as an anti-acid agent (Chiou, Chen and Li 2014).

11.10 Food supplement

Calcium carbonate acquired from crushed oyster shells has the potential to be utilised as a calcium supplement (Fujita and others 1990). Test subjects in trials showed a significant bone mineral density increase after 12 and 24 month periods of taking these supplements (Fujita and others 1990). Oyster shells therefore have potential applications as a food supplement.

12. Discussion: Alternative uses

Results from this study show that Pacific oysters are present throughout Cornwall and south Devon in varying densities. Whilst management techniques to control the population have been trialled, there are few opportunities that also enable economic use as was determined during the stakeholder workshop hosted by TEVI.

There is currently a small market for the consumption of feral Pacific oysters in the south west of England. Oysters are sold whole by several companies who have reported a small increase in the market over recent years. It is still unclear whether creating a larger market would be feasible in the longer term. With very few Shellfish Classified Areas in relation to areas that have an abundance of feral Pacific oysters it is unlikely to result in effective control on its own. Outside of these very limited areas, large amounts of Pacific oysters which cannot legally be harvested for human consumption remain.

Feral Pacific oysters inhabiting areas of soft sediment grow on top of each other, fusing together, and therefore cannot be separated and depurated for consumption. Individuals that have colonised rocky substrates are not really suitable for consumption as the process of removing the lower shell can cause damage to the oyster. Removal of oysters from rock is also time consuming and risks damaging MPA interest features. Although it may seem that the abundant Pacific oysters present around the coasts could provide a protein source, it is likely that only a small proportion of these are accessible and suitable for consumption. Feral Pacific oysters may be less appealing than farmed oysters due to lack of shell uniformity, their large size and what has been described as a ‘muddy’ taste. All of these factors are perhaps inhibiting the creation of new markets for consumption.

Despite these issues, the recent increase in the market for local and feral Pacific oysters has seen depuration facilities and purification systems open in Gweek, Flushing and Mylor dockyard.

Non-food related uses of Pacific oyster shell have been investigated and trialled around the world with potential uses to agriculture (soil conditioners and poultry feed), construction (as aggregate and an alternative to concrete), water treatment, food supplementation, material production and aquaculture described. Historically it was common practice for fish waste, seaweed, and bivalves to be put on to farmers' fields as a source of nutrients; however, under the Animal By-Products Order (1999) it is now illegal to put meat onto fields without prior heat treatment. Whilst whole oysters can be heat treated by boiling (rendering) or steaming and meat removed, this process adds considerably to the costs of processing oysters into agricultural products such as soil conditioner.

This project has demonstrated that there is a significant quantity of feral Pacific oyster material around Devon and Cornwall foreshores, however exact quantities are difficult to estimate. Some reefs that are forming may consist of thousands of tonnes of oysters, yet it is difficult to determine whether there would be enough material for the continual manufacture of products. Crushed oyster shell product has a definite value, but at this stage it is difficult to predict whether the value is worth more than the cost of production. Further research would be needed to determine this.

Whilst there are many great ideas or proposed projects, there is still significant uncertainty over whether these products are financially feasible or even marketable. More studies are warranted and funding for larger scale investigations into alternative uses would be welcomed.

13. Project conclusions and recommendations

13.1 Conclusions

This project has demonstrated that using human (volunteer) effort to physically control Pacific oyster abundance at specific locations can be an effective short-term management tool, reducing the abundance of Pacific oysters at statistically significant levels, in the areas targeted by the cull. Partial culls by volunteers and members of the public are likely to be less effective at reducing the abundance of Pacific oysters where they occur. Doing nothing (not culling) leads to an increase in Pacific oyster abundance that can be at statistically significant levels. However, despite culls being effective where they occur, the spatial and temporal distribution of culls to date has not been enough to reduce the growth in Pacific oyster populations overall. It is clear that there needs to be a coordinated and targeted effort if removal of Pacific oysters by volunteers is to be used as an effective management tool, and to reverse the overall increase. Committed volunteer groups can have a significant impact in tackling the spread of Pacific oysters, but culling must cover entire shorelines and take place at regular intervals to be effective.

Culling of Pacific oysters on rocky intertidal habitats is relatively straightforward, with oyster valves being smashed and the oysters left *in situ*. Removal from sediment habitats is much more challenging, with access being problematic and sometimes hazardous. The logistics surrounding removal of large quantities of oysters, and mechanisms for their disposal, still need to be addressed and solutions to these challenges may need to be site specific.

Several Pacific oyster hotspots were identified within south Devon and south Cornwall MPAs, as well as areas with high densities of oysters. These areas will require management to maintain site features or recover them to favourable condition. Notable levels of Pacific oysters were present across almost all of the areas surveyed, and these areas will require monitoring to ensure MPAs are not impacted. Where funding permits, proactive management would be prudent to avoid Pacific oysters becoming an issue in the first place.

A citizen science approach can be effective in recording and monitoring the density of Pacific oysters across a region and allows monitoring to take place at scale across a number of sites. Effective coordination and frequent communication with citizen scientists is essential to ensure methodology is carried out correctly and data are suitable for analysis. Monitoring methods will need to be amended for future work to ensure all collected data can be analysed.

Regular monitoring of seagrass MPA features where Pacific oysters have been identified is strongly advised (Salcombe and Kingsbridge SSSI; St John’s Lake SSSI) and funding for regular *sensitive* removal of Pacific oysters from these sites is needed to prevent reefs forming. Pacific oyster reefs could pose a significant risk to these sensitive MPA features that have an important natural capital value.

Identification of source populations or ‘broodstock’, both within and outside of MPAs, would allow targeted removal of established populations that are thought to pose the greatest risk. eDNA studies could help to contribute to current knowledge on larval transport mechanisms.

It would be beneficial to continue to develop these citizen science networks and look to continue the removal of Pacific oysters from problem areas, ideally putting them to good use. It is essential however that environmental assessments (e.g. Habitats Regulations Assessments; MCZ Assessments) are carried out beforehand to ensure that removal does not cause further damage to sensitive habitats. SSSI consent may also be required.

All removal of oysters from the shore is likely to incur significant initial costs. Until it can be demonstrated that a market exists for Pacific oysters, and plans can be put in place to process and sell the material, it is unlikely that commercial ventures will attempt to harvest from Pacific oyster reefs.

13.2 Recommendations

We make the following key recommendations for future work:

- **Provision of sufficient funding for regular monitoring and increased targeted management** in areas where MPA features are either already unfavourable or at risk of becoming unfavourable in the very near future.

- **Creation of a project coordinator role to ensure effective coordination of Pacific oyster management actions at a landscape scale.** This is needed to ensure there is targeted action within problem areas, consistency of approach across sites, and effective management informed by monitoring. A long-term commitment is required.

- **Establishment of a network of Local Action Groups** to enable citizen scientists to contribute to biosecurity monitoring and action, with funding for efficient coordination of these groups (see above). This was recommended by the Environmental Audit Committee and welcomed by Government[1].

- **Initial management of Pacific oysters should focus on hotspots within the Fal and Helford and Plymouth Sound and Estuaries SACs** where high densities of Pacific oysters are causing these MPAs to be unfavourable. **Management should also target at-risk areas within MPAs where more recent settlement has occurred**, to prevent populations becoming established in these sites and threatening their condition.

- **A review of the costs and logistics associated with removal and disposal of large quantities of Pacific oysters from sediment habitats alongside an investigation into the most sensitive methods of removal** (i.e. that do not cause abrasion, disturbance, or damage to sensitive intertidal habitats).

- **Regular monitoring of intertidal seagrass sites and an investigation into sensitive removal methods** (see above), to prevent degradation and loss of these important blue carbon habitats.

- **An investigation into changes in community composition in response to increasing densities of Pacific oyster settlement**. This should focus on rocky shore communities, mixed sediment communities and seagrass.

- **Removal of hard debris and abandoned structures from intertidal areas where Pacific oysters are impacting MPA features**. These can act as a substrate for attachment and may lead to broodstock populations becoming established on structures that cannot be accessed.

- **Further investigations into variables influencing the spread of Pacific oysters to help identify source populations; this could include eDNA studies**. We recommend that Pacific oysters are monitored and managed in source population areas, irrespective of whether they are within an MPA.

- **Consideration of the addition of Pacific oyster biotopes to the Marine Habitat Classification of Britain and Ireland biotope descriptions.** This would facilitate the MPA condition assessment process and more accurately list the range of biotopes currently present.

14. References

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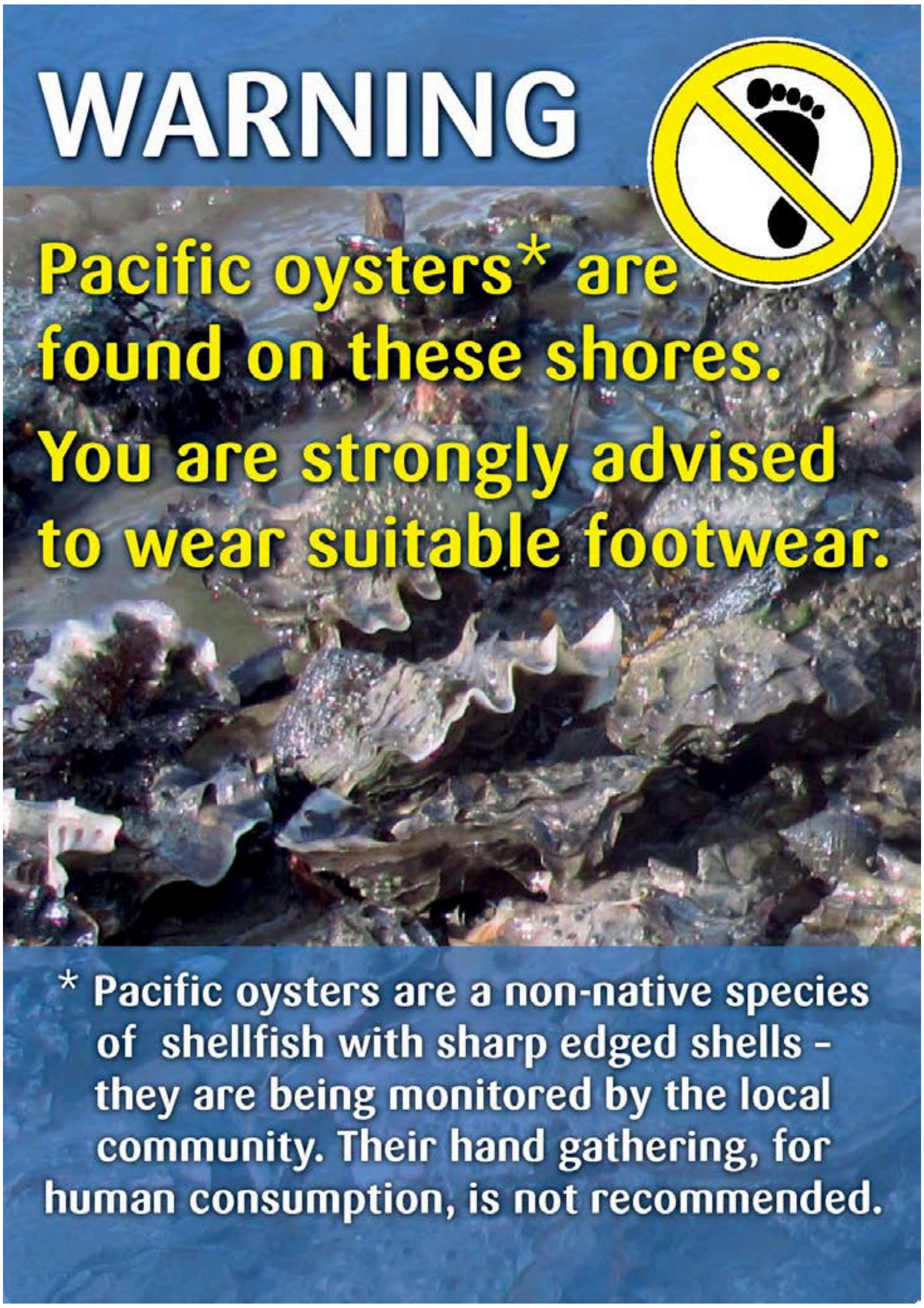
Appendices

Appendix 1: Pacific oyster warning sign



Designed and funded by South Devon AONB Estuaries Partnership. On display around the Yealm estuary and at Stoke Gabriel on the Dart estuary ©South Devon AONB Estuaries Partnership

Appendix 2: Community group flyer produced by Natural England

Cornwall Wildlife Trust

South Devon AONB Estuaries Partnership
Encouraging sustainable use and enjoyment

Survey and management of wild settlements of Pacific Oyster by community groups

This is to make you aware of a 24 month project that is a collaboration between Natural England, Cornwall Wildlife Trust and South Devon AONB.

Starting from spring 2018 the project involves partner organisations recruiting local community groups and volunteers to complete surveys which will provide baseline information on the distribution and 'hot spot' locations of wild settlement of the Pacific oyster (*Magallana gigas)*

Photos courtesy of Matt Slater

As part of the project it is anticipated that some of these groups will also trial management methods such as culling or 'oyster bashing' on rocky shores identified as 'hot spots' and re-survey those areas for re growth and Natural England will evaluate the effectiveness of trial management techniques

The control of wild settlement population of Pacific oyster is important in designated marine sites because of the potential for invasive species to modify the ecology of rocky shore communities
Pacific oyster accumulations are also becoming an increasing hazard to recreational activities within estuaries because the sharp edges to the shells are causing cuts to hands, feet and pets paws when walking/scrambling in the intertidal area.

For more information or if you have any concerns regarding this survey work please contact
Ruth Crundwell Project Officer Ruth.Crundwell@naturalengland.org.uk 020 802 67547 Mob 07795637762

Frequently Asked Questions

Why do the oysters need to be culled?

Because of the potential for the oyster population to create reefs which replace the current rocky shore environment. This may be detrimental to what the area looks like and how the system operates at an ecological level.
Evidence from a project which culls oysters on beaches in Kent indicates that culling activity over time has reduced the numbers of oysters found on the chalky reefs which form part Marine Protected Area (MPA), therefore this is the technique which is being trialled in the south west

Can the oysters be eaten rather than culled?

We recommend oysters should not be gathered/foraged to be consumed because;

- The process of physically removing them from rocks may damage a feature of an MPA
- Water quality may not be within the requirements of the legislation which ensures shellfish meat is fit for human consumption

Do we have permission of landowners to be on the shores?

Most of the areas visited by the volunteers will be open public access areas. Permission from landowners or authorities which have responsibility in other locations has been sought by project personnel

What about protected areas?

Each group goes through a training to correctly identify the Pacific oyster and make sure the project method, which minimises impact to surrounding environment, is followed.
Because the project is co-ordinated by Natural England we have undertaken assessments, as the legislation requires where necessary, to ensure that there will be no detrimental effects to features of protected sites.

How can I get involved?

If you feel that you would like to join our groups please contact
Matt Slater Marine Awareness Officer Cornwall Wildlife Trust 01872 302251
Nigel Mortimer Estuaries Officer South Devon AONB 01803 861465

Community group flyer produced by Natural England for volunteers and public interest ©Natural England

Appendix 3: Survey recording form

PACIFIC OYSTER SURVEY RECORDING FORM: SECTION A

Surveyor Names: **Date:** **Time:** **Site Location (Name & Number):**

GPS coordinates of start location (WGS 84) (decimal degrees)

Photo number (optional photograph of shore to be surveyed)

Section Description (Try and briefly describe the extent of the survey section in a way that someone repeating the survey would know where to begin and end).

- **Directions to the survey section according to landmarks on ordnance survey maps or obvious landmarks.**
- **How was the shore accessed?**
- **Approximate length of the shore:**
- **Notable habitat features, (please add % of substrata present in the boxes below and add any other points of interest)**

Rock ☐ Boulders ☐ Cobbles ☐ Pebbles ☐ Gravel ☐ Sand ☐ Mud ☐ Seaweed cover ☐ Other ……………………..

- **Other notes (e.g. is there presence of densely clustered Pacific oysters, native oysters present, other non-native species or interesting habitat features or evidence of human activity that may affect the intertidal habitat?)**

Following the survey were Pacific oyster control methods carried out? **(please circle the relevant answer)** (Natural England guidance has been produced to assist volunteers when carrying out control effort: Please contact Marine-Southwest@naturalengland.org.uk to request a copy).

Yes **No** **Was this for all or part of the shore?** **Notes (e.g. location)**

Survey Method- Quadrat (Q) or Walk-over (W)	Coordinates at start of walk-over route**		Coordinates at end of walk-over route** Please also enter coordinates at significant changes of direction and/or every 50 Pacific oysters recorded.		Number of Pacific Oysters (live)	Description of substratum Substratum where Pacific oysters are observed on the walkover route, or in a quadrat (if an optional photo is taken please record the photo number or reference)	Coordinates of each Quadrat	
	Position N	Position W	Position N	Position W			Position N	Position W
Walk-over (W)	50.31367	-4.05469	50.31367	-4.05463	13	Cobbles and pebbles on gravel 40%, sand and mud substratum 60% (photo 2)		
Quadrat (Q)					6	Cobbles 20 % and bedrock 80%	50.31363	-4.05463

- ***If preferred record Waypoint number on survey sheet and download and enter coordinates from GPS unit at home/office before submitting.**
- ****At the end of a walkover survey, or before changing to quadrat recording, enter location coordinates (as above, the waypoint may be quicker to enter in the field, but please enter full coordinates before submitting the form).**

Appendix 4: Pacific Oysters within MPAs in South Devon and Cornwall

This section summarises data on Pacific oysters in south Devon and Cornwall that Natural England either held or was aware of prior to the start of this project, along with results of other surveys that were carried out during the timeframe of this project but were separate to it.

Mounts Bay MCZ

Pacific oysters were recorded in 2005 on St Michael's Mount, and between St Michael's Mount and Marazion in 2016 and 2017. They were recorded in Penzance and Newlyn in 2018 (National Biodiversity Network Atlas 2020).

Fal and Helford Estuaries

Pacific oyster surveys have been undertaken in selected areas of the Fal and Helford estuaries since 2014.

In 2014, the average density of Pacific oysters in the Fal and Helford SAC was 0.07 individuals/m^2, calculated from walkover surveys where the area covered, and number of oysters seen were known. In higher density areas of >8 oysters per m^2 densities were calculated using quadrats (Russell 2019).

Fal

Between 2009 and 2011, 75 feral Pacific oysters were collected from the Fal estuary as part of a study into the genetics of Pacific oysters in the British Isles (Lallias and others 2015).

The highest density of Pacific oysters recorded in the Fal estuary during the 2014 surveys was 0.06 oysters per m^2 (Russell 2019).

Surveys in 2017 focused on the shoreline between St Mawes and Turnaware Point as these sites were reported as having very high numbers of Pacific oysters by members of the public (Natural England 2018c). Peaks of 48 oysters per m^2 were seen in some areas (Natural England 2017e).

There are records of Pacific oysters from 2016 and 2018 at the mouth of Carrick Roads, from 2018 in the Percuil River and in 2019 by St Mawes (National Biodiversity Network Atlas 2020). There are also reports in September 2020 of Pacific oysters near Tregothnan estate and on Roundwood Quay (Gall, A. personal communication 2020).

Helford

There are records of Pacific oysters at Men-aver Point from 1994 (National Biodiversity Network Atlas 2020).

The highest density of Pacific oysters in the 2014 walkover surveys was in the Helford at 1.12 individuals per m^2 (Russell 2019).

In 2015 the area with the highest Pacific oyster density at Port Navas Creek was revisited. Between 2014 and 2015 average densities had increased from 0.17 per m^2 to 2.1 per m^2, with highest densities increasing from 1.12 per m^2 to 12.3 per m^2. On the relatively small area of shore at Calamansac a large increase in the number of juvenile Pacific oysters was seen, rising from 38 in 2014 to 2695 in 2015. The numbers of adults also increased from 190 to 1029 between 2014 and 2015 (Russell 2019).

There are further records on the Helford from 2015 north of Ponsence Cove and in 2017 near Treath (National Biodiversity Network Atlas 2020).

Fowey Estuary

Pacific oysters were recorded in Fowey in 2005, in the outer Fowey estuary in 2012, and north of Bodinnick in 2013 (National Biodiversity Network Atlas 2020).

Surveys of Pacific oyster density have been undertaken in selected areas since 2014.

In 2014 a survey was carried out between Penpoll Creek and Pont Pill. Pacific oysters were found to be Common (SACFOR scale) at 1 – 2.7 per m^2 in Pont Pill Creek. Pockets where Pacific oyster density was Frequent, 0.1 – 0.9 per m^2, occurred upstream on the Fowey estuary (Evans 2014).

In May 2017 abundance (SACFOR scale) was recorded at specific sites between Wiseman's Reach and Pont Pill. This was estimated from a 3m motorboat at a distance of 2 – 3m from the shore. Sites along the town quays in Fowey were also accessed by foot. The density of pacific oysters was estimated to have increased in all areas to Common, 1 – 9 per m^2, or Abundant, 10 - 99 per m^2 (Natural England 2017f).

One area of intertidal mud contained Superabundant densities, 100 – 999 per m^2.

Quadrats were also used to record densities at Pont Pill, downstream of Upper Fowey and Pont Pill MCZ, and densities of between 4 and 356 Pacific oysters per m^2 were recorded (Natural England 2017f).

Friends of Fowey Estuary Volunteer Group have undertaken Pacific oyster monitoring as part of wider intertidal and rocky shore monitoring (e.g. bio blitz) and recorded low densities in the outer Fowey estuary (Natural England 2017f).

In 2018 an intertidal survey of Upper Fowey and Pont Pill MCZ was carried out (Natural England 2019g). Densities of Pacific oysters were recorded using the SACFOR scale. Pacific oysters were Superabundant on the Northern shore of Pont Pill. The Pacific oyster was also observed between the southern boundary of the MCZ and Golant in Common to Rare abundances. Much higher densities were found within Pont Pill where up to 25 individuals per m^2 were observed in patches; mostly along the littoral rock/littoral sediment interface. However, less than 1% of the total area of littoral communities within the MCZ were considered to be significantly affected by the abundance of Pacific oysters (Natural England 2019g).

Whitsand and Looe Bay MCZ

There are records of Pacific oysters from East Looe and Seaton from 2005 and on Long Sands from 2016 (National Biodiversity Network Atlas 2020).

An intertidal survey of the rocky habitats within Whitsand and Looe Bay MCZ was carried out in 2019 (Natural England 2020c). The Pacific oyster was rarely observed to the west of Whitsand Bay, with only a few individuals being observed close to Looe. However, in Whitsand Bay they were recorded as Occasional to Frequent (SACFOR scale) on most of the mid to lower areas of rock and common in some areas. Two small areas were observed to be significantly affected, one at the western end of Whitsand Bay and one close to Freathy. Deliberate attempts to remove the oysters from the rocks could also be seen in many of the more easily accessible areas of Whitsand Bay.

Plymouth Sound and Estuaries

Pacific oysters have been recorded in the Yealm estuary since 1997 (National Biodiversity Network Atlas 2020). In 2001 a biotope survey of the MPA was carried out (Bunker and others 2002) and Pacific oysters were found to have colonised the main Yealm river channel. Wild populations of Pacific oysters had become established on bedrock and boulders on the north bank of the river between Warren Point and Thorn House, and to the north of there on the bedrock of the steeper headlands.

Pacific oysters were subsequently recorded as present at Newton Ferrers in 2007 and in the outer estuary in 2006, 2007 (National Biodiversity Network Atlas 2020) and 2009 (Bishop Group -Marine Biological Association. 2020, unpublished).

In 2011 a Natural England Condition Assessment of the Yealm Estuary SSSI was undertaken and Pacific oysters were found to be Common in abundance (SACFOR scale) at Clitters Wood (Natural England 2011).

Further surveys of Pacific oyster density have been undertaken in selected areas since 2014. Densities were calculated from walkover surveys. In higher density areas, where there were more than 8 oysters per m^2, densities were calculated using quadrats. In 2014 the average Pacific oyster density on the Yealm was 0.13 per m^2. However, quadrats in denser areas showed that the average densities were at Newton Ferrers 4.4 per m^2, Passage Wood 30.9 per m^2, Court Wood 32 per m^2, and at Clitters Wood 14.2 per m^2 and 20.4 per m^2 in the two transects surveyed there (Russell 2019).

In 2015 the two Clitters Wood sites were revisited. Densities in the areas where the walkover transect survey method was undertaken increased by 11% and in areas where quadrats were taken average density increased by 43.6% and the highest density increased by 132%. An area of Pacific oyster reef with more than 100% cover (oysters stacked on top of each other) was also observed but not surveyed due to time constraints (Russell 2019).

In 2016 Natural England undertook surveys of the intertidal rock to inform a Condition Assessment and test out a new method in the Plymouth Sound and Estuaries SAC and underlying SSSIs. The Yealm Estuary SSSI had the highest abundance of Pacific oysters of all sites sampled within Plymouth Sound and Estuaries SAC with an average of 8 (±8.4) individuals per m^2. A maximum number of 47 individuals was recorded in a $0.25m^2$ quadrat at Clitters Wood (Marine Ecological Surveys Limited 2017), which equates to 188 per m^2. Pacific oysters were observed at 14 locations in the estuary at all shore heights across the site, but particularly between Mouthstone and the Harbour Authority boundary. They were prevalent between the Harbour Authority boundary and Warren Point, with one $0.25m^2$ quadrat recording a total of 47 individuals. At Clitters Wood there was an average of 7 individuals per $0.25m^2$ quadrat in both the transects at this location. No Pacific oysters were found further up the Yealm at Court Wood. At Warren point, located within Wembury Point SSSI, Pacific oysters were recorded at three midshore stations with a peak abundance of 11 individuals per $0.25m^2$ quadrat at one station (Marine Ecological Surveys Limited 2017).

Surveys in 2017 focused on the shore at Noss Mayo between The Ship Inn and Kilpatrick Steps where densities above 10 oysters per m^2 were consistently recorded with peaks densities of 80 oysters per m^2 (Natural England 2018c).

Further intertidal biotope surveys were undertaken in 2017 along with an additional objective to map areas of littoral habitat that had been ‘notably’ altered by the presence of the Pacific oyster. Again, Pacific oysters were more abundant in the Yealm estuary than anywhere else in the SAC. Abundances ranged from Occasional

(1-9 individuals per 1000 square metres) to Abundant (1-9 individuals per square metre) on the SACFOR scale (Curtis 2018).

The densest aggregations of Pacific oysters were found between Warren Cottages and Clitters Wood. Here they were mostly recorded on mixed stable substrate colonised by *Fucus vesiculosus* and/or *Fucus serratus* (Biotope codes: LR.MLR.BF.FvesB or LR.MLR.BF.Fser.R). However, individuals were also attached to bedrock outcrops dominated by barnacle communities (Curtis 2018). This survey included Newton Creek which is outside the boundary of the Plymouth Sound and Estuaries SAC and Yealm estuary SSSI but adjoins these sites. Densities of Pacific oysters ranged from between 20–50 per m^2 at the lower end of Newton creek and 1–2 per m^2 at the upper end of the Newton Creek (Curtis 2018). The distribution was broadly comparable to that recorded in 2014 and suggests no substantial change in abundance since 2014 (Russell 2019).

Recently Pacific oysters have also been recorded at Cellar Beach and Noss Mayo in 2018 and 2019 (Bishop Group -Marine Biological Association, unpublished).

Pacific oysters appeared to have spread since 2011 and had also altered the extent and distribution of the rocky shore communities found in the Yealm. This led to the condition of the Yealm SSSI being assessed as unfavourable (Natural England 2016c).

Pacific oysters have been recorded at Mountbatten since 2004 (Bishop Group - Marine Biological Association Unpublished; National Biodiversity Network Atlas 2020). Pacific oysters have been recorded at Jennycliffe since 2007, Batten Bay since 2004, and at Beggars island on Torpoint in 2008, and Mount Edgcumbe in 2019 (National Biodiversity Network Atlas 2020).

Surveys of Pacific oyster density have been undertaken in selected areas around Plymouth Sound since 2014. In 2014 Plymouth Sound and Estuaries SAC was surveyed. Densities of Pacific oysters were calculated from walkover surveys. In higher density areas, where there were more than 8 oysters per m^2, densities were calculated using $0.25m^2$ quadrats (Russell 2019). In 2014 average densities from walkover surveys ranged from 0 – 0.18 oysters per m^2. However, four sites had a highest density of greater than 1 oyster per m^2 with the highest density estimated at 107 oysters per m^2. Quadrat surveys were conducted at two areas as they had higher densities. At Beggars island the average density was 15.5 oysters per m^2 and at Wearde the average density was 2.4 per m^2 (Russell 2019).

In 2015 the Cornwall Inshore Fisheries and Conservation Authority undertook a study of the blue mussel beds in the Tamar Estuary Sites MCZ. Pacific oysters were present on the Lynher at Jupiter Point and Shillingham Point but were sparsely populated and not in sufficient numbers to form a bed (Cornwall Inshore Fisheries and Conservation Authority 2015). Pacific oysters were again noted on both these mussel beds during a repeat survey in 2016. Oysters were present as large individuals and very sparsely populated and no juveniles were observed (Jenkin and others 2016).

In 2017 Pacific oysters were found to be Occasional on the SACFOR scale at Mount Batten and Frequent in several locations in the lower Tamar-Tavy estuary. Notable numbers of Pacific oysters were found in St John's Lake. These were at levels of Common or higher on the SACFOR scale which equates to more than 1 – 9 individuals per m^2. These were mostly found on the lower shore within cockle dominated habitat (Biotope: LS.LSa.MuSa.CerPo). Within St John's Lake the total area of littoral sediment that was mapped as 'notably' affected amounted to 11% of the total area of littoral sediment mapped within the SAC. The distribution in the Tamar – Tavy estuary SSSI did not appear to have changed since 2010 (Curtis 2018).

In 2018, Pacific oysters were recorded from the upper Tamar estuary at Hole's Hole and Kingsmill Lake to Plymouth Sound and Mountbatten (Bishop Group -Marine Biological Association, unpublished).

Hooper (2020) revisited several of the sites within the Plymouth Sound and Estuaries SAC in 2019 that had been surveyed by Natural England in 2014, although not all acquired data could be compared with Natural England 2014 data due to minor differences in methodologies. Walkover surveys recorded no Pacific oysters at Kingsand in 2014 however there was an average density of 0.48 per m^2 in 2019. No Pacific oysters were recorded at Cawsand in 2014 either during the walkover survey, however there was an average density of 1.02 per m^2 in 2019. At Sandways, the average density increased from 0.02 to 0.86 per m^2 and at Cremyll from 0.004 to 0.07 per m^2 between 2014 and 2019. At Torpoint, no Pacific oysters were recorded in either 2014 or 2019. Three Pacific oyster reefs were recorded on the Rame Peninsula at Beggars Island and Cove Point near the entrance to the Lynher and Empercombe at the mouth of St John's Lake. Shingle-gravel mudflats were seemingly influential in reef formation. Pacific oyster abundance was found to be greater in areas of low wave exposure and strong tidal currents.

Erme Estuary MCZ

Pacific oysters were recorded at the mouth of the estuary in 2005 and 2007 (National Biodiversity Network Atlas 2020).

Avon Estuary MCZ

The MCZ verification field report notes that a couple of specimens of Pacific oysters were observed in the Avon estuary in 2013 (Natural England 2013b). A small number of feral Pacific oysters were seen by Natural England staff while visiting the estuary near Hexdown in 2016 (Natural England 2018d).

Salcombe to Kingsbridge Estuary SSSI

Between 2009 and 2011, 95 feral Pacific oysters were collected from the estuary as part of a study into the genetics of Pacific oysters in the British Isles (Lallias and others 2015).

Pacific oysters were noted by Natural England staff near to Cliff Road during a site visit in 2016 (Natural England 2018d) and on both sites of the lower estuary during a visit looking for non-native species in 2018 (Singfield. C, personal communication 2020).

Dart Estuary MCZ

In 2013 and 2014 Pacific oysters were recorded near Galmpton Creek, Middle Back and Dittisham Creek during the MCZ phase 1 and phase 2 verification surveys (Natural England 2013c) with relatively high densities at several sites (Natural England 2013c).

During the phase 1 sediment survey in 2013 Pacific oysters were observed as being Common (SACFOR scale) at station 8 at Middle Back on a very low water mid channel gravelly sandbank (Natural England 2014c). In 2014 during the phase 2 sediment survey at station Da8, also at Middle Back, Pacific oysters were recorded as Abundant in adjacent pools (Natural England 2014c).

During the phase 2 rock survey in 2013 one Pacific oyster was recorded in a quadrat (Transect 3, quadrat 4B) near to Galmpton Creek, and one Pacific oyster was recorded in a quadrat (Transect 4, quadrat 1C) near to Dittisham Creek (Natural England 2013c).

Pacific oysters were found to be Common in abundance on the surface of sediments in Galmpton Creek (Natural England, 2013c). Natural England staff visited the upper estuary in 2016 and confirmed that this still appeared to be the case (Natural England 2018c).

Pacific oysters have been recorded more recently in the estuary in 2017, 2018 and 2019 (Bishop Group -Marine Biological Association, unpublished). In 2018 along the shore at Duncannon, Pacific oysters were found to be Frequent to Common, and at Greenway and Mill Point Abundant to Superabundant (SACFOR scale) (Bishop Group - Marine Biological Association, unpublished).

Exe Estuary

Pacific oysters were recorded on the Exe estuary at Cockwood and the Dawlish Warren oyster beds in 1985 during the Marine Nature Conservation Review surveys (National Biodiversity Network Atlas 2020, accessed 15/06/2020) and there are a few more recent records in the estuary from 2009 and 2014 (National Biodiversity Network Atlas 2020; Bishop Group - Marine Biological Association, unpublished).

Natural England staff have seen small numbers of individual adult Pacific oysters while undertaking mussel surveys on the western side of the estuary between Starcross and Cockwood in 2016 (Natural England, 2018c) and during a visit to Exmouth in 2017 (Natural England 2017g).

In 2017 Devon and Severn IFCA reported that the three mussel beds near Lympstone had a significant number of Pacific oysters present and in certain areas they could be considered an oyster bed (Devon & Severn IFCA 2017).

The Exe estuary Management Partnership conducted an initial scoping visit to Cockwood Foreshore on the 11th December 2019. A high number of Pacific oysters were observed during this survey and it was then decided that a detailed survey would be beneficial to gain more information. In February 2020 a more thorough survey of the area was conducted following the method used in Natural England's 2014-2015 survey. 33 quadrats were placed at 5m intervals across 165m of the shoreline. The total number of Pacific oysters recorded on this survey was 139 with an average of 4.2 individuals per $0.25m^2$. One case of cementation was also recorded, which could suggest that without management this area could start 'reefing'. Although only one survey has been conducted, the findings of this initial study show that there are substantial numbers of Pacific oysters in the Exe estuary. They hope to continue monitoring and managing this species to prevent further colonisation and habitat damage in the Exe (Boyle 2020).

Appendix 5: South Devon and Cornwall MPAs and their condition

This section accompanies Table 3 in Section 2.2, providing further information on south Devon and Cornwall MPAs, their features, their condition, and their potential to be impacted by Pacific oysters.

Mounts Bay

Mounts Bay is located in south west Cornwall. Mounts Bay Marine Conservation Zone (MCZ) covers an area of almost 12 km^2 and includes the area surrounding the iconic tidal island of St. Michael's Mount.

The site protects a range of habitats from moderate and high energy intertidal and subtidal rock to intertidal sand and muddy sand, intertidal coarse sediment, and subtidal sand. The range of habitats support a variety of life, which includes worms and bivalves living in soft sediments and sea snails, anemones, starfish, and sea squirts found on rocky shores. The designation protects the seagrass beds within the site which provide a food source for birds, and shelter and nursery areas for a range of fish and shellfish. The site also protects the rare giant goby which lives in the rockpools and three species of stalked jellyfish which are typically found attached to seaweed or seagrass. (Defra 2016a).

Condition:

All the intertidal features of Mounts Bay MCZ have the potential to be impacted by Pacific oysters.

A Condition Assessment has not yet been carried out for Mounts Bay MCZ. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time all the features were considered likely to be in favourable condition (Natural England & JNCC 2012 & Natural England 2016b).

Fal and Helford Estuaries

The Fal and Helford estuaries are located on the southern coast of west Cornwall. They are ria systems (drowned river valleys) which receive low freshwater input and therefore contain a notable range of fully marine habitats with a high diversity of species. These habitats are highly influenced by the degree of exposure of the site which varies greatly from extremely sheltered mudflats in the upper Fal to more exposed rocky coastal areas around the mouth of the Helford. The south-westerly location promotes warmer seawater temperatures which allow species to occur that are usually more southerly in their distribution. The area is protected through a variety of international and national designations including SAC, SPA, MCZ and a suite of SSSIs.

The **Fal and Helford SAC** covers both the Fal and Helford ria systems as well as Falmouth Bay. The site protects the estuary and large shallow inlets and bays as well as saltmarsh, intertidal mud and sand flats, reefs, subtidal sandbanks, and shore dock *Rumex rupestris*.

The majority of the shores of the upper Fal and Helford are fringed by sheltered intertidal sandflats and mudflats which are recognised for their important sediment dwelling species and communities. These mudflats and sandflats support a wide range of invertebrate and bird communities, which make a vital contribution to the structure and function of the Fal and Helford system.

In several areas of the upper reaches of the estuaries, Atlantic salt meadows are present. Salt meadow transition from mudflats through to woodland also occurs which is a rare occurrence in the UK.

Extensive beds of the unattached coralline red algae maerl *Lithothamnion corallioides* are present which support a high diversity of flora and fauna, including large numbers of thornback rays *Raja clavata*. These maerl beds are the most south-westerly examples in Britain. The seagrass *Zostera marina* is found in both the Fal and the Helford. These seagrass beds act as nursery areas for species such as bass *Dicentrarchus labrax*, and cuttlefish, and are also important habitats for a variety of other species. Intertidal seagrass beds *Zostera noltii* are also present in the Fal Ruan. The site supports a population of native oyster *Ostrea edulis*, which supports a traditional commercial fishery.

Both intertidal and subtidal rocky reef features are also present in the SAC. This includes circalittoral reef in Falmouth Bay which supports the nationally important pink sea fan *Eunicella verrucosa*. Other rocky habitats include highly productive kelp forest communities, estuarine reef, and littoral rocky shore communities (Natural England 2017a).

The **Falmouth Bay to St Austell Bay SPA** covers 25,898 ha of the marine environment incorporating five shallow, sandy bays: Falmouth Bay, Gerrans Bay, Veryan Bay, Mevagissey Bay and St Austell Bay. It also includes Carrick Roads, an estuarine area which meets the sea between Falmouth and St Mawes, and part of the tidal Helford river. The SPA protects three wintering diving bird species: Black-throated diver *Gavia arctica*, great northern diver *Gavia immer* and Slavonian grebe *Podiceps auritus* (Natural England 2019c).

The **Lower Fal and Helford Intertidal SSSI** protects both sheltered and exposed rocky shores as well as a range of sediment shore types. Consequently, these support a high diversity of biological communities and species of particular note. A number of species more typical of open coasts are able to penetrate into the lower reaches, contributing to the rich intertidal communities (Natural England 1997a).

Malpas Estuary SSSI has tidal mudflats as its major feature. These are feeding grounds for wildfowl and wading birds, including nationally important numbers of black-tailed godwit *Limosa limosa islandica*. The site also includes saltmarsh, adjoining ancient semi-natural woodland and a heronry (Natural England 1992).

The **Upper Fal Estuary and Woods SSSI** covers the upper reaches of the Fal estuary. The combination of extensive areas of tidal mudflats together with associated areas of saltmarsh combine to provide suitable winter feeding and roosting grounds for nationally important numbers of black-tailed godwit *Limosa limosa islandica*. An important transition from saltmarsh through carr to oak dominated woodlands is illustrated particularly well above Sett Bridge. There are few sites in Europe where such an integration occurs, and the Fal estuary is one of the least disturbed examples (Natural England 1996a).

Rosemullion SSSI protects exposed and moderately exposed rocky shores including their algal community at Rosemullion Head on the northern entrance of the Helford river inlet. The large rock pools are of national importance for their rich algal communities. An important feature of these is the abundance of seaweeds, particularly of several rare southern species (Natural England 1990a).

The Helford estuary is also designated as an MCZ. The **Helford Estuary MCZ** covers an area of approximately 6 km^2. The site is designated to specifically protect the native oyster *Ostrea edulis*. Native oysters are usually found in quite shallow water on mixed sediments. They attach to a substrate, usually an oyster shell, and remain immobile after settling. They filter food from the water around them and can live for as long as 20 years. Native oysters have been described as ecosystem engineers, providing both a habitat and a food source for a variety of species, and filtering seawater (Defra 2019a).

Condition

All the intertidal features of the SAC, SSSIs and MCZ have the potential to be impacted by Pacific oysters. The black-tailed Godwit (*Limosa limosa islandica*) protected within the Malpas Estuary and Upper Fal Estuary and Woods SSSIs has the potential to be impacted by Pacific oysters indirectly through loss of feeding habitat.

A Condition Assessment of the **Fal and Helford SAC** was completed in 2020 (Natural England 2018a & 2020b). All of the intertidal features and sub features were assessed apart from the feature Atlantic salt meadow *Glauco-Puccinellietalia maritimae*.

Currently 8% of the Estuaries feature is in favourable condition, with 88% in unfavourable condition and 4% not assessed. The assessment of unfavourable condition is in part due to the impact of Pacific oysters. The intertidal component of the Estuaries feature is comprised of four different sub features: Intertidal coarse sediment, Intertidal mixed sediment, Intertidal mud and Intertidal sand and muddy sand. Each of these sub features is currently in unfavourable condition for a variety of reasons which includes Infaunal Quality Index (IQI) scores, which indicate the feature is not in good condition and for water contaminants and nutrients. The IQI is the metric used to assess benthic infauna communities for Good Ecological Status for the Water Framework Directive (Prior and others 2004). However, three of these sub features - Intertidal mixed sediment, Intertidal mud and Intertidal sand and muddy sand - are also unfavourable due the presence of various invasive non-native species including Pacific oysters which have been recorded as Abundant.

The feature ‘Mudflats and sandflats not covered by seawater at low tide’ has 1% in favourable condition and 99% in unfavourable condition. The assessment of unfavourable condition is in part due to the impact of Pacific oysters. This feature is comprised of five different sub features: Intertidal seagrass beds, Intertidal coarse sediment, Intertidal mixed sediment, Intertidal mud, and Intertidal sand and muddy sand. The Intertidal seagrass beds are in favourable condition; however, the remaining sub features were assessed as being in unfavourable condition for the same reasons as those given under the Estuaries feature above. This means that the ‘Mudflats and sandflats not covered by seawater’ feature is also in part unfavourable due to the presence of Pacific oysters in the Intertidal mixed sediment, Intertidal mud and Intertidal sand and muddy sand sub features.

The condition of the feature ‘Large shallow inlets and bays’ is 20% favourable and 80% unfavourable. The assessment of unfavourable condition is in part due to the impacts of Pacific oysters. The intertidal component of this feature is comprised of three different sub features: Intertidal rock, Intertidal coarse sediment and Intertidal sand and muddy sand. Each of these sub features is in unfavourable condition. The Intertidal coarse sediment and Intertidal sand and muddy sand are in unfavourable condition for the same reasons as given under the Estuaries feature above, which includes the presence of Pacific oysters. The Intertidal rock is in unfavourable condition due to the presence of various invasive non-native species including Pacific oysters which have increased over time and can be found in high numbers, as well as water contaminants and nutrients.

The Reefs feature is 52% favourable and 48% unfavourable. The assessment of unfavourable condition is in part due to the impact of Pacific oysters. This feature only has one intertidal sub feature – Intertidal rock. As for the Large shallow inlets and bays feature, the Intertidal rock is unfavourable due the presence of invasive non-native species including Pacific oysters as well as water contaminants and nutrients.

None of the **SSSIs** underlying the SAC have had a Condition Assessment since 2010 and not all the features were assessed. At that time any intertidal features that were assessed were considered to be in favourable condition. **It is possible that the condition of some of these sites has changed since then, particularly given that during this study Pacific oysters have been recorded as Abundant or higher on the SACFOR scale within the Upper Fal and Helford Woods SSSI and Lower Fal and Helford Intertidal SSSI. There were no surveys in Malpas Estuary SSSI or Rosemullion SSSI as part of this study but again given the increase in Pacific oysters in the area it is possible that the condition of these sites has also changed.** As a result, the intertidal features of these SSSIs that could be potentially be affected by Pacific oysters have been listed in the table below noting that an updated Condition Assessment is required. Condition Assessments for these SSSIs are likely to reflect those of the Fal and Helford SAC.

A Condition Assessment has not yet been carried out for the **Helford Estuary MCZ** as this site was only designated in 2019. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether the native oyster was likely to be in unfavourable condition. Based on the available evidence at the time the native oyster *Ostrea edulis* was considered likely to be in unfavourable condition. This is due to the species' vulnerability to recreational anchoring and mooring which occurs in the area, along with historic Pacific oyster aquaculture activities in the site. Pacific oysters used to be relayed onto the seabed then transferred to trestles once they had reached a certain size (Natural England 2019d).

Summary of site features within the Fal and Helford estuaries and Falmouth Bay that could potentially be impacted by Pacific oysters, and their condition based on last assessment (Natural England: 2018a, 2019d; 2020b).

Marine Protected Area	Protected Feature	Condition of Feature (year assessed)	Subfeature	Last Assessed Condition of Subfeature (year assessed) and if due to Pacific oysters
Fal and Helford SAC	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)	n/a	n/a	Not Assessed
Fal and Helford SAC	Estuaries	Favourable 8% Unfavourable 88% Not Assessed 4% (2018 & 2020)	Intertidal coarse sediment	Unfavourable (2018): Structure: species composition of component communities – due to IQI; Water quality – contaminants; Water quality – nutrients
			Intertidal mixed sediment	Unfavourable (2020): Structure: species composition of component communities – due to IQI; Structure: non-native species and pathogens water – various INNS including **Pacific oysters**; Water quality – contaminants; Water quality – nutrients
			Intertidal mud	Unfavourable (2020): Structure: non-native species and pathogens water – various INNS including **Pacific oysters**;

				Water quality – contaminants; Water quality – nutrients
			Intertidal sand and muddy sand	Unfavourable (2020): Structure: species composition of component communities – due to IQI; Structure: non-native species and pathogens water – various INNS including **Pacific oysters**; Water quality – contaminants; Water quality – nutrients
Fal and Helford SAC	Mudflats and sandflats not covered by seawater at low tide	Favourable 1% Unfavourable 99% (2018 & 2020)	Intertidal seagrass beds	Favourable (2018)
			Intertidal coarse sediment	Unfavourable (2018) – As for Estuaries feature
			Intertidal mixed sediment	Unfavourable (2020) – As for Estuaries feature including **Pacific oysters**
			Intertidal mud	Unfavourable (2020) – As for Estuaries feature including **Pacific oysters**
			Intertidal sand and muddy sand	Unfavourable (2020) – As for Estuaries feature including **Pacific oysters**
Fal and Helford SAC		Favourable 20%	Intertidal rock	Unfavourable (2020): Structure: non-native species and pathogens water –

	Large shallow inlets and bays	Unfavourable 80% (2018 & 2020)		various INNS including **Pacific oysters**; Water quality – contaminants; Water quality – nutrients
			Intertidal coarse sediment	Unfavourable (2018) – As for Estuaries
			Intertidal sand and muddy sand	Unfavourable (2020) – As for Estuaries feature including **Pacific oysters**
Fal and Helford SAC	Reefs	Favourable 52% Unfavourable 48% (2020)	Intertidal rock	Unfavourable (2020): Structure: non-native species and pathogens water – various INNS including **Pacific oysters**; Water quality – contaminants; Water quality – nutrients

Marine Protected Area	**Protected Feature**	**Condition of Feature (year assessed) and if due to Pacific Oysters**
Lower Fal and Helford Intertidal SSSI	Exposed rocky shores (predominantly extremely exposed to wave action)	Updated Condition Assessment required
Lower Fal and Helford Intertidal SSSI	Moderately exposed rocky shores	Updated Condition Assessment required
Lower Fal and Helford Intertidal SSSI	Moderately exposed sandy shores (with polychaetes and bivalves)	Updated Condition Assessment required

Lower Fal and Helford Intertidal SSSI	Muddy gravel shores	Updated Condition Assessment required
Lower Fal and Helford Intertidal SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Lower Fal and Helford Intertidal SSSI	Sheltered rocky shores (predominately sheltered to very sheltered from wave action)	Updated Condition Assessment required
Lower Fal and Helford Intertidal SSSI	Shores of mixed substrata (stones AND sediment)	Updated Condition Assessment required
Rosemullion SSSI	Combinations of species - other groups (fungi and algae)	Updated Condition Assessment required
Rosemullion SSSI	Exposed rocky shores (predominantly extremely exposed to wave action)	Updated Condition Assessment required
Rosemullion SSSI	Moderately exposed rocky shores	Updated Condition Assessment required
Malpas Estuary SSSI	Aggregations of non-breeding birds - Black-tailed Godwit, *Limosa limosa islandica*	Updated Condition Assessment required
Malpas Estuary SSSI	Moderately exposed sandy shores (with polychaetes and bivalves)	Updated Condition Assessment required
Malpas Estuary SSSI	Muddy gravel shores	Updated Condition Assessment required

Malpas Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Malpas Estuary SSSI	Sheltered rocky shores (predominately sheltered to very sheltered from wave action)	Updated Condition Assessment required
Malpas Estuary SSSI	Shores of mixed substrata (stones AND sediment)	Updated Condition Assessment required
Malpas Estuary SSSI	Saltmarsh	Updated Condition Assessment required
Upper Fal Estuary and Woods SSSI	Aggregations of non-breeding birds - Black-tailed Godwit, *Limosa limosa islandica*	Updated Condition Assessment required
Upper Fal Estuary and Woods SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Upper Fal Estuary and Woods SSSI	Saltmarsh	Updated Condition Assessment required
Upper Fal Estuary and Woods SSSI	Vascular plant assemblage	Updated Condition Assessment required
Helford Estuary MCZ	Native oyster (*Ostrea edulis*)	Likely Unfavourable (risk based vulnerability assessment 2019) – Recreational anchoring and mooring, and **historic Pacific oyster aquaculture.** Condition Assessment required.

Fowey Estuary

The Fowey estuary is located on the southern Cornwall coast. The upper tidal reaches of the Fowey and the Pont Pill tributary are designated as the **Upper Fowey and Pont Pill MCZ**. The MCZ protects an area that is representative of the estuarine habitats found in the southwest. The site protects intertidal sediments, low energy rock habitats and coastal saltmarshes and saline reedbeds. Areas of estuarine rock are important as they contribute to the richness of life within estuaries by providing an alternative habitat to the sediment habitats that usually characterise estuarine environments (Defra 2016b).

Condition

All the features of Upper Fowey and Pont Pill MCZ have the potential to be impacted by Pacific oysters.

A condition assessment has not yet been carried out for Upper Fowey and Pont Pill MCZ. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time all the features were considered likely to be in favourable condition. (Natural England 2013a & 2016b). **It is possible that the condition of some of these features has changed since then, particularly given that during this study Pacific oysters have been recorded as Abundant or higher on the SACFOR scale immediately adjacent to the site boundary (see results section).**

Summary of site features that could potentially be impacted by Pacific oysters in Upper Fowey and Pont Pill MCZ and their last assessed condition based on the risk based vulnerability assessment carried out as part of the MCZ designation process (Natural England 2013a & 2016b).

Marine Protected Area	Protected Feature	Last Assessed Condition (risk based vulnerability assessment) (year)
Upper Fowey and Pont Pill MCZ	Intertidal coarse sediment	Likely Favourable (2013) – Condition Assessment required
Upper Fowey and Pont Pill MCZ	Intertidal mud	Likely Favourable (2013) – Condition Assessment required

Upper Fowey and Pont Pill MCZ	Low energy intertidal rock	Likely Favourable (2013) – Condition Assessment required
Upper Fowey and Pont Pill MCZ	Coastal saltmarshes and saline reedbeds	Likely Favourable (2013) – Condition Assessment required
Upper Fowey and Pont Pill MCZ	Estuarine rocky habitats	Likely Favourable (2013) – Condition Assessment required
Upper Fowey and Pont Pill MCZ	Sheltered muddy gravels	Likely Favourable (2013) – Condition Assessment required
Upper Fowey and Pont Pill MCZ	Intertidal sand and muddy sand	Likely Favourable (2016) – Condition Assessment required

Whitsand and Looe Bay

Whitsand and Looe Bay is located on the south coast of Cornwall and is designated as an MCZ. The **Whitsand and Looe Bay MCZ** extends from Hore Stone in the west to Rame Head in the east and covers 52km^2. Whitsand Bay is a 6 km stretch of sand and shingle with gullies that have been carved by strong tides and cross-currents. The site contains intertidal and subtidal sand and coarse sediment habitats, as well as intertidal rocky habitats.

The sediment communities support populations of bivalves and marine worms and provide habitats for fish and shellfish. There are extensive seagrass beds within the shallower part of the site. These provide nursery grounds for a variety of fish and shellfish. The ocean quahog *Arctica islandica* has been recorded within sediment habitats in the site.

The site’s intertidal rocky habitats are characterised by animals such as sponges, bryozoans, anemones, and sea squirts, and support a high diversity of seaweeds and invertebrates. The rocks around Hannafore in Looe Bay are especially rich in intertidal species. The rocky habitats also support commercially important species such as common lobster and edible crab, and the rare giant goby has been recorded in mid-shore rockpools within the site.

Further out to sea there are shipwrecks and areas of subtidal rocky reef that support pink sea-fans *Eunicella verrucosa* and rare sea-fan anemones, both of which are protected within the site.

Stalked jellyfish *Haliclystus* sp., *Calvadosia campanulata* and *Calvadosia cruxmelitensis* are also present within this MCZ (Defra 2019b; Natural England 2019e).

Condition

All the intertidal features of Whitsand and Looe Bay MCZ have the potential to be impacted by Pacific oysters.

A Condition Assessment has not yet been carried out for Whitsand and Looe Bay MCZ. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time all the intertidal features were considered to be in favourable condition. (Natural England and JNCC 2012, Natural England 2013a & 2019d).

A baseline monitoring survey of the intertidal rocky habitats undertaken in 2019 by Ecospan for Natural England (Field 2020) suggests that the condition target for invasive non-native species is not likely to be met due to the presence of Pacific oysters and non-native pom-pom weed *Caulacanthus okamurae*. In addition, walkover surveys from this study (see results section) suggest that Pacific oysters are Abundant around Freathy in Whitsand Bay. The condition of some of the intertidal features may therefore change when a Condition Assessment is carried out.

Summary of site features that could potentially be impacted by Pacific oysters in Whitsand and Looe Bay MCZ and their last assessed condition based on the risk based vulnerability assessment carried out as part of the MCZ designation process (Natural England and JNCC 2012, Natural England 2013a & 2019d).

Marine Protected Area	Protected Feature	Last Assessed Condition (risk based vulnerability assessment) (year)
Whitsand and Looe Bay MCZ	Intertidal coarse sediment	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	Intertidal sand and muddy sand	Likely Favourable (2013) – Condition Assessment required

Whitsand and Looe Bay MCZ	Low energy intertidal rock	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	Moderate energy intertidal rock	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	High energy intertidal rock	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	Seagrass beds	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	Stalked jellyfish (Haliclystus auricular)	Likely Favourable (2013) – Condition Assessment required
Whitsand and Looe Bay MCZ	Stalked jellyfish (Calvadosia campanulata)	Likely Favourable (2019) – Condition Assessment required
Whitsand and Looe Bay MCZ	Stalked jellyfish (Calcadosia cruxmelitensis)	Likely Favourable (2019) – Condition Assessment required
Whitsand and Looe Bay MCZ	Giant goby (Gobius cobitis)	Likely Favourable (2019) – Condition Assessment required

Plymouth and the Yealm Estuary

Plymouth Sound and its estuaries straddle the border between Devon and Cornwall. The area is a complex site of marine inlets made up of Plymouth Sound and its associated tributaries of the Lynher, Tamar, Tavy, Plym and the Yealm. The area is protected through a variety of international and national designations including SAC, SPA, MCZ and a suite of SSSIs.

The high diversity of reef and sedimentary habitats, and salinity conditions, give rise to diverse communities representative of ria systems. The extensive mudflats are highly productive and form a critical part of the food chain providing important feeding grounds for internationally important numbers of wildfowl. Extensive areas of saltmarsh are present, particularly on the Lynher estuary. The area is especially important for its reef communities, being one of the best areas in the UK, and is one of two sites in the south west with limestone reef. Intertidal reefs with rockpools at Wembury, Penlee, Hooe Lake Point and the mouth of the Yealm support a nationally uncommon sponge, seasquirt and red algae community. The intertidal underboulder communities at Jennycliff are of note for their species richness (Natural England 2017b).

Plymouth Sound and Estuaries SAC covers the whole of the sound and estuaries complex. Intertidally it protects Atlantic salt meadows, mudflats and sandflats not covered by seawater at low tide, and reefs, as well as the large shallow inlets and bays. The site also protects the only population of the Allis shad *Alosa alosa* in the UK as well as shore dock *Rumex rupestris* (Joint Nature Conservation Committee 2016).

The Tamar Estuaries Complex SPA covers the upper parts of St John’s Lake and the Lynher, Tamar and Tavy estuaries. The extensive intertidal mudflat communities, areas of mixed muddy sediment communities and saltmarsh communities provide important feeding and roosting areas for the over wintering avocet *Recurvirostra avosetta* and little egret *Egretta garzetta* which the site protects. In addition to the designated features the SPA is of importance within Britain and the EU for a range of wildfowl and wader species with peak mean numbers at designation of more than 11,000 overwintering waterfowl (Natural England 2017c).

A suite of SSSIs protect a range of intertidal habitats and species, including several bird species that use these areas.

Unusually for a ria system, the **Lynher Estuary SSSI** has developed extensive areas of saltmarsh particularly on its northern shores. The SSSI protects this along with the sheltered muddy shores which provide important feeding and roosting grounds for large populations of wintering waterfowl and waders including black-tailed godwit *Limosa limosa islandica* and wigeon *Anas Penelope* (Natural England 1987a).

Intertidally **Plymouth Sound Shores and Cliffs SSSI** protects exposed and moderately exposed rocky shores and areas of stone mixed with sediment found throughout. The site contains examples from open coast to sheltered bays and communities with southwest influence (Natural England 1997b).

Rame Head & Whitsand Bay SSSI is important for shore dock *Rumex rupestris* and other rare plants, and protects the coastal geomorphology of the area (Natural England 1996b).

St. John's Lake SSSI has extensive mud flats at low tide which are important feeding grounds for the >20,000 non-breeding waterbirds that can be found there in the winter. The site also specifically protects a nationally important population of wintering black-tailed godwit *Limosa limosa islandica*. The saltmarsh here contains a strong population of sea purslane *Halimione portulacoides* and beds of eelgrass *Zostera marina* and dwarf eel grass *Zostera noltii* can be found here (Natural England 1986a).

The **Tamar-Tavy Estuary SSSI** supports the upper reaches of this system and supports a nationally important wintering population of the avocet *Recurvirostra avosetta*. Saltmarsh communities border the extensive mudflats (Natural England 1991).

Wembury Point SSSI comprises extensive reefs of interest for their intertidal plant and animal communities together with coastal sand, shingle and steep slopes of sea-cliff grassland and mixed scrub. Intertidally the reefs and shores comprised of stone and sediment are protected, and these support a wide variety of plant and animal species and communities, including southern species of seaweeds (Natural England 1984a).

The **Yealm Estuary SSSI** is a steep sided and narrow inlet with several tributaries. These contain rocky shores with a range of exposure from 'exposed' to 'sheltered' as well as muddy, mixed, and sandy shores and their differing communities (Natural England 1997c).

In 2013 the upper reaches of the Tamar, Tavy and Lynher estuaries were designated as the **Tamar Estuary Sites MCZ**. The MCZ protects smelt *Osmerus eperlanus* which breed in the Tamar. Blue mussel *Mytilus edulis* beds form living reefs which provide a home or refuge for seaweed and animals such as barnacles, winkles, and small crabs. Intertidal coarse sediments are protected as well as the native oyster *Ostrea edulis* which declined significantly in the 20^{th} century (Defra 2013).

Condition

All the intertidal features of the SAC and SSSIs have the potential to be impacted by Pacific oysters. The estuarine bird species protected within the SPA and various SSSIs also have the potential to be impacted by Pacific oysters indirectly through loss of feeding habitat.

A Condition Assessment of **Plymouth Sound and Estuaries SAC** was completed in 2018 (Natural England 2018b). All of the intertidal features and sub features were assessed apart from the feature Atlantic salt meadow *Glauco-Puccinellietalia maritimae*.

At the most recent Condition Assessment 60% of the Estuaries feature was in favourable condition with 32% in unfavourable condition and 8% not assessed. This is in part due to the impact of Pacific oysters. The intertidal component of the Estuaries feature is comprised of four sub features: Intertidal mixed sediments, Intertidal mud, Intertidal rock and Intertidal seagrass beds. Each of these sub features is currently in unfavourable condition.

The Intertidal rock was unfavourable due Pacific oysters impacting the presence and spatial distribution of its biological communities, the presence of various invasive non-native species including Pacific oysters, and water contaminants. Increased presence of Pacific oysters, which have formed Pacific oyster reefs on the feature, has led to a total of 18.72 Ha (12%) of the Intertidal rock sub feature being assessed as unfavourable.

The remaining sub features were all in unfavourable condition for a variety of reasons including Infaunal Quality Index (IQI) scores, which indicate the feature is not in good condition, or sediment and water contaminants, and in the case of Intertidal seagrass beds the presence of macroalgae. The IQI is the metric used to assess benthic infauna communities for Good Ecological Status for the Water Framework Directive (Prior and others 2004). **The targets for these three sub features have recently been reviewed in the Conservation Advice Package for the site and three targets have been set to Restore to favourable condition due to the presence of Pacific oysters (Natural England 2020c). These are Distribution: presence and spatial distribution of biological communities; Structure: non-native species and pathogens and Structure: species composition of component communities. This may lead to a change in factors contributing to the unfavourable condition status of these features when they next undergo a Condition Assessment.**

The feature 'Mudflats and sandflats not covered by seawater at low tide' was last assessed as 95% favourable and 5% in unfavourable. This feature is comprised of five sub features: Intertidal mixed sediments, Intertidal coarse sediment, Intertidal mud, Intertidal sand and muddy sand, and Intertidal seagrass beds. The Intertidal coarse sediment, Intertidal mud and Intertidal sand and muddy sand sub features are in favourable condition. The Intertidal mixed sediments and Intertidal seagrass beds are in unfavourable condition for the same reasons as those given under the Estuaries feature in the table below. **As for the Estuaries feature, the targets in the Conservation Advice Package for these two sub features and the Intertidal mud have been updated acknowledging the presence of Pacific oysters. This may lead to a change in condition, or the factors contributing to unfavourable condition status, when they are next assessed.**

The 'Large shallow inlets and bays' feature which covers the Plymouth Sound area is 35% favourable, 47% unfavourable and 18% not assessed. This feature only has one intertidal sub feature, Intertidal rock, which is currently in favourable condition.

The Reefs feature is 99% favourable and 1% unfavourable. This is in part due to the impact of Pacific oysters. This feature only has one intertidal sub feature – Intertidal rock. The Intertidal rock is in unfavourable condition for the same reasons as those given under the Estuaries feature in the table below.

In the **Tamar Estuaries Complex SPA** there are two features that depend on the intertidal environment, little egret *Egretta garzetta* and the avocet *Recurvirostra avosetta*. Both of these features are considered to be in favourable condition. Although a Condition Assessment has not yet been completed for the site we have used the proxy assessment that was undertaken for the production of the site's Conservation Advice Package in 2017 here (Natural England 2017c).

Most of the **SSSI** features that have the potential to be impacted by Pacific oysters have either not been assessed or were last assessed in 2010. Since then **it is clear from the Condition Assessment for the SAC that there have been changes particularly with regard to the densities of Pacific oysters in the area and it is therefore likely that the condition of these sites has changed.** As a result, the intertidal features of these SSSIs that could potentially be affected by Pacific oysters have been listed in the Plymouth Sounds and Estuaries SAC site feature table, noting that an updated Condition Assessment is required. Condition Assessments for these SSSIs are likely to reflect those of the Plymouth Sound and Estuaries SAC.

In the **Lynher Estuary SSSI** intertidal and bird features that could be potentially impacted by Pacific oysters have either not been assessed or require an updated Condition Assessment. All the intertidal features of the **Plymouth Sound Shores and Cliffs SSSI** require an updated Condition Assessment.

In **St. John's Lake SSSI** two bird features could potentially be impacted by Pacific oysters affecting their feeding habitat, >20,000 Non-breeding waterbirds and Aggregations of non-breeding birds – Black-tailed Godwit, *Limosa limosa islandica*, as well as the Saltmarsh and *Zostera* communities features. The >20,000 Non-breeding waterbirds and saltmarsh were assessed as favourable in 2014 (Natural England 2014a). In 2017 the *Zostera* communities were due to the presence of macroalgae. The black-tailed godwit was also assessed as unfavourable as the wintering population had declined by 66% compared to the baseline population level, however the cause for this is unknown (Natural England 2017d).

Saltmarsh is the only intertidal feature in the **Tamar-Tavy Estuary SSSI,** and this was assessed as favourable in 2014 (Natural England 2014b). The feature Aggregations of non-breeding birds – avocet *Recurvirostra avosetta* also has the potential to be impacted by Pacific oysters affecting their feeding habitat. This feature has not been assessed.

Wembury Point SSSI has two intertidal features: Reefs, and Shores of mixed substrata (stones AND sediment). These both require an updated Condition Assessment.

All the features of the **Yealm Estuary SSSI** are intertidal and they were found to be in unfavourable condition in 2016 due to the presence of Pacific oysters. These are: Reefs, Shores of mixed substrata (stones AND sediment), Exposed rocky shores (predominantly extremely exposed to wave action), Moderately exposed rocky shores, Moderately exposed sandy shores (with polychaetes and bivalves), Muddy gravel shores, Sheltered muddy shores (including estuarine muds), Sheltered rocky shores (predominately sheltered to very sheltered from wave action) and Shores of mixed substrata (stones AND sediment). Pacific oysters were found to be spreading abundantly across these habitats, and in these areas changing the communities (biotopes) that are present (Natural England 2016c).

A Condition Assessment has not yet been carried out for the **Tamar Estuaries Sites MCZ**. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time the blue mussel beds *Mytilus edulis*, Intertidal biogenic reefs and Intertidal coarse sediment were considered likely to be in favourable condition (Natural England 2013a). The native oyster *Ostrea edulis* was considered to be likely to be in unfavourable condition due to exposure to industrial and agricultural discharges (Natural England & JNCC 2012; Natural England 2013a).

Summary of site features that could potentially be impacted by Pacific oysters in Plymouth and the Yealm and condition based on last assessment (Natural England & JNCC 2012, Natural England 2013a, 2014a&b, 2016c, 2018b, 2020c)

Marine Protected Area	Protected Feature	Condition of Feature (year assessed)	Subfeature	Last Assessed Condition of Subfeature (year assessed) and if due to Pacific Oysters
Plymouth Sound and Estuaries SAC	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)			Not assessed
Plymouth Sound and	Estuaries	Favourable 60%	Intertidal mixed sediments	Unfavourable (2018): Structure: species composition

Estuaries SAC		Unfavourable 32% Not assessed 8%		of component communities – due to IQI; Supporting processes: sediment contaminants. Updated Condition Assessment required*.
			Intertidal mud	Unfavourable (2018): Supporting processes: sediment contaminants; Supporting processes: water quality – contaminants. Updated Condition Assessment required*.
			Intertidal rock	Unfavourable (2018): Distribution: presence and spatial distribution of biological communities – due to **Pacific oysters**; Structure: non-native species and pathogens water – various INNS including **Pacific oysters;** Supporting processes: water quality – contaminants.
			Intertidal seagrass beds	Unfavourable (2018): Sediment contaminants and macroalgae. Updated Condition

				Assessment required*.
Plymouth Sound and Estuaries SAC	Mudflats and sandflats not covered by seawater at low tide	Favourable 95% Unfavourable 5%	Intertidal mixed sediments	Unfavourable (2018) – As for Estuaries feature. Updated Condition Assessment required*.
			Intertidal coarse sediment	Favourable (2018)
			Intertidal mud	Favourable (2018). Updated Condition Assessment required*.
			Intertidal sand and muddy sand	Favourable (2018)
			Intertidal seagrass beds	Unfavourable (2018) – As for Estuaries feature
Plymouth Sound and Estuaries SAC	Large shallow inlets and bays	Favourable 35% Unfavourable 47% Not assessed 18%	Intertidal rock	Favourable (2018)
Plymouth Sound and Estuaries SAC	Reefs	Favourable 99% Unfavourable 1%	Intertidal rock	Unfavourable (2018) – As for Estuaries feature including **Pacific oysters**
Tamar Estuaries	Avocet (*Recurvirostra*			Favourable (2017) – based on proxy assessment completed for

Complex SPA	*avosetta*), Non-breeding			Conservation Advice Package
Tamar Estuaries Complex SPA	Little egret (*Egretta garzetta*), Non-breeding			Favourable (2017) – based on proxy assessment completed for Conservation Advice Package
Start Point to Plymouth Sound and Eddystone SAC	Reefs	Not assessed	Infralittoral reef	Not assessed
			Circalittoral reef	Not assessed

Marine Protected Area	Protected Feature	Last Assessed Condition of Feature (year assessed) and if due to Pacific Oysters
Lynher Estuary SSSI	Aggregations of non-breeding birds - Black-tailed Godwit, *Limosa limosa islandica*	Not assessed
Lynher Estuary SSSI	Aggregations of non-breeding birds - Wigeon, *Anas Penelope*	Not assessed
Lynher Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Lynher Estuary SSSI	Saltmarsh	Updated Condition Assessment required
Plymouth Sound Shores and Cliffs SSSI	Exposed rocky shores (predominantly extremely exposed to wave action)	Updated Condition Assessment required
Plymouth Sound	Moderately exposed rocky shores	Updated Condition Assessment required

Shores and Cliffs SSSI		
Plymouth Sound Shores and Cliffs SSSI	Shores of mixed substrata (stones AND sediment)	Updated Condition Assessment required
St. John's Lake SSSI	>20,000 Non-breeding waterbirds	Favourable (2014)
St. John's Lake SSSI	Aggregations of non-breeding birds - Black-tailed Godwit, *Limosa limosa islandica*	Unfavourable (2017) – unknown reason
St. John's Lake SSSI	Zostera communities	Unfavourable (2017) – macroalgae
St. John's Lake SSSI	Saltmarsh	Favourable (2014)
The Tamar-Tavy Estuary SSSI	Aggregations of non-breeding birds - Avocet, *Recurvirostra avosetta*	Not assessed
The Tamar-Tavy Estuary SSSI	Saltmarsh	Favourable (2014)
Wembury Point SSSI	Reefs	Updated Condition Assessment required
Wembury Point SSSI	Shores of mixed substrata (stones AND sediment)	Updated Condition Assessment required
Yealm Estuary SSSI	Exposed rocky shores (predominantly extremely exposed to wave action)	Unfavourable (2016) – due to **Pacific oysters**
Yealm Estuary SSSI	Moderately exposed rocky shores	Unfavourable (2016) – due to **Pacific oysters**

Yealm Estuary SSSI	Moderately exposed sandy shores (with polychaetes and bivalves)	Unfavourable (2016) – due to **Pacific oysters**
Yealm Estuary SSSI	Muddy gravel shores	Unfavourable (2016) – due to **Pacific oysters**
Yealm Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Unfavourable (2016) – due to **Pacific oysters**
Yealm Estuary SSSI	Sheltered rocky shores (predominately sheltered to very sheltered from wave action)	Unfavourable (2016) – due to **Pacific oysters**
Yealm Estuary SSSI	Shores of mixed substrata (stones AND sediment)	Unfavourable (2016) – due to **Pacific oysters**
Tamar Estuaries Sites MCZ	Blue mussel (*Mytilus edulis*) beds	Likely Favourable (risk based vulnerability assessment 2013)
Tamar Estuaries Sites MCZ	Intertidal biogenic reefs	Likely Favourable (risk based vulnerability assessment 2013)
Tamar Estuaries Sites MCZ	Intertidal coarse sediment	Likely Favourable (risk based vulnerability assessment 2013)
Tamar Estuaries Sites MCZ	Native oyster (*Ostrea edulis*)	Likely Unfavourable (risk based vulnerability assessment 2013) – due to exposure to industrial and agricultural discharges

*Conservation Advice Package targets have recently been updated which may lead to the addition of Pacific oysters as a reason for unfavourable condition once an updated Condition Assessment is complete.

Erme Estuary

The Erme estuary is a small secluded estuary on the south Devon coast. The estuary is designated as a SSSI and MCZ.

The **Erme Estuary SSSI** contains fine examples of estuarine, saltmarsh, freshwater and oak-hazel woodland habitats and supports an important breeding bird community (Natural England, 1986b). Intertidally the SSSI designation protects moderately exposed sandy shores, sheltered muddy shores and saltmarsh communities (Natural England, 2010a).

The estuary was designated as an MCZ in 2019. The **Erme Estuary MCZ** is approximately 1km^2 and covers the whole of the estuary from the sea to the tidal limit near the village of Ermington. It contains a wide variety of habitats from rocky shores to intertidal mud flats. The MCZ designation protects a range of rock and sediment habitats that are not protected under the SSSI designation, as well as the scarce tentacled lagoon worm *Alkmaria romijni*. High and moderate energy intertidal rock are found at the mouth of the river. These exposed rocks are pounded by waves and currents washing away sand and mud leaving only bedrock or boulders. Mussels, limpets, and barnacles can be found clinging to the rocks with patches of brown and red seaweeds growing in the crevices and on the landward side of the rocks. Low energy intertidal rock at the mouth of the river and estuarine rocky habitats found within the estuary itself provide a hard surface for algae and animals to attach in an area dominated by sand and mud with variable salinity. At low tide these areas become foraging grounds for birds and crustaceans, and at high tide they create shelter for juvenile species of fish. Intertidal mixed sediments, sheltered muddy gravels and intertidal coarse sediment are also protected. These habitats support a large number of important species including several that are rare (Defra, 2019c).

Condition

All the intertidal features of the Erme Estuary SSSI and all the features of the Erme Estuary MCZ have the potential to be impacted by Pacific oysters.

The saltmarsh communities within the **Erme Estuary SSSI** were considered to be in favourable condition when they were last assessed in 2009 and an updated Condition Assessment is required (Natural England 2009). The moderately exposed sandy shores and sheltered muddy shores features of the SSSI have not yet been assessed.

A condition assessment has not yet been carried out for the **Erme Estuary MCZ** as it was only recently designated. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time all the features except for intertidal coarse sediment were considered to be in favourable condition. The condition of the Intertidal coarse sediment was assessed as unfavourable using direct condition evidence. However, this was based on the latest Infaunal Quality Index (IQI) data with the feature being classified as 'poor' under the Water Framework Directive (WFD) which indicated that the feature was not in 'good' ecological condition, rather than from any impacts relating to Pacific oysters (Natural England, 2019d).

Summary of site features in the Erme estuary that could potentially be impacted by Pacific oysters and their last assessed condition (Natural England 2009 & 2019d).

Marine Protected Area	Protected Feature	Last Assessed Condition (year assessed)
Erme Estuary SSSI	Moderately exposed sandy shores (with polychaetes and bivalves)	Not assessed
Erme Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Not assessed
Erme Estuary SSSI	Saltmarsh	Updated Condition Assessment required
Erme Estuary MCZ	Estuarine rocky habitats	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	High energy intertidal rock	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	Intertidal mixed sediments	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	Low energy intertidal rock	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	Moderate energy intertidal rock	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	Sheltered muddy gravels	Likely Favourable (2019)* – Condition Assessment required

Erme Estuary MCZ	Tentacled lagoon-worm (*Alkmaria romijni*)	Likely Favourable (2019)* – Condition Assessment required
Erme Estuary MCZ	Intertidal coarse sediment	Unfavourable (2019) – due to IQI

*Based on risk based vulnerability assessment carried out during the MCZ designation process

Avon Estuary

The Avon estuary is narrow meandering drowned river valley on the south Devon coast that is sandy in its lower reaches and grades into intertidal mud further up the estuary. It was designated as the **Devon Avon Estuary MCZ** in 2019. The MCZ covers an area of 2km^2 and includes the whole of the estuary from the mouth of the estuary to the tidal weir at Aveton Gifford. The MCZ designation protects a range of rock and sediment habitats as well as saltmarsh and the scarce tentacled lagoon worm *Alkmaria romijni*. Moderate energy rock can be found at the mouth of the estuary as semi-exposed rock platforms with rockpool, boulder and overhang communities. Intertidal sand and muddy sand can be found at the mouth of the estuary. The sediments become muddier towards the upper third of the estuary where they provide a habitat for crustaceans and molluscs, a nursery area for fish and feeding grounds for birds (Defra, 2019d).

Condition

All the intertidal features of the Devon Avon Estuary MCZ have the potential to be impacted by Pacific oysters.

A condition assessment has not yet been carried out for the **Devon Avon Estuary MCZ** as it was only recently designated. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time all the features were considered likely to be in favourable condition (Natural England, 2019d).

Summary of site features that could potentially be impacted by Pacific oysters in the Devon Avon MCZ and their last assessed condition based on the risk based vulnerability assessment carried out as part of the MCZ designation process (Natural England 2019d).

Marine Protected Area	Protected Feature	Last Assessed Condition (risked based vulnerability assessment 2019)
Devon Avon Estuary MCZ	Coastal saltmarshes and saline reedbeds	Likely Favourable – Condition Assessment required
Devon Avon Estuary MCZ	Intertidal mud	Likely Favourable – Condition Assessment required
Devon Avon Estuary MCZ	Intertidal sand and muddy sand	Likely Favourable – Condition Assessment required
Devon Avon Estuary MCZ	Moderate energy intertidal rock	Likely Favourable – Condition Assessment required
Devon Avon Estuary MCZ	Tentacled lagoon worm (*Alkmaria romijni)*	Likely Favourable – Condition Assessment required

Salcombe to Kingsbridge Estuary

The Salcombe to Kingsbridge estuary is a medium sized estuary on the south Devon Coast and is designated as a SSSI. The **Salcombe to Kingsbridge Estuary SSSI** has very rich and diverse intertidal and subtidal flora and invertebrate fauna, with certain communities that are outstanding examples of their type in the North-east Atlantic. The SSSI covers both the intertidal and subtidal zones. The drowned river valley (a dendritic ria) is partially separated from the sea by a submerged sand bar. The streams flowing into the estuary are small, therefore marine conditions prevail over most of the estuary and as a result many truly marine plants and animals are found that rarely occur intertidally in estuaries elsewhere. The upper estuary contains soft sediments that are sheltered from wave action allowing exceptionally diverse invertebrate faunas to develop, particularly around the Saltstone. Extensive areas of *Zostera marina* are found within the lower estuary at and below the mean low water line, and *Zostera noltii* within the mid to upper estuary, intertidally below ca. 3m BCD. The rocky shores support typical communities found at the mouth of sheltered estuaries but are particularly rich in marine algae. Small areas of saltmarsh occur at the heads of the creeks. The estuary is also used as an overwintering ground by wildfowl such as Wigeon, Teal and Shelduck, and is an important feeding ground for passage waders (Natural England 1987b).

Condition

All the intertidal features of the Salcombe to Kingsbridge Estuary SSSI have the potential to be impacted by Pacific oysters.

The sheltered rocky shores within the Salcombe to Kingsbridge Estuary SSSI were considered to be in favourable condition when they were last assessed in 2010. The *Zostera* communities and saltmarsh features of the SSSI have not yet been assessed. The sheltered muddy shores were assessed as being in unfavourable condition in 2010. However, this was due to an impoverished infauna and seasonal algal blooms rather than from any impacts relating to Pacific oysters (Natural England 2010b). **Given that this project has highlighted that Pacific oysters have begun to form reefs in the intertidal seagrass at Collapit Creek the condition of the features within this SSSI may have changed and an updated Condition Assessment is required.**

Summary of features in Salcombe to Kingsbridge Estuary SSSI that could potentially be impacted by Pacific oysters, and their last assessed condition (Natural England 2010b).

Marine Protected Area	Protected Feature	Last Assessed Condition (year assessed)
Salcombe to Kingsbridge Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Updated condition assessment required
Salcombe to Kingsbridge Estuary SSSI	Sheltered rocky shores (predominately sheltered to very sheltered from wave action)	Updated condition assessment required
Salcombe to Kingsbridge Estuary SSSI	*Zostera* communities	Not assessed
Salcombe to Kingsbridge Estuary SSSI	Saltmarsh	Not assessed

Dart Estuary

The Dart estuary is found in south east Devon and consists of large areas of intertidal mud. The river Dart drains into Lyme Bay. The upper estuary down to the Anchor Stone just south of Dittisham was designated as an MCZ in 2019 and covers an area of approximately 5km^2.

The **Dart Estuary MCZ** protects a range of rock and sediment habitats as well as saltmarsh and the nationally scarce tentacled lagoon worm *Alkmaria romijni*. Low energy intertidal rock and estuarine rocky habitats are found along the fringes of the estuary and provide a hard surface for animals and seaweeds to attach themselves to. These habitats create important foraging areas for crustaceans and birds at low tide as well as foraging areas and a refuge for juvenile fish at high tide. The expansive areas of intertidal mud are highly productive and provide feeding and resting grounds for wading and migratory birds. The tentacled lagoon worm *Alkmaria romijni* can be found living in tubes it creates within the mud. Saltmarsh and saline reed beds are found at the upper end of the estuary (Defra 2019e).

Condition

All the intertidal features of the Dart Estuary MCZ have the potential to be impacted by Pacific oysters.

A condition assessment has not yet been carried out for the **Dart Estuary MCZ** as it was only recently designated. However, as part of the designation process a risk based vulnerability assessment was carried out to determine whether any of the features to be protected were likely to be in unfavourable condition. Based on the available evidence at the time coastal saltmarshes and saline reedbeds were considered likely to be in favourable condition. The condition of the intertidal mud was assessed as unfavourable using direct condition evidence. This was based on the latest Infaunal Quality Index (IQI) data with the feature being classified as ‘moderate’ under the Water Framework Directive (WFD) which indicated that the feature was not in ‘good’ ecological condition. Estuarine rocky habitats and low energy intertidal rock were assessed as likely to be in unfavourable condition due to the presence of Pacific oysters on these features (Natural England 2016b & 2019d).

Summary of site features that could potentially be impacted by Pacific oysters in the Dart Estuary MCZ and their last assessed condition based on the risk based vulnerability assessment carried out as part of the MCZ designation process (Natural England 2016b & 2019d).

Marine Protected Area	Protected Feature	Last Assessed Condition (risk based vulnerability assessment 2019) and if due to Pacific oysters
Dart Estuary MCZ	Coastal saltmarshes and saline reedbeds	Likely Favourable – Condition Assessment required
Dart Estuary MCZ	Tentacled lagoon-worm (*Alkmaria romijni*)	Likely Favourable – Condition Assessment required
Dart Estuary MCZ	Estuarine rocky habitats	Likely Unfavourable – due to **Pacific oysters.** Condition Assessment required.
Dart Estuary MCZ	Intertidal mud	Unfavourable (2019) – due to IQI
Dart Estuary MCZ	Low energy intertidal rock	Likely Unfavourable) – due to **Pacific oysters.** Condition Assessment required.

Exe Estuary

The Exe estuary is located on the south Devon coast. The Exe estuary is a ria or drowned river valley sheltered from the open sea by the Dawlish Warren sand spit across the mouth of the estuary (Natural England 2016d). The estuary is designated as an SPA, Ramsar and SSSI, and Dawlish Warren is also designated as a SSSI and SAC.

The **Exe Estuary SPA** extends 10 km south from Exeter city on the river Exe to the open sea beyond Dawlish Warren. It encompasses the coastal and offshore waters, intertidal mudflat and sandflats, low lying land and marshes, and the beaches and dunes of Dawlish Warren. The SPA protects a range of non-breeding waders as well as the Slavonia grebe and the overall non-breeding waterbird assemblage. The intertidal mud and sandflats support seagrass *Zostera* beds, a supporting habitat for the birds, as well as *Ulva* species. These enhance the abundance and diversity of food items for site's interest features. The blue mussel *Mytilus edulis* beds including those on the harder substrates of the lower estuary are also available as intertidal prey items for wading birds such as oystercatcher. The saltmarsh communities and surrounding grazing marshes provide feeding and roosting areas for wildfowl and waders, particularly for the dark-bellied brent goose, avocet, and black-tailed godwit (Natural England 2016d).

The estuary is also designated as a Ramsar site which means that it is a wetland of international importance. It supports >20,000 overwintering waterfowl and overwintering avocet *Recurvirostra avosetta* as well as black-tailed godwit *Limosa limosa islandica* (Joint Nature Conservation Committee 1992).

The **Exe Estuary SSSI** is of international importance for wintering and migratory birds and of national importance for its marine life, especially that associated with intertidal sand and mud flats. The site is also designated for its breeding birds and an outstanding dragonfly assemblage. Intertidally the SSSI protects sheltered muddy shores and saltmarsh communities. These in turn support various species of overwintering birds and the assemblage of breeding birds that are also protected (Natural England 1986c).

Dawlish Warren is a geomorphologically important sand spit that protects the mouth of the Exe. It is an area of international importance for several species of wildfowl and wading birds. Dawlish Warren is designated as a SAC and SSSI. **Dawlish Warren SAC** protects the sand dunes and Petalwort *Petalophyllum ralfsii* - a thaloid liverwort (Joint Nature Conservation Committee 2015). Dawlish Warren SSSI protects nonbreeding waterbirds, various vascular plants and insects, saltmarsh, and muddy shores, as well as the coastal geomorphology (Natural England 1984b).

Condition

The wading estuarine bird species protected within the SPA and various SSSIs have the potential to be impacted by Pacific oysters indirectly through loss of feeding habitat. All the intertidal features of the SSSIs have the potential to be impacted by Pacific oysters.

The **Exe estuary SPA** has six wading bird features that utilise the intertidal environment to feed. These are: Avocet, *Recurvirostra avosetta*, black-tailed godwit *Limosa limosa islandica*, Dark-bellied Brent goose *Branta bernicla bernicla*, Dunlin *Calidris alpina alpine*, Grey plover *Pluvialis squatarola*, Oystercatcher *Haematopus ostralegus* and the Waterbird assemblage. A Condition Assessment has not yet been carried out for the Exe Estuary SPA however we have used the proxy assessment that was undertaken for the production of the site's Conservation Advice Package in 2019 here (Natural England 2019f). Avocet *Recurvirostra avosetta*, black-tailed godwit *Limosa limosa islandica*, dunlin *Calidris alpina alpine* and grey plover *Pluvialis squatarola* are considered to be in favourable condition. Dark-bellied Brent goose *Branta bernicla bernicla*, are unfavourable due to their population decline and recreational disturbance. Oystercatcher *Haematopus ostralegus* are unfavourable due to their population decline, recreational disturbance, and the availability of mussels, a key prey item. The waterbird assemblage is also considered to be in unfavourable condition due to recreational disturbance.

All the intertidal and non-breeding bird features that utilise the estuarine environment to feed in the **Exe Estuary SSSI** and **Dawlish Warren SSSI** have the potential to be impacted by Pacific oysters. These were last assessed in 2010. **Since then densities of Pacific oysters in the area may have increased. Data submitted to us and detailed in this report shows that Pacific oysters are Abundant at Cockwood, therefore the condition of these sites and features may have changed.** As a result, these features have been listed in Table 12 noting that an updated Condition Assessment is required.

Summary of site features in the Exe estuary that could potentially be impacted by Pacific oysters and last assessed condition (Natural England 2019f).

Marine Protected Area	Protected Feature	Last Assessed Condition (year assessed)
Exe Estuary SPA	Avocet (*Recurvirostra avosetta*), Non-breeding	Favourable (2019)*
Exe Estuary SPA	Black-tailed godwit (*Limosa limosa islandica*), Non-breeding	Favourable (2019)*
Exe Estuary SPA	Dark-bellied brent goose (*Branta bernicla bernicla*), Non-breeding	Unfavourable (2019) – due to population decline and recreational disturbance*
Exe Estuary SPA	Dunlin (*Calidris alpina alpina*), Non-breeding	Favourable (2019)*
Exe Estuary SPA	Grey plover (*Pluvialis squatarola*), Non-breeding	Favourable (2019)*
Exe Estuary SPA	Oystercatcher (*Haematopus ostralegus*), Non-breeding	Unfavourable (2019) – due to population decline, recreational disturbance, and availability of mussels a key prey item.*

Exe Estuary SPA	Waterbird assemblage, Non-breeding	Unfavourable (2019) – due to recreational disturbance.*
Exe Estuary SSSI	Aggregations of non-breeding birds - Avocet, *Recurvirostra avosetta*	Updated Condition Assessment required
Exe Estuary SSSI	Aggregations of non-breeding birds - Black-tailed Godwit, *Limosa limosa islandica*	Updated Condition Assessment required
Exe Estuary SSSI	Aggregations of non-breeding birds - Brent Goose (Dark-bellied), *Branta bernicla bernicla*	Updated Condition Assessment required
Exe Estuary SSSI	Aggregations of non-breeding birds - Ringed Plover, *Charadrius hiaticula*	Updated Condition Assessment required
Exe Estuary SSSI	Aggregations of non-breeding birds - Wigeon, *Anas penelope*	Updated Condition Assessment required
Exe Estuary SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Exe Estuary SSSI	Saltmarsh	Updated Condition Assessment required
Dawlish Warren SSSI	>20,000 Non-breeding Waterbirds	Updated Condition Assessment required
Dawlish Warren SSSI	Sheltered muddy shores (including estuarine muds)	Updated Condition Assessment required
Dawlish Warren SSSI	Saltmarsh	Updated Condition Assessment required

* Based on SPA proxy assessment completed for development of the Conservation Advice Package

Appendix 6: Detailed results for statistical analysis of quadrat data

Methodology Details

Review of survey methods and data

- **Quadrat surveys**

Quadrat surveys were carried out before walkover surveys and culls (where they overlapped). Quadrat data points included accurate latitude and longitude positions for each quadrat, and a total number of Pacific oysters for each 0.25m^2 quadrat. Whilst the quadrats were not distributed to be representative of the whole beach, they were placed pseudo-randomly without bias at approximately 5m intervals along the length of a section of beach. After some investigation it was clear several beaches had repeat surveys over multiple years which would enable comparisons between years, and comparisons between areas where culls had occurred or not. Sometimes surveys were done over multiple days and weeks but jointly covered a whole section of beach (these sections were joined for analysis). Surveys in subsequent years did not always cover the same stretch of beach. Sometimes they partially resurveyed an area or surveyed an entirely different section of beach. This limited the amount of data that could be used for direct comparison and required a search in QGIS to find repeat surveys that directly overlapped.

- **Walkover surveys**

Walkover surveys involved counting Pacific oysters along a line running parallel to the shore edge, where surveyors were advised to start a new segment and collect a waypoint after 50 Pacific oysters were counted. The method recommends a limit to the count area 2m either side of the walkover line (4m width). Analysis challenges included:

a) The method said to start a new segment after 50 Pacific oysters, so all segments were different lengths.

b) Not all volunteers stopped at the 50 Pacific oyster limit as some segment counts were much larger but the rationale for selecting start and end points for the section was unclear.

c) It is understood that some later surveys followed a new method (with a lack of clarity on the changes).

d) It was not certain that volunteers stuck to the width limits as initial efforts to standardise densities between segments showed large disparities between neighbouring segments which suggested otherwise.

As such it was decided that this data could not be standardised accurately enough to use for quantitative analysis and would be best presented through a mapping exercise.

- **Cull data**

Before culls were done, a walkover survey was done beforehand. Once the walkover surveys were complete, volunteers doubled back over these same areas to undertake a cull of the Pacific oysters. The cull areas were not restricted to the width limits and should have covered the entire width of the beach along the line of the walkover surveys. For formally organised culls one total for the whole stretch of the cull was provided. This was difficult to use quantitatively as the actual width of area culled is unknown. So, whilst densities could be estimated and mapped for the walkover surveys (assuming the surveys covered the area between mean and high water), we felt it was best not to use that assumption for statistical analysis as the distribution of oysters is not evenly distributed between low and high water which would significantly affect the true density. Furthermore, the number culled was from the entire survey, and the length of these are not the same as the quadrat surveys or sections chosen for modelling analysis, so are not comparable. However, mapping the walkover surveys does indicate which lengths of the beach were culled and on what date, and we know they aimed to remove all oysters along the width of the beach where they were found.

Data cleaning and preparation

Data were mapped and interrogated in QGIS to see if survey sites were correctly labelled, and correctly placed. Names were initially corrected in the original Excel spreadsheet but then using the software R for transparency. All quadrat and walkover data were given unique survey numbers manually in excel, and each point a unique ID in R. Then the *Lines to Points* plugin in QGIS was used to connect a line between the start and end of each walkover survey group, ordered by the unique IDs in order to map the “cull lines” in relation to quadrat points. This process identified positional errors which were investigated and corrected where necessary.

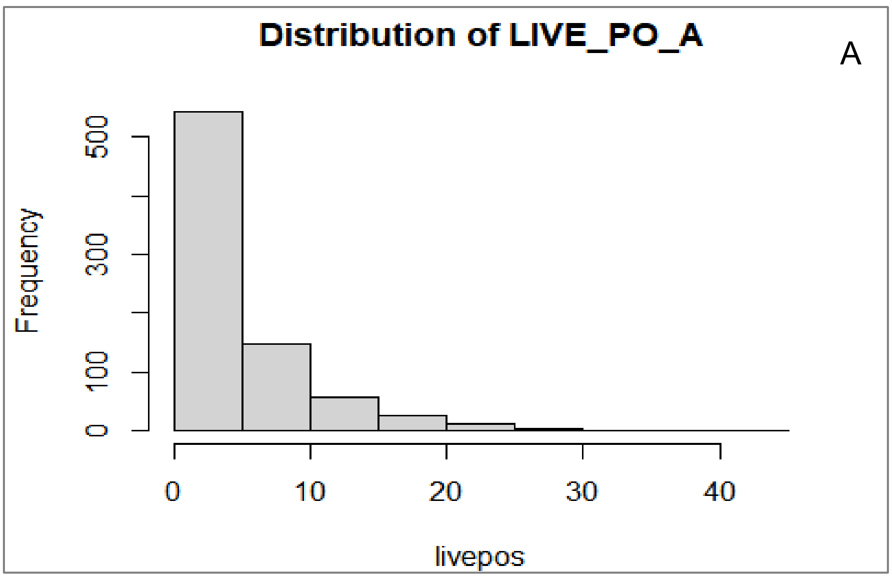
As repeat quadrat surveys did not always cover the exact same stretch of beach, the quadrat points were inspected in QGIS and polygons were used to group areas which had directly overlapping repeat quadrat points for at least two years or more that could be compared. These sites were then subdivided according to whether or not they were covered by cull lines. The polygons were given a unique code (e.g. TURS_3A_PC) which represented the location, survey and cull dates, and cull treatment. The polygon names were joined to the quadrat points using the QGIS general vector processing tool *Join attributes by location,* so they could be separated into analysis groups in R. Some further cull data became available afterwards, so some of the codes and data groupings were further edited in R where necessary (so there may be some differences in the maps below).

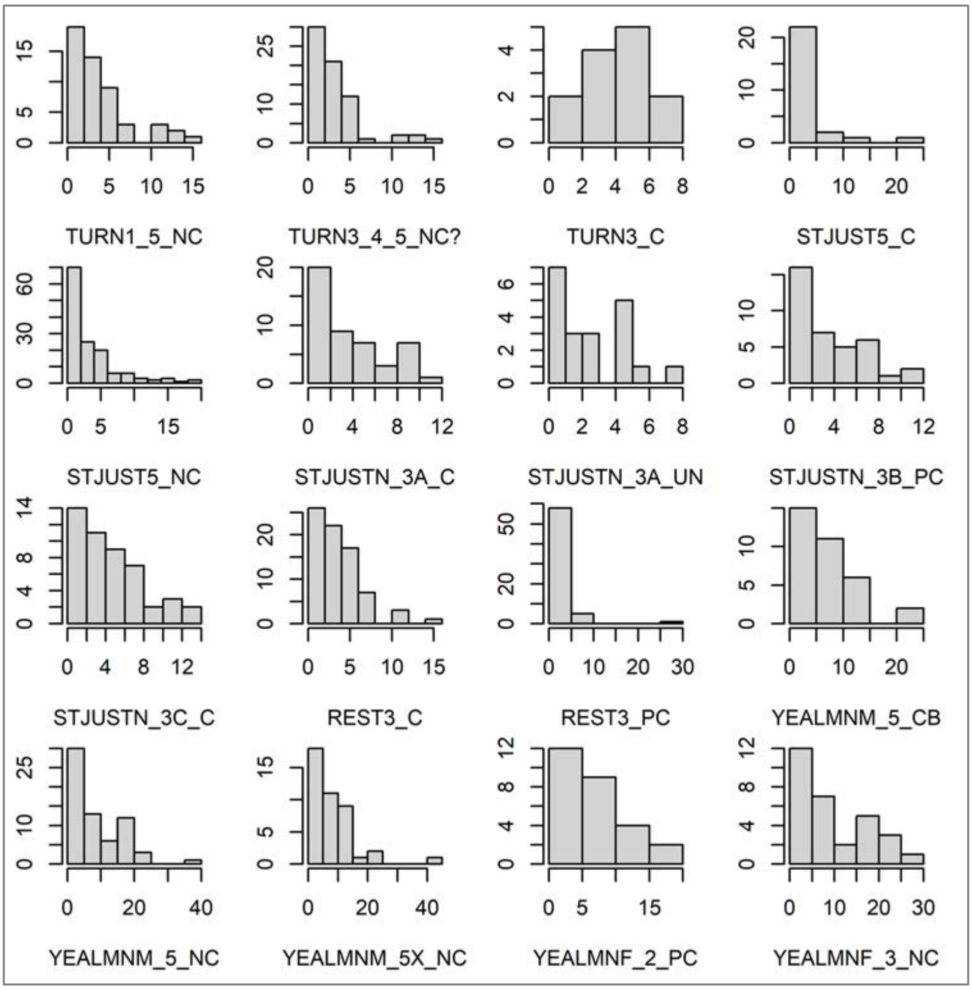
Method to create final analysis groups

Quadrat and walkover data were read into R and quadrat analysis groups were made by subsetting data by the analysis polygon code joined in QGIS. For each subset, columns were created to format dates, in order to use date as an explanatory variable (the x variable). Walkover data were subsetted into site groups using site names, so they could be re-mapped with each quadrat data group in R. This provided a second step to reviewing cull lines and led to some changes in data groupings if conditions were known to be different. If there were multiple polygons in different areas of the beach with the same survey dates (e.g. 3B, 3C) these were grouped together. As some quadrat surveys were carried out over multiple dates (over several days or weeks), these were inspected and combined so were treated as a single survey. In some cases, surveys spread over different months, and these were also combined if they were within a month and jointly covered a stretch of beach (without overlapping). In these cases, the date of the later survey was changed to match the early survey though all dates are provided in the summary table. This was necessary to make R treat them as single surveys rather than separate time series. These final groupings are reflected in the names of the final analysis groups. They are mapped next to each individual model result for clarity with both the quadrat and cull lines.

Count data distributions

The first stage of analysis was to look at the distribution of the Pacific oyster quadrat counts jointly for the mixed model, and individually for each final grouping for the individual models. An initial review highlighted that count data was typical of a Poisson distribution, though Linear models (LM) and Generalized linear models (GLM) were run with normal, gaussian, Poisson and negative binomial distributions to see which fit best, and with a quasi-Poisson distribution if they were over dispersed. All models fitted best with a GLM and negative binomial distribution. Those that remain slightly over dispersed were not improved by using a quasi-Poisson distribution.





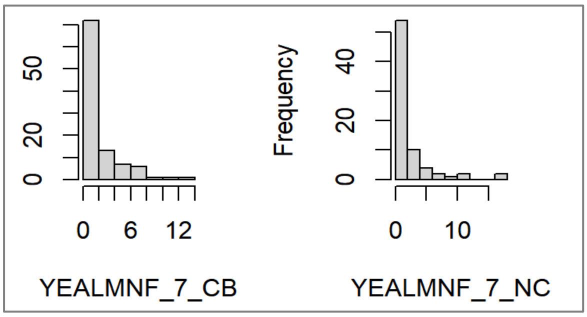


Figure 39: Plots to show the distribution of count data for (A) the whole dataset (B) individual analysis groups 1:14, and (C) analysis group 15

Detailed results from the mixed models

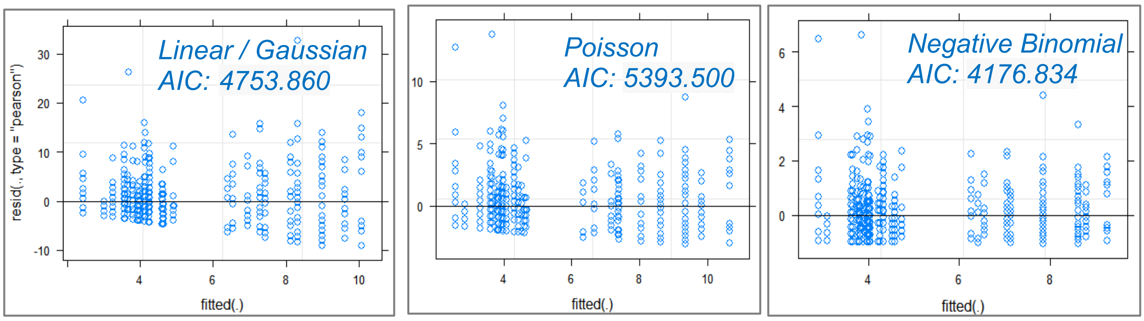


Figure 40: Plots to show fitted residuals from basic models for the whole dataset fitted with different distributions, with their AIC score, to assess heteroskedasticity and find the best distribution

All models showed a significant difference between non culled sites (the intercept term), and model groups that were culled and partially culled. The table below is from a simpler model without the three-way interaction as the results are clearer to understand, but these results are similar for all the models. Please note these values are logged, therefore don't represent the true reduction, but the significance between the intercept term (Not culled) and sites culled (`GROUP_STATUSC:` p=0.00968 `/DAY:GROUP_STATUSC;` p=<0.001), can clearly be seen, and are highlighted below.

```
Formula: Live_POs_A ~ DAY * GROUP_STATUS + (1 | Modelgroup)

Fixed effects:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)         1.5536839  0.1781312   8.722  < 2e-16 ***
DAY                 0.0003172  0.0001091   2.907  0.00365 **
GROUP_STATUSC       0.8561029  0.3309163   2.587  0.00968 **
GROUP_STATUSCB     -0.2131344  0.4939104  -0.432  0.66609
GROUP_STATUSPC      0.7489703  0.5633573   1.329  0.18369
DAY:GROUP_STATUSC  -0.0017550  0.0002872  -6.110 9.97e-10 ***
DAY:GROUP_STATUSCB  0.0005204  0.0003408   1.527  0.12672
DAY:GROUP_STATUSPC -0.0010841  0.0005035  -2.153  0.03132 *
```

However, this was not the best model, the best model included a three-way interaction between day(time), group status and the location. The results for the best model (mixed.modelNB5) are harder to interpret due to the interaction but are provided anyway. The results are best represented by the plots in the main report.

```
mixed.modelNB5<-(glmer(Live_POs_A~DAY*GROUP_STATUS*LOC_GROUP +(1|Modelgroup), family=ne
gative.binomial(theta = 1.25), data = dta))

## fixed-effect model matrix is rank deficient so dropping 26 columns / coefficients

## boundary (singular) fit: see ?isSingular

summary(mixed.modelNB5)
```

```
Generalized linear mixed model fit by maximum likelihood (Laplace
Approximation) [glmerMod]
Family: Negative Binomial(1.25)  ( log )
Formula: Live_POs_A ~ DAY * GROUP_STATUS * LOC_GROUP + (1 | Modelgroup)
   Data: dta

     AIC      BIC   logLik deviance df.resid
  4085.3   4197.3  -2018.6   4037.3      763

Scaled residuals:
   Min      1Q  Median      3Q     Max
-1.0533 -0.6207 -0.1622  0.4080  6.2704

Random effects:
 Groups     Name        Variance Std.Dev.
 Modelgroup (Intercept) 0        0
Number of obs: 787, groups:  Modelgroup, 14

Fixed effects:
                                        Estimate Std. Error z value Pr(>|z|)
(Intercept)                            0.6532604  1.1601987   0.563   0.5734
DAY                                    0.0010558  0.0012079   0.874   0.3821
GROUP_STATUSC                          1.5711886  1.2374090   1.270   0.2042
GROUP_STATUSCB                        -0.6021843  0.2964855  -2.031   0.0422 *
GROUP_STATUSPC                         1.2118043  0.9748053   1.243   0.2138
LOC_GROUPSTJUST                        0.3376098  1.1693492   0.289   0.7728
LOC_GROUPSTJUSTN                       1.1518901  0.6334021   1.819   0.0690 .
LOC_GROUPTURNAWARE                     0.6297219  1.1682721   0.539   0.5899
LOC_GROUPYEALM_NEWTONFER               1.0294026  0.9832756   1.047   0.2951
LOC_GROUPYEALM_NOSMAYO                 1.2923784  1.1713153   1.103   0.2699
DAY:GROUP_STATUSC                     -0.0020365  0.0013004  -1.566   0.1173
DAY:GROUP_STATUSCB                     0.0005331  0.0003686   1.446   0.1481
DAY:GROUP_STATUSPC                    -0.0016920  0.0009862  -1.716   0.0862 .
DAY:LOC_GROUPSTJUST                   -0.0003325  0.0012363  -0.269   0.7879
DAY:LOC_GROUPSTJUSTN                  -0.0012720  0.0007016  -1.813   0.0698 .
DAY:LOC_GROUPTURNAWARE                -0.0009547  0.0012191  -0.783   0.4336
DAY:LOC_GROUPYEALM_NEWTONFER          -0.0003730  0.0010354  -0.360   0.7187
DAY:LOC_GROUPYEALM_NOSMAYO            -0.0007527  0.0012255  -0.614   0.5391
GROUP_STATUSC:LOC_GROUPSTJUST         -0.3764748  1.2946241  -0.291   0.7712
GROUP_STATUSC:LOC_GROUPTURNAWARE      -1.6014079  1.3159229  -1.217   0.2236
DAY:GROUP_STATUSC:LOC_GROUPSTJUST     -0.0029667  0.0015536  -1.910   0.0562 .
DAY:GROUP_STATUSC:LOC_GROUPTURNAWARE   0.0022348  0.0013956   1.601   0.1093
 ---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation matrix not shown by default, as p = 22 > 12.
Use print(x, correlation=TRUE)  or   vcov(x) if you need it
```

```
fit warnings:
fixed-effect model matrix is rank deficient so dropping 26 columns / coefficients
optimizer (Nelder_Mead) convergence code: 0 (OK)
boundary (singular) fit: see ?isSingular
```

```
fixed.effects(mixed.modelNB5)

##                         (Intercept)                                  DAY
##                        0.6532604178                         0.0010558246
##                       GROUP_STATUSC                       GROUP_STATUSCB
##                        1.5711886168                        -0.6021842594
##                      GROUP_STATUSPC                     LOC_GROUPSTJUST
##                        1.2118042918                         0.3376098156
##                    LOC_GROUPSTJUSTN                   LOC_GROUPTURNAWARE
##                        1.1518901340                         0.6297218822
##            LOC_GROUPYEALM_NEWTONFER              LOC_GROUPYEALM_NOSMAYO
##                        1.0294025820                         1.2923783506
##                   DAY:GROUP_STATUSC                   DAY:GROUP_STATUSCB
##                       -0.0020365111                         0.0005330619
##                  DAY:GROUP_STATUSPC                 DAY:LOC_GROUPSTJUST
##                       -0.0016920327                        -0.0003325463
##                DAY:LOC_GROUPSTJUSTN               DAY:LOC_GROUPTURNAWARE
##                       -0.0012719875                        -0.0009546866
##        DAY:LOC_GROUPYEALM_NEWTONFER          DAY:LOC_GROUPYEALM_NOSMAYO
##                       -0.0003729508                        -0.0007527099
##         GROUP_STATUSC:LOC_GROUPSTJUST      GROUP_STATUSC:LOC_GROUPTURNAWARE
##                       -0.3764747966                        -1.6014079482
##     DAY:GROUP_STATUSC:LOC_GROUPSTJUST DAY:GROUP_STATUSC:LOC_GROUPTURNAWARE
##                       -0.0029666583                         0.0022348483
```

AIC Results for all mixed models, demonstrating that mixed.modelNB5 is the best model:

```
AIC(mixed.modelNB,mixed.modelNB2,mixed.modelNB3,mixed.modelNB4,mixed.modelNB5,mixed.mod
elNB6)

                  df      AIC
 mixed.modelNB    7      4176.834
 mixed.modelNB2   10     4129.873
 mixed.modelNB3   10     4134.679
 mixed.modelNB4   11     4131.924
 mixed.modelNB5   24     4085.674
 mixed.modelNB6   44     4125.298
```

Results from the Anova function demonstrating that the interaction term in mixed.modelNB5 is significant:

```
Anova (mixed.modelNB3, mixed.modelNB5)
Models:
mixed.modelNB3: Live_POs_A ~ DAY * GROUP_STATUS + (1 | Modelgroup)
mixed.modelNB5: Live_POs_A ~ DAY * GROUP_STATUS * LOC_GROUP + (1 | Modelgroup)
                 npar    AIC    BIC   logLik   deviance Chisq Df Pr(>Chisq)
mixed.modelNB3    10  4134.7  4181.4  -2057.3   4114.7
mixed.modelNB5    24  4085.7  4197.7  -2018.8   4037.7 7 7.005 14  1.012e-10 ***
```

Detailed Results for Individual Models

Six sites were suitable for analysis including St Just Pool, St Just Creek, Turnaware and Restronguet Creek in the Fal and Helford SAC, and Newton Ferrers and Noss Mayo both in the Yealm estuary within the Plymouth Sound and Estuaries SAC. For each of the sites, a map is inserted below to show the original QGIS polygons used to group data in relation to quadrat points and cull lines, and a further map showing the cull lines mapped in R with dates.

Each of these sites contained multiple analysis groups, and each analysis group has a separate model. Results of each model are provided separately in the results below along with maps to visualise the relevant quadrat points and cull lines for the group, and a description of survey dates, cull dates and sample sizes for each analysis group. For each model, the following information is provided:

i. A plot to show the model results in relation to the survey count data (x=date, y= PO counts). The model slope (trend) is represented as a green line to show the population growth or decline between survey years, along with dashed grey standard error lines.

ii. Cull dates are added on the plots as vertical lines for visualisation. Red lines represent full culls, orange lines represent partial or uncertain culls.

iii. Box and whisker plots are also provided to show the difference in median and interquartile measures between surveys dates (note these assume normal distribution but are useful to understand the spread of the data).

iv. For each analysis group a table of results is provided to show:

- The (posterior) mean for the intercept (start survey) and coefficient estimate (final survey), and their 95% confidence intervals.
- The total and annual population growth rate in percent.
- The model statistic p value (z-test) which demonstrates if there is a significant statistical difference between the start and end survey population posterior mean. We only highlight caution when a p value is more than 0.1 (10 % probability that there is no difference in sample posterior means), rather than the conventional 0.05 (a 5% probability).
- The chi square test of deviance which provides a further statistical measure to consider, this describes how likely the model is to be true given the data (where a p value less than 0.05 indicates a poor fit).
- DEV: Goodness of fit measure representing the percent of deviance explained for these GLM models, where 0 is worst and 100% is best (but not ever achieved)).
- ODP: Over dispersion parameter which should be close to 1.1 or less. Where models are over this, some caution is required.

To note for the following section, R recognises and produces time in plots as universal time (UTC) format (YEAR-MONTH-DAY e.g. 2020-05-30) but the standard UK format (DAY/MONTH/YEAR e.g. 30/05/20) is used in text.

Site 1: Turnaware, Fal Estuary

There were a number of erroneous points in this area that could not be fixed so it is possible there are missing stretches of “cull lines” at Turnaware. The short length of the cull line on 05/06/2019 looks unlikely, though it was confirmed there was a short cull at this location.

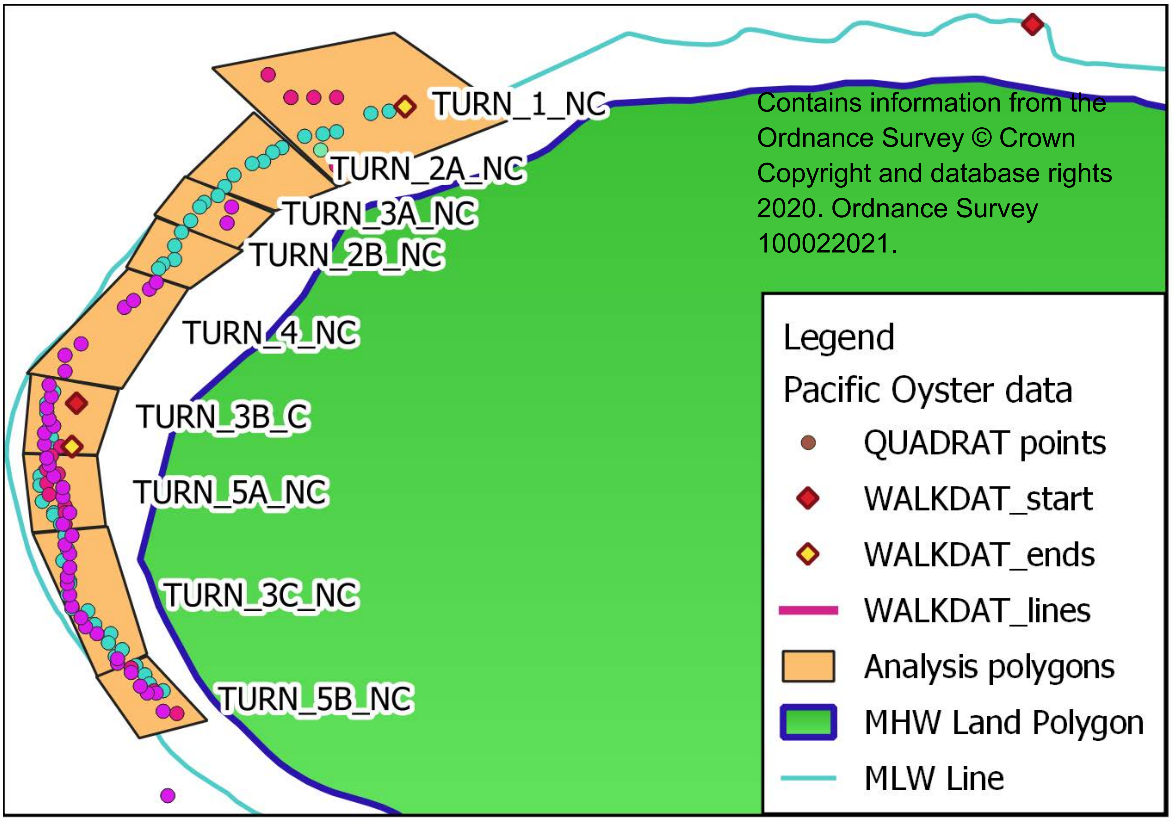


Figure 41: Quadrats, walkover start, and end points and analysis polygons mapped in QGIS, at Turnaware, Fal estuary

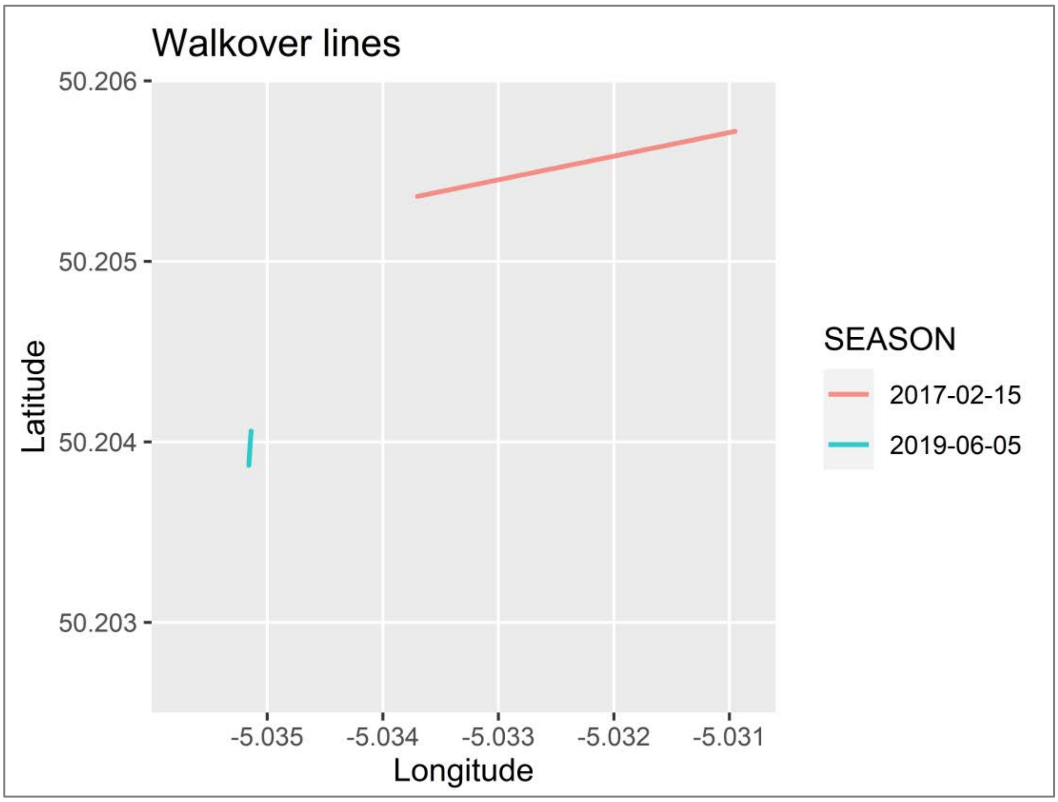


Figure 42: Cull lines mapped in R, at Turnaware, Fal estuary

Model 1: Results for TURN1_5_NC

Model TURN1_5_NC had 3 years of data with a two year, and then one year interval (15/02/17 (n=18), 05/06/19 (n=20), and combined dates 21/05/20, 04/06/20 (n=13)). There is evidence of a cull on 15/02/17 and cull on 05/06/19 close to the quadrats but there does not seem to be an overlap with the data points, so it was decided to group these as not culled. An annual population growth rate of 7.99% was calculated, but the model statistic showed there was not a very significant statistical difference (28% chance or more there is no difference), but this could be in part due to small sample sizes. All model diagnostic thresholds were met.

Results of model 1 Turn1_5_NC

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	3.58	(2.17-4.99)				
COEFFICIENT ESTIMATE	4.84	(3.23-6.45)	0.29	0.25	2.22	**1.13**
TOTAL GROWTH IN %	26.06					
ANNUAL GROWTH IN %	**7.99**					

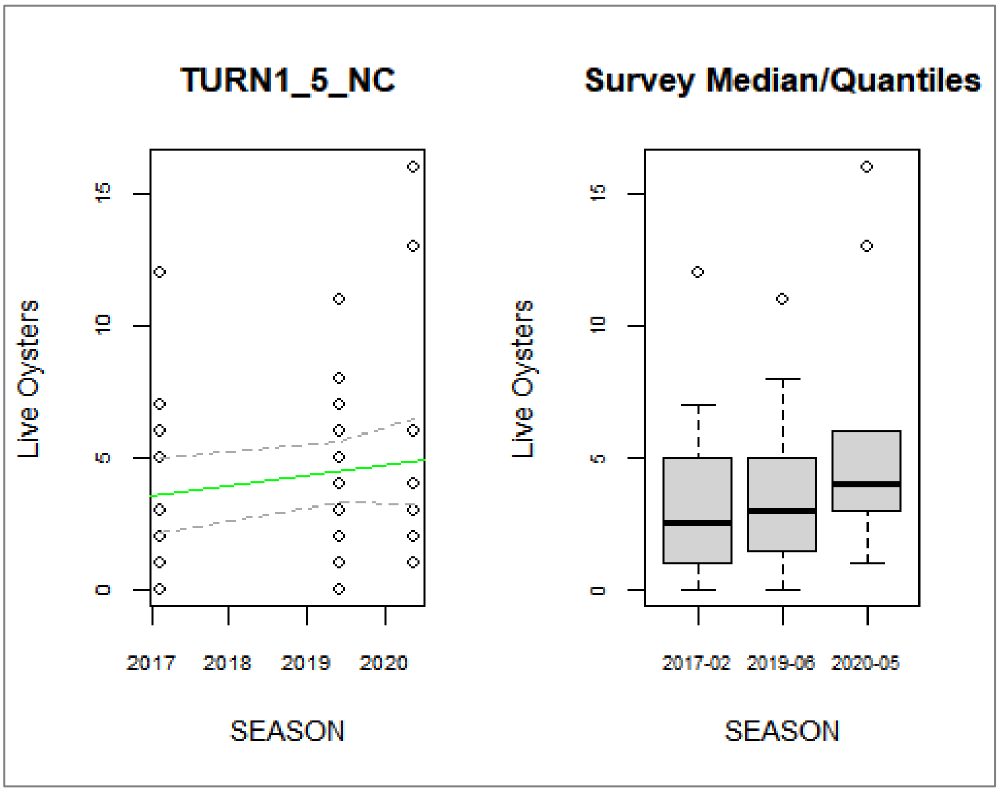


Figure 43: Survey count data, model results (green line with grey standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

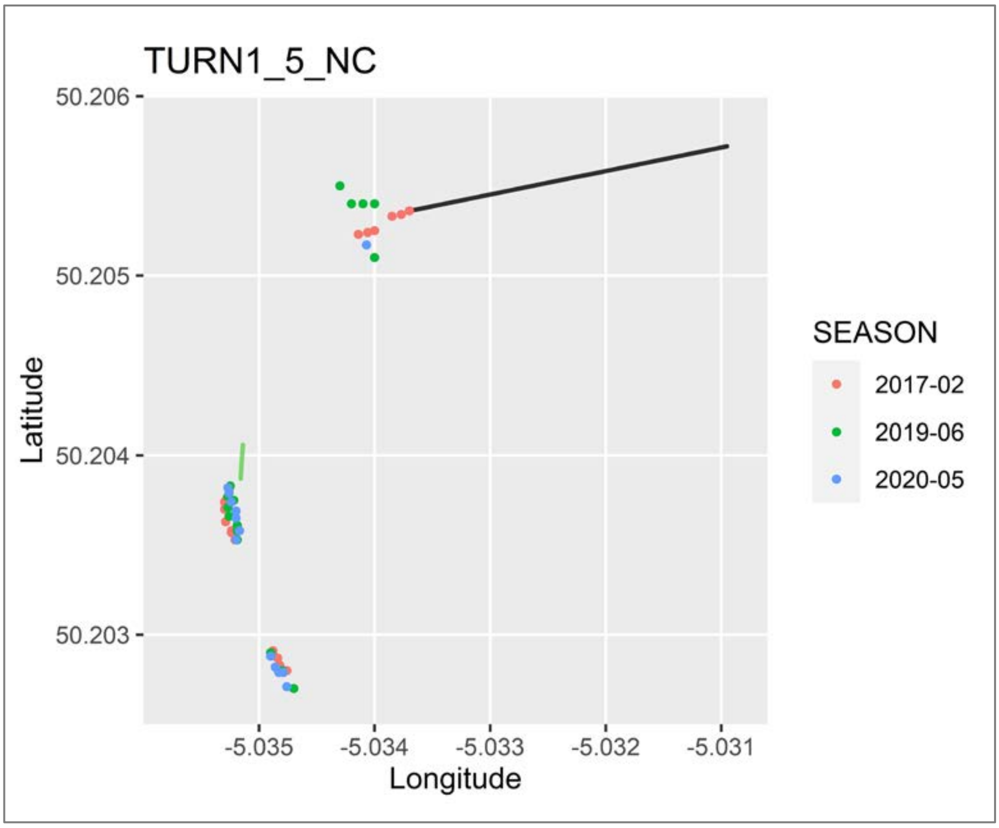


Figure 44: Quadrat points for this analysis group, in relation to cull lines for this site

Model 2: Results TURN3_4_5_NC

Model TURN3_4_5_NC had 2 years of data, but with a 3-year interval (15/02/2017 (n=35), and 21/05/2020 (n=34)). This model contains some of the same data as model TURN1_5_PC above but excludes the third year of 2019 data as it is not present everywhere. This data were joined with additional polygons with the same dates in 2017 and 2020. None of these polygons contained indications that culls have occurred, but it is possible there was some overlap with the cull on 05/06/19. Whilst the chi square test indicated an adequate fit, the percent of deviance explained was very low, so some caution is recommended. The model statistic shows there is 92% chance there is no change between years and the total population decline was only -2.04% (0.61 per annum).

Results of Model 2 TURN3_4_5_NC

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	3.57	2.57-4.57				
COEFFICIENT ESTIMATE	3.5	2.51-4.49	0.92	0.3	0.01	**1.08**
TOTAL GROWTH IN %	-2					
ANNUAL GROWTH IN %	**-0.61**					

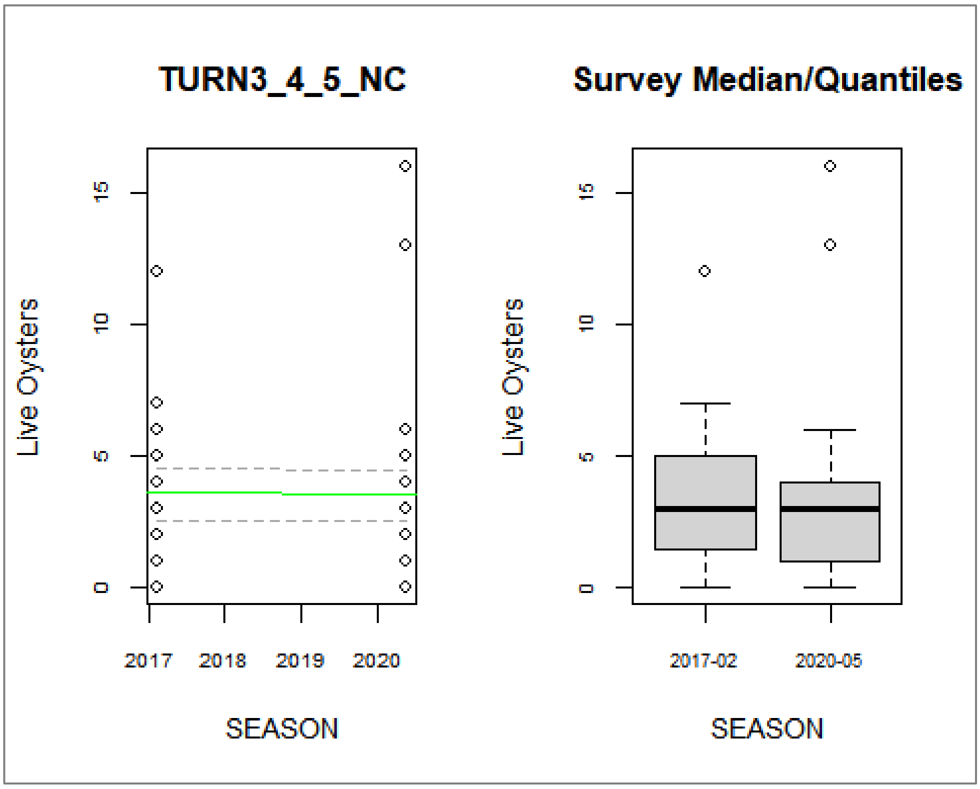


Figure 45: Survey count data, model results (green line with grey standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

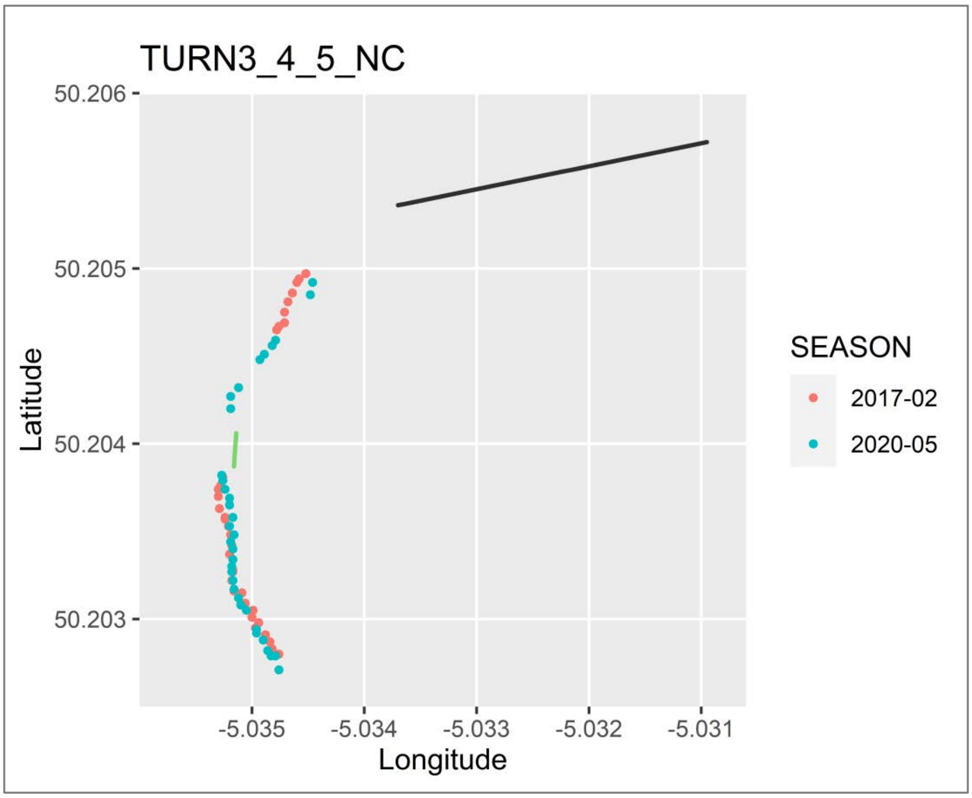


Figure 46: Quadrat points for this analysis group, in relation to cull lines for this site

Model 3: Results for TURN3_C

Model TURN3_C has 2 survey years with a 3-year interval (15/02/2017 (n= 6), and 21/05/2020(n=7)), but these data lie in a polygon adjacent to the small cull line on the 05/06/2019. It should be noted this is a very short section of the beach, and the number of points per survey is small, which affects the ability of the model to get a good fit. No models fit well for this data. The only model that was not more than 2 dispersion units still had a dispersion factor of 1.69, so some cautions apply. A population growth rate of 9.19 % per annum was calculated but the p statistic shows there is a 26% probability or more. There is no significant difference between years, however this is probably symptomatic of small sample numbers.

Results of model 3 TURN3_C

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	3.5	1.78-5.22				
COEFFICIENT ESTIMATE	5	2.99-7.01	0.27	0.07	6.17	**1.7**
TOTAL GROWTH IN %	30					
ANNUAL GROWTH IN %	**9.2**					

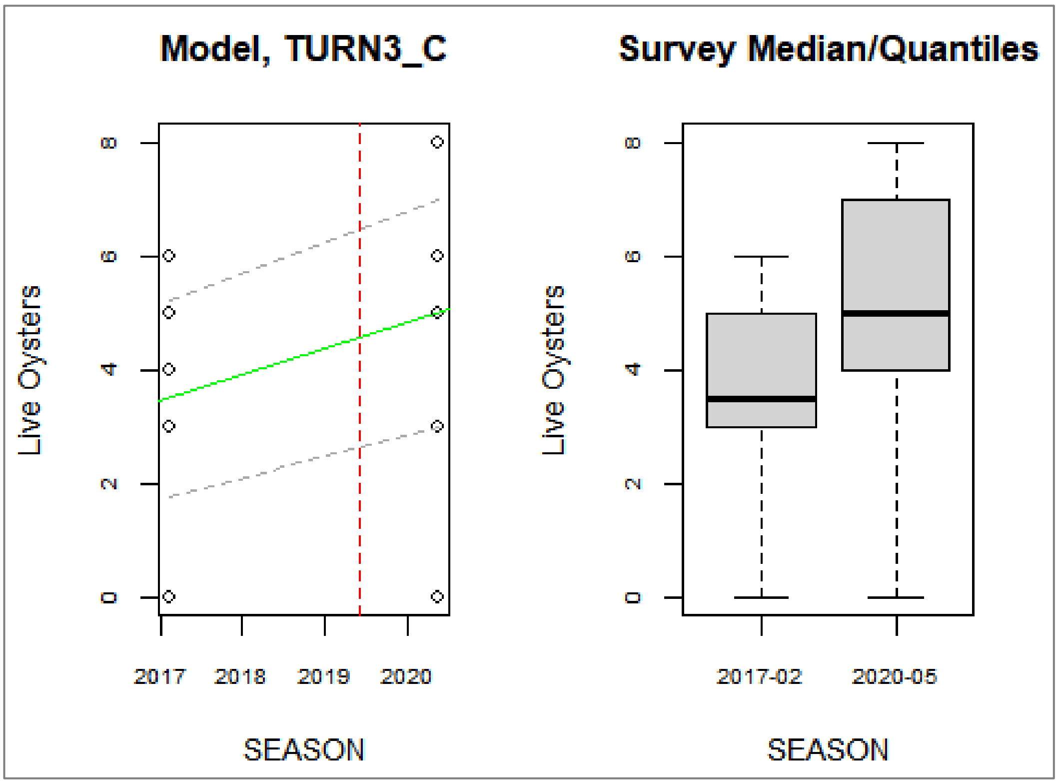


Figure 47: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

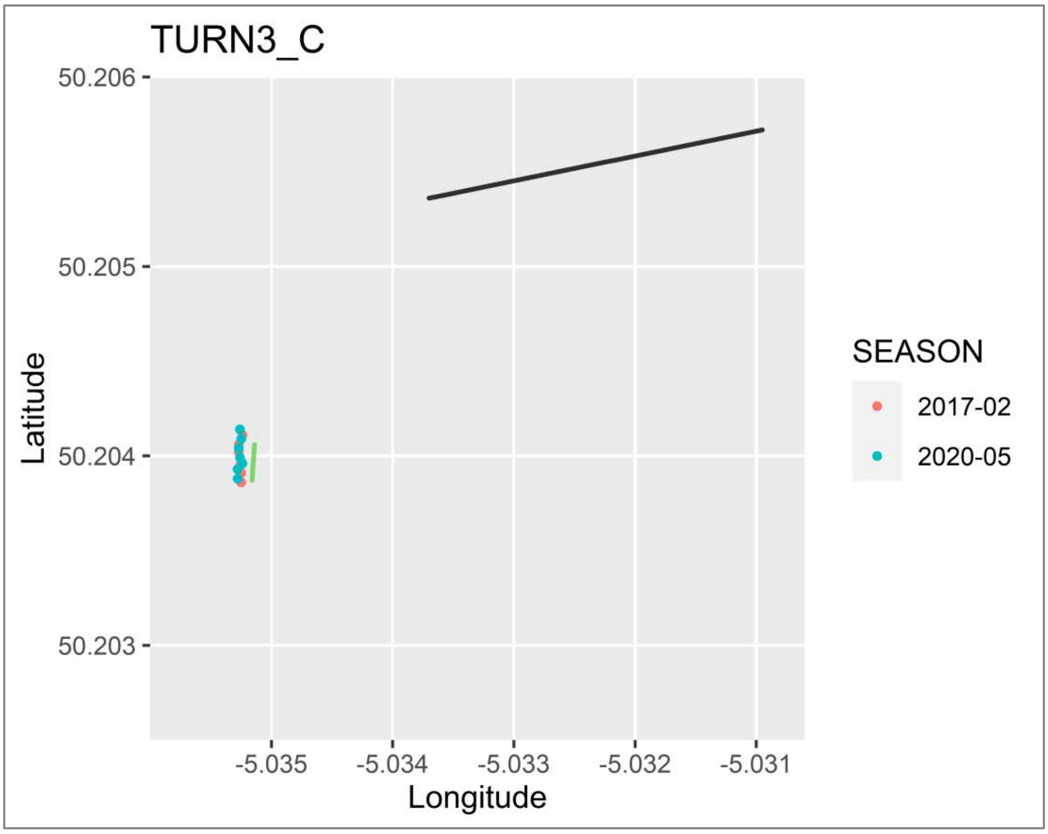


Figure 48: Quadrat points for this analysis group, in relation to cull lines for this site

Site 2: St Just, Fal Estuary

The following map shows the cull lines for St Just.

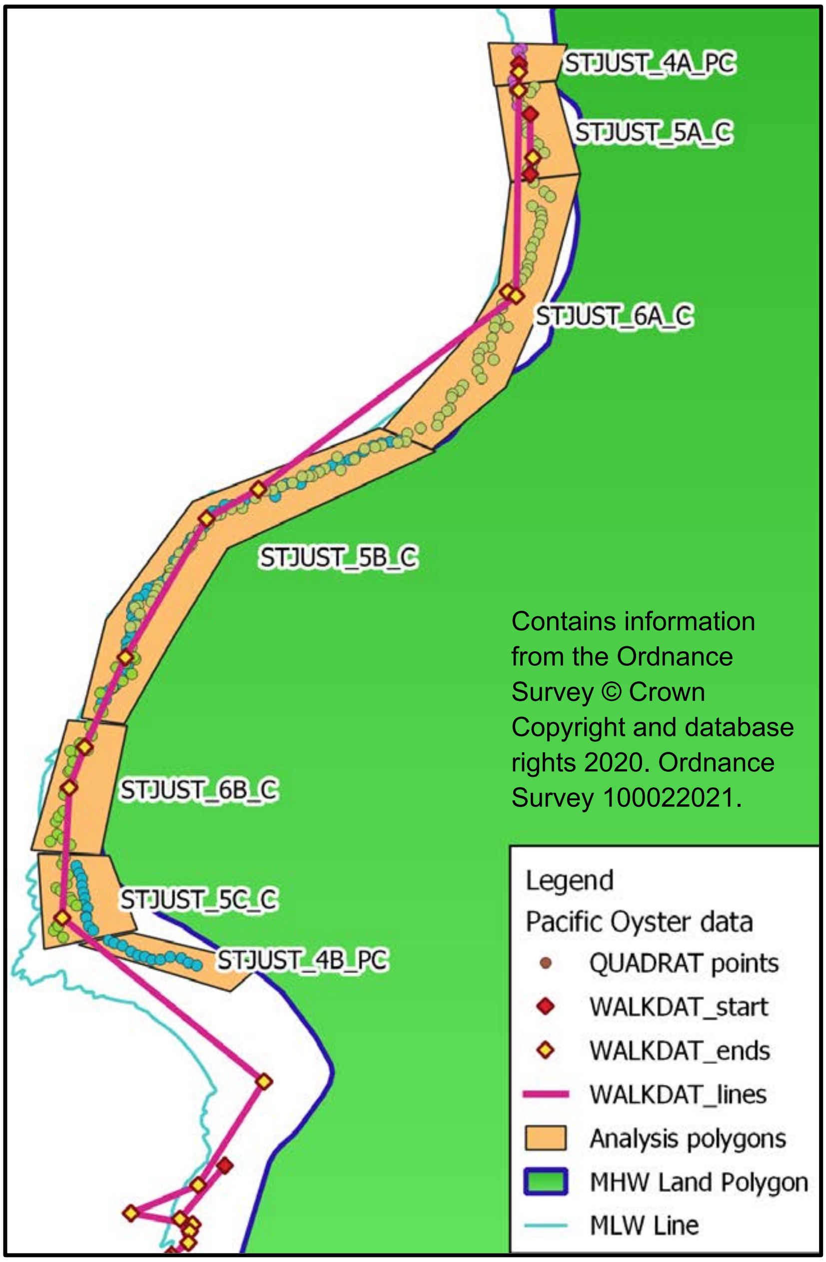


Figure 49: Quadrats, walkover start and end points and analysis polygons mapped in QGIS, at St Just, Fal estuary

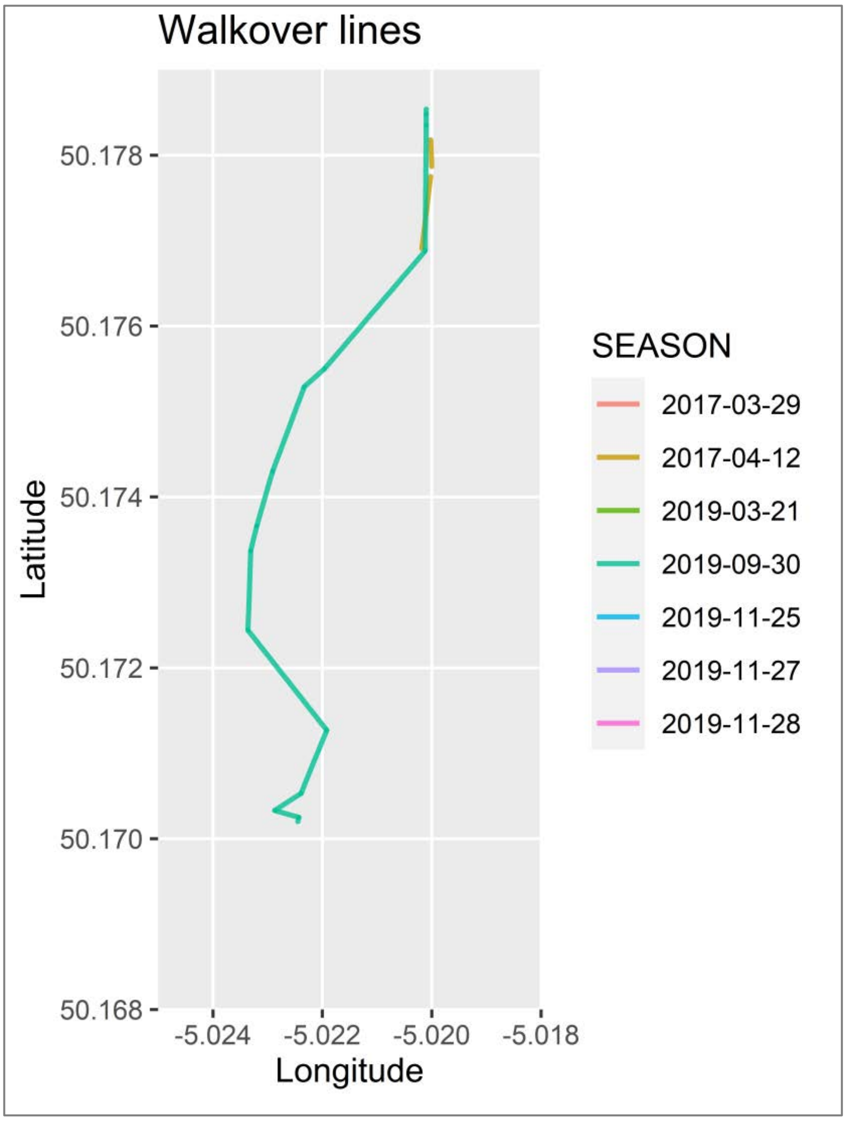


Figure 50: Cull lines mapped in R, at St Just, Fal estuary

To note the legend shows all the dates from St Just and St Just creek as these data were previously grouped for the whole area, but the only dates which apply for this southern area of St Just are 12/04/2017 and 30/09/2019.

Model 4: Results for STJUST5_C

The STJUST5_C model contains 2 years of data with a 2-year interval (12/04/2017 (n=9), and combined dates 11/03/2019 and 19/03/2019 (n=11)), with cull lines straight after the first and after the second surveys (12/04/2017 and 30/09/2019). In this model plot, it looks like there are only a few points in the second year, but this is because the majority are 0. All model diagnostic thresholds were met. The test of significance was very high at 0.01 (i.e., a near to zero probability that the difference is not significant) despite low sample sizes. The Pacific oyster population declined by a rate of -49.66% per annum.

Results of model 4 STJUST5_C

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	7	1.98-12.02				
COEFFICIENT ESTIMATE	0.35	0.02-0.68	0.01	0.48	55.7	**0.98**
TOTAL GROWTH IN %	-94.96					
ANNUAL GROWTH IN %	**-49.72**					

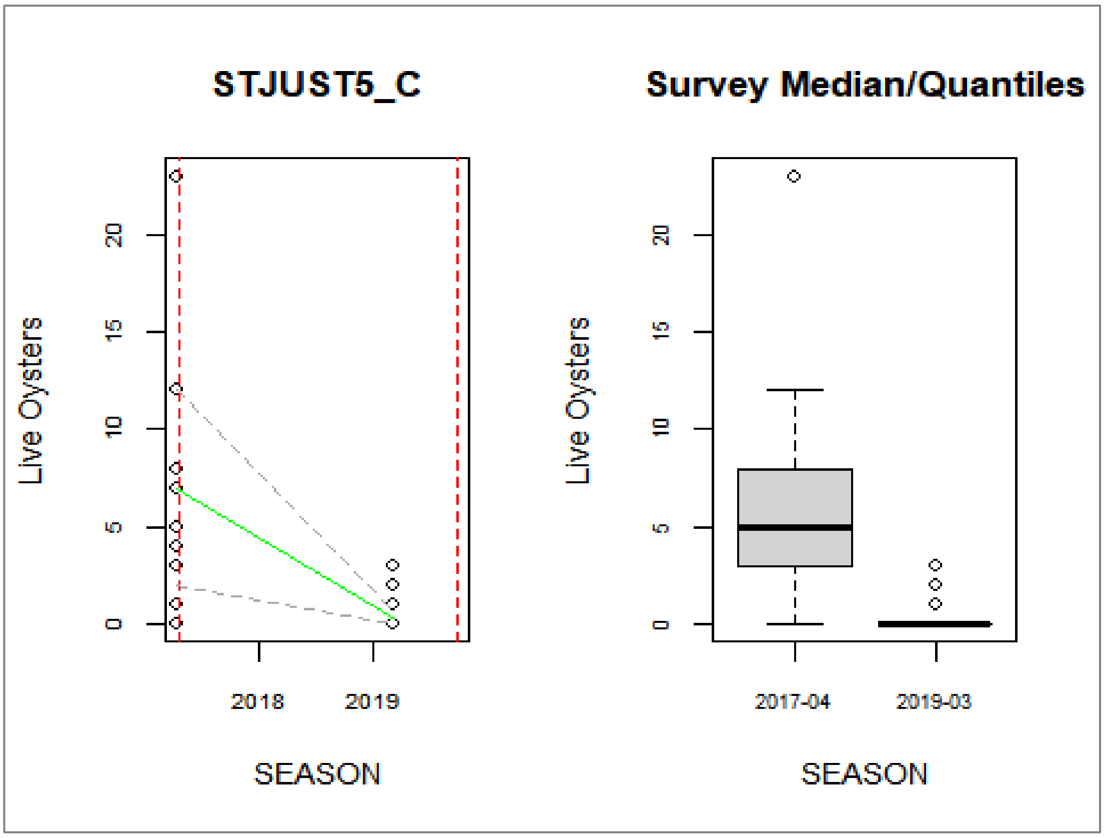


Figure 51: Survey count data, model results (green line with grey standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

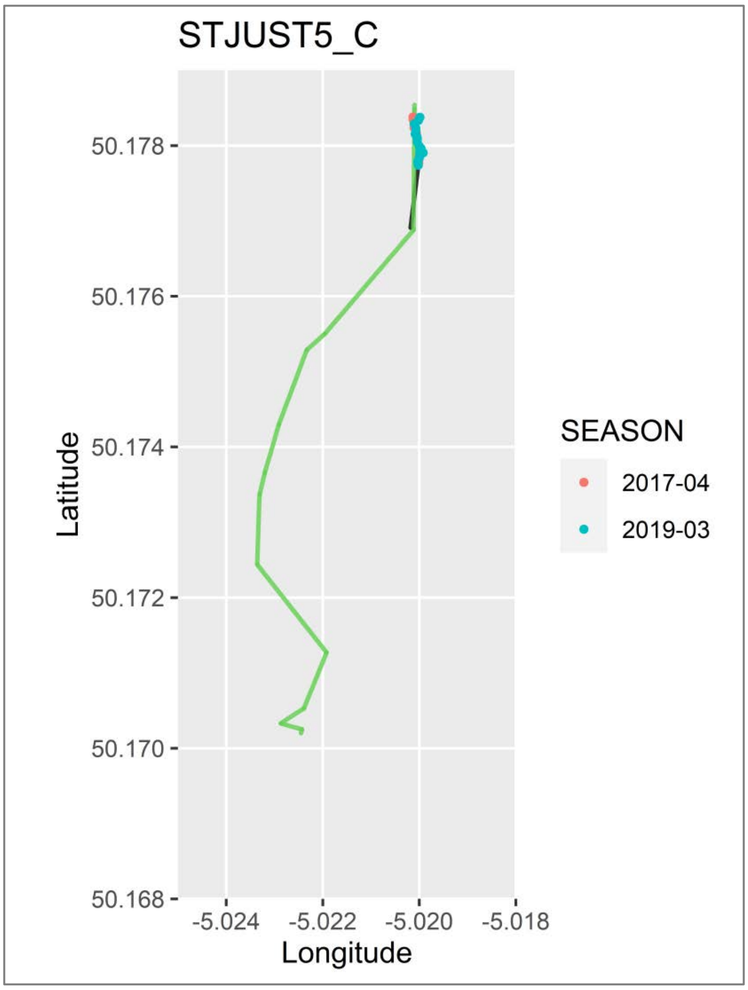


Figure 52: Quadrat points for this analysis group, in relation to cull lines for this site

Model 5: Results for STJUST5_NC

The STJUST5_NC model contains 2 years of data with a 2 year interval (11/05/2017 (n=69), and combined dates 11/03/2019 and 19/03/2019 (n=69)). The green cull line visible in the map occurred after the final survey (30/09/2019) and is therefore not shown in the map. A highly significant (0.012) population increase of 20.91% per annum was calculated. All model diagnostic thresholds were met.

Results of model 4 STJUST5_NC

MEASURE	RESULTS	CI	P_VALUE	CHIS Q	DEV	ODP
INTERCEPT	2.87	2.11-3.63				
COEFFICIENT ESTIMATE	4.65	3.48-5.82	0.01	0.14	4.17	**1.13**
TOTAL GROWTH IN %	38.32					
ANNUAL GROWTH IN %	**20.94**					

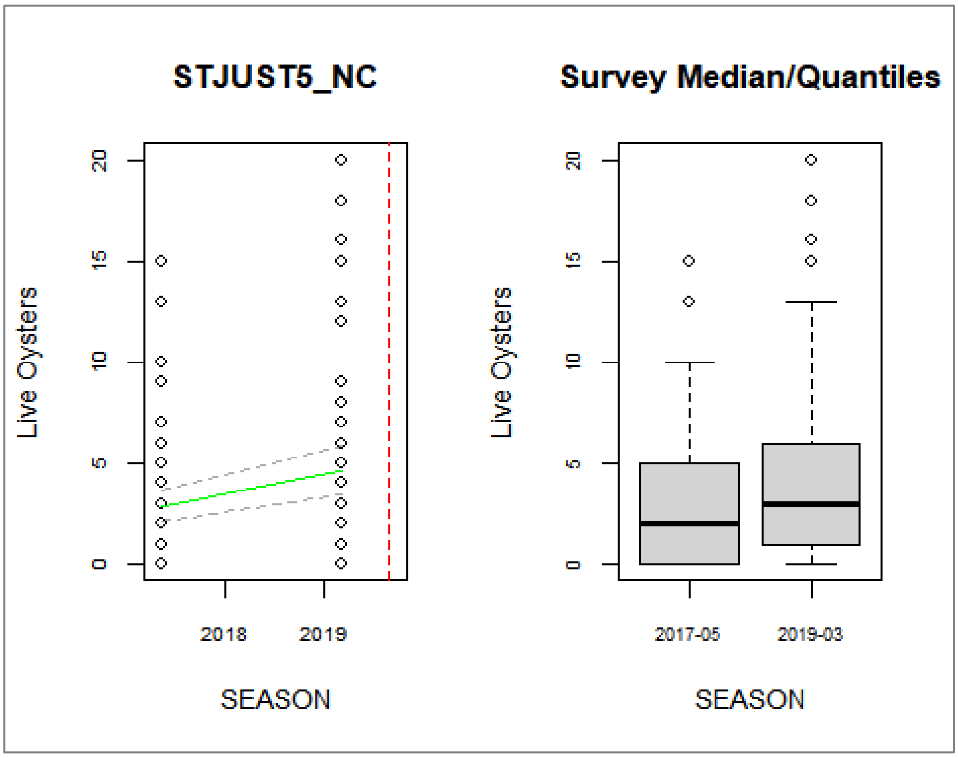


Figure 53: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

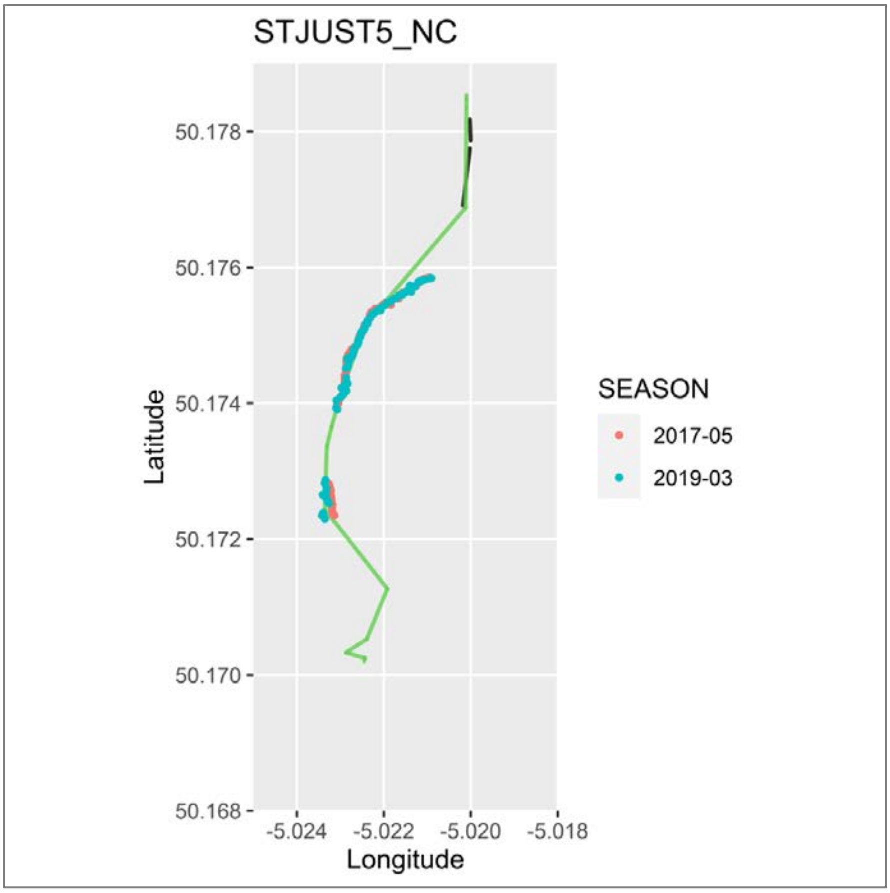


Figure 54: Quadrat points for this analysis group, in relation to cull lines for this site

Site 3: St Just North creek, Fal estuary

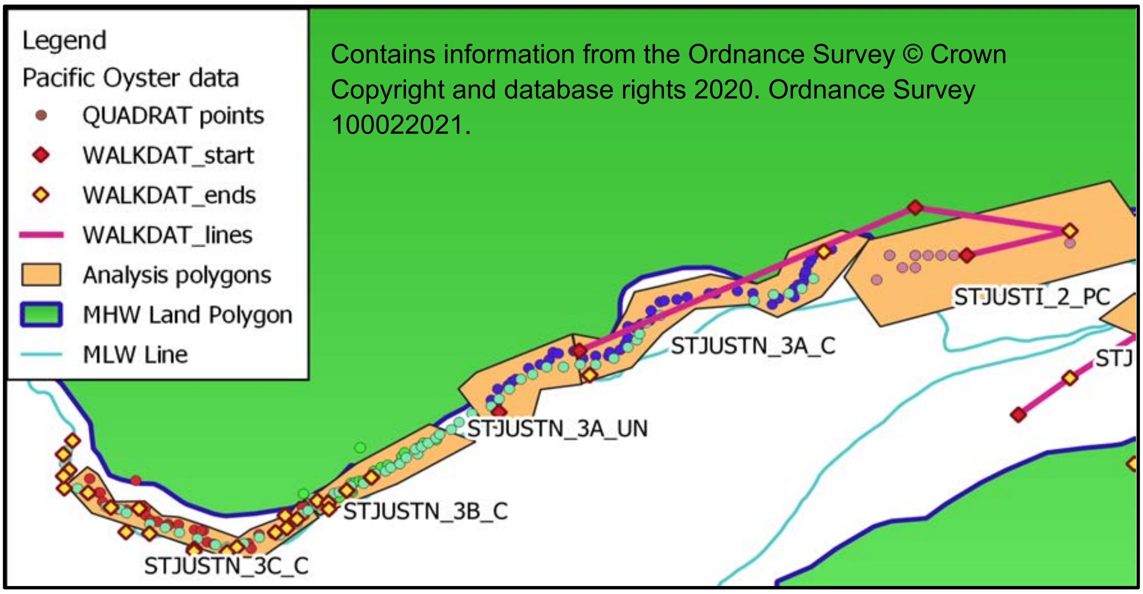


Figure 55: Quadrats, walkover start and end points and analysis polygons mapped in QGIS, at St Just Creek, Fal estuary

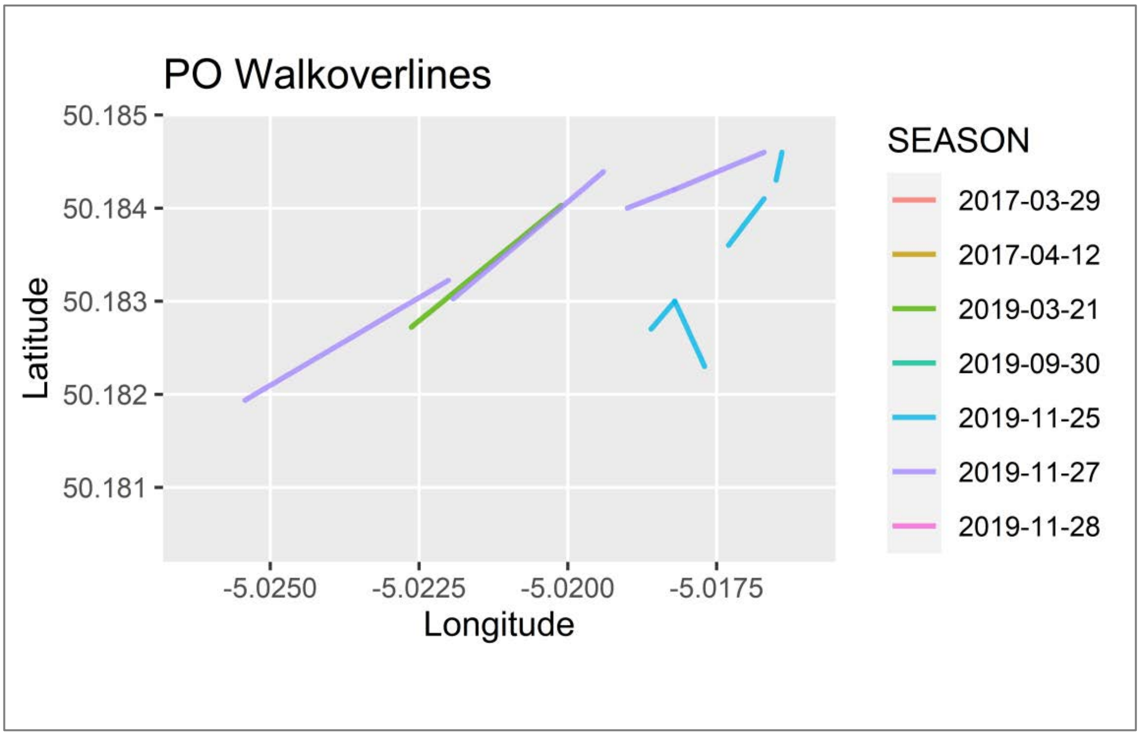


Figure 56: Cull lines mapped in R, at St Just Creek, Fal estuary

Model 6: Results for STJUSTN_3A_C (incl. STJUSTN_3A_C and STJUSTN_3A_UN Combined)

The dataset for model STJUSTN_3A_Comb contains data from two analysis groups as before this stage it was not clear if one of the sites was culled or not, but once mapped in R the culls clearly covered both areas so the datasets had identical conditions. As such data for STJUSTN_3A_C which contained two years of data with an interval of just over one year (21/03/2019 (n=34), and 04/06/2020(n=13)) was merged with STJUSTN_3_UN which added the additional data (21/03/2019 (n=13), and 04/06/2020 (n=7)). All points overlap with cull lines on the 21/03/2019 and 27/11/2019. The best model had a dispersion factor of 1.2, which is fractionally over the "good" threshold but was better than other models. There was a highly significant (0.001) reduction in population growth between years with a reduction of -41.57% per annum.

Results of model 6 STJUSTN_3A_C

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	4.32	3.32-5.32				
COEFFICIENT ESTIMATE	2.15	1.26-3.04	0	0.11	9.56	**1.22**
TOTAL GROWTH IN %	-50.22					
ANNUAL GROWTH IN %	**-41.51**					

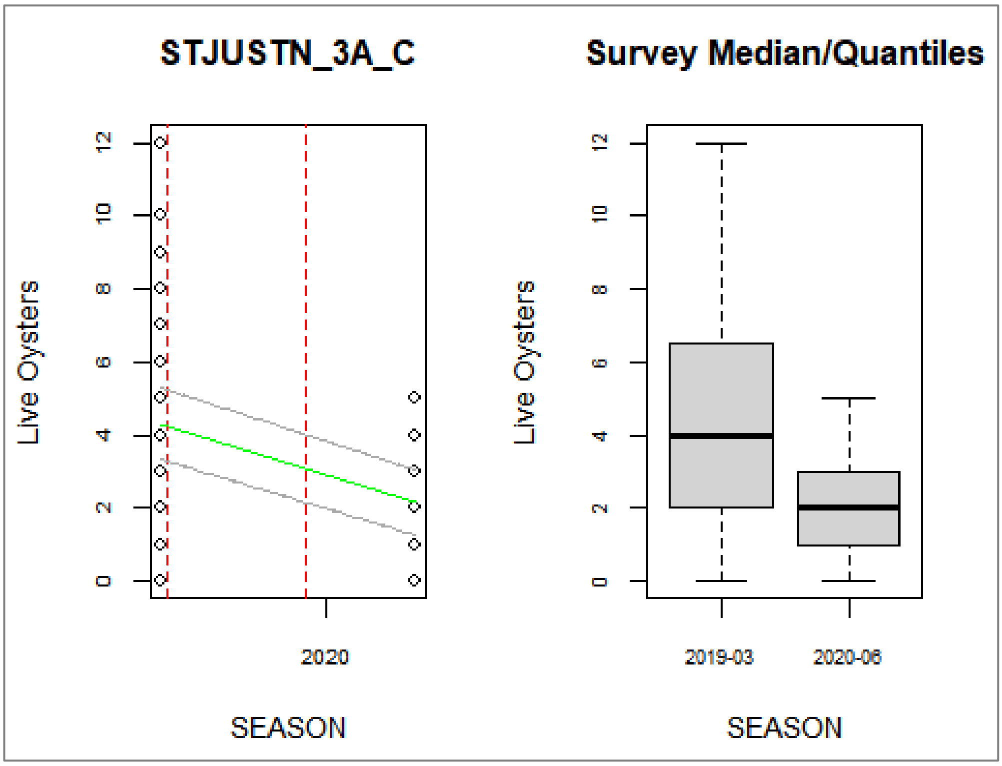
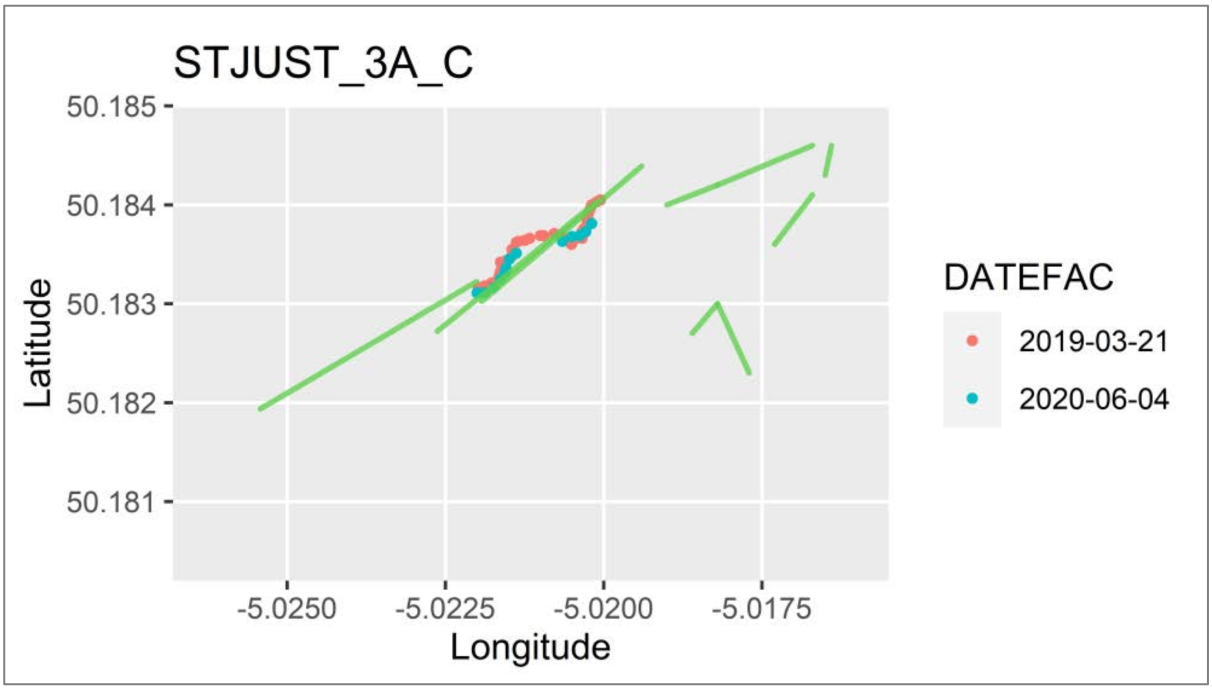


Figure 57: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)



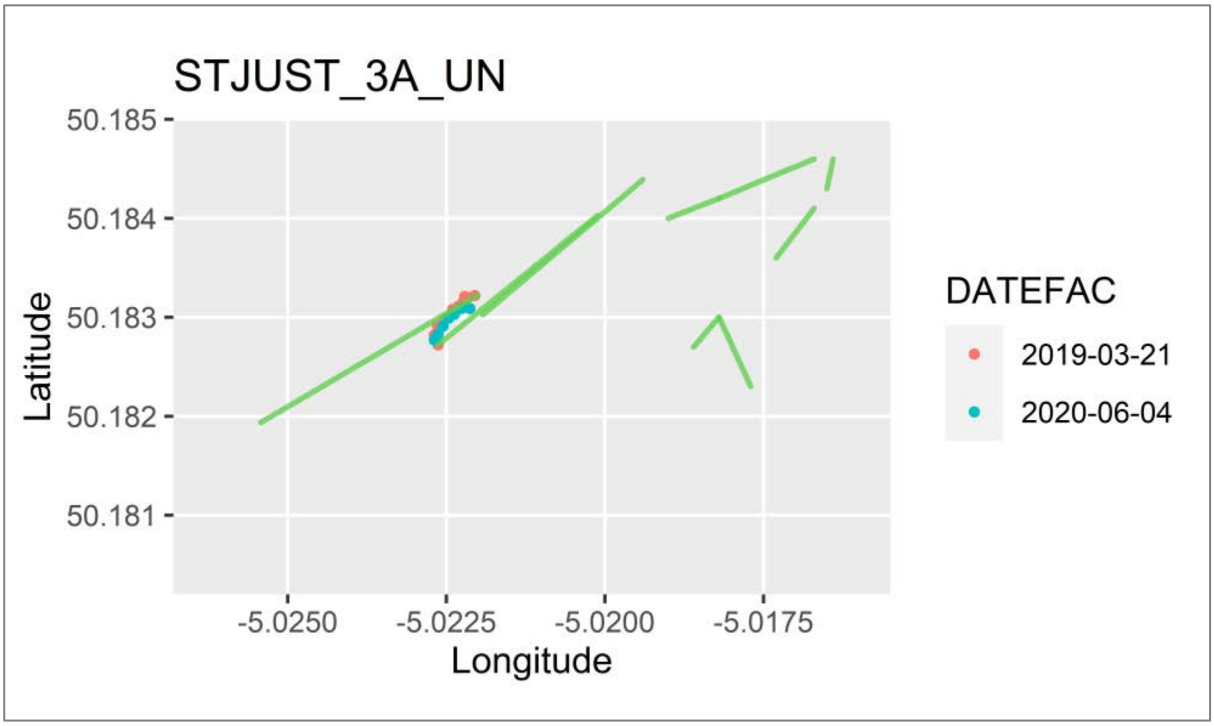


Figure 58: Quadrat points for this combined analysis group, in relation to cull lines for this site

Model 7: Results for STJUSTN_3BC_C (incl. STJUSTN_3B_PC and STJUSTN_3C_C Combined)

The dataset for this model contains data from two analysis groups as the information around cull lines were unclear in QGIS suggesting it was only partially culled. Lines became clearer in R demonstrating the area was covered by the same culls, plus there is a walkover point with an additional date in QGIS. Therefore, this model contains points from groups which had two years of survey with a one year interval, STJUSTN_3B_PC (18/02/2019 (n=17), and 04/06/2020 (n=20)) and STJUSTN_3C_C (11/02/19 (n=30), and 04/06/2020 (n=18)). Cull lines suggest a cull occurred 27/11/2019 and an additional point was from 14/10/2019. Combining these datasets improved the model fit considerably but it was still fractionally over dispersed. Regardless, there was an extremely significant (less than 0.001) reduction in population growth between surveys with a decline of -54.54% per annum.

Results of model 7 STJUSTN_3BC_C

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	6.57	5.66-7.49				
COEFFICIENT ESTIMATE	1.87	1.4-2.34	0	0.09	45.8	**1.22**
TOTAL GROWTH IN %	-71.58					
ANNUAL GROWTH IN %	**-54.64**					

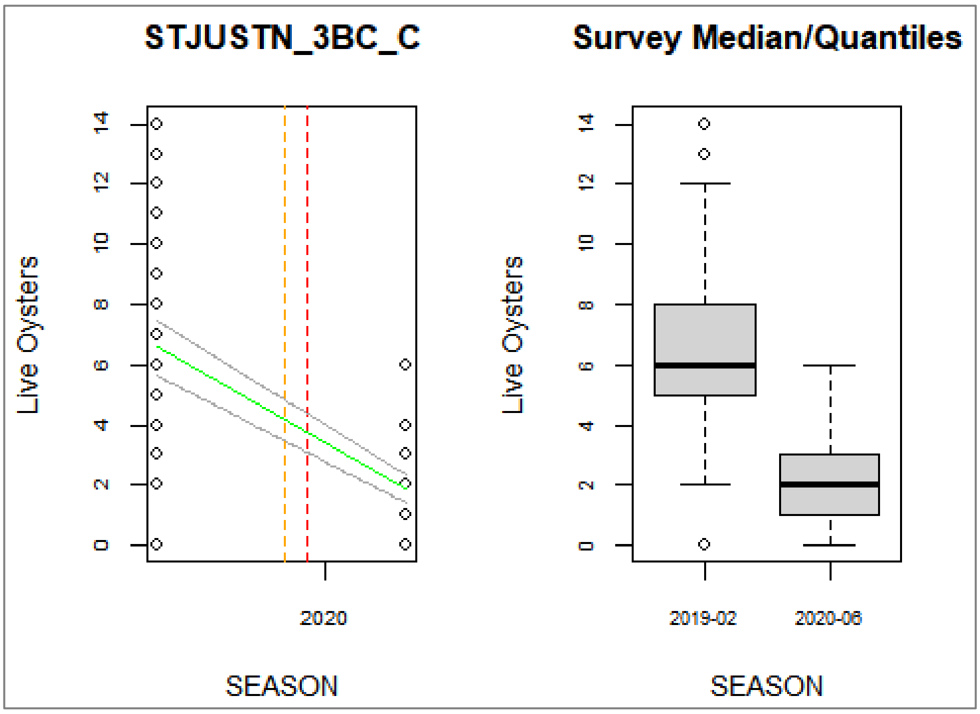
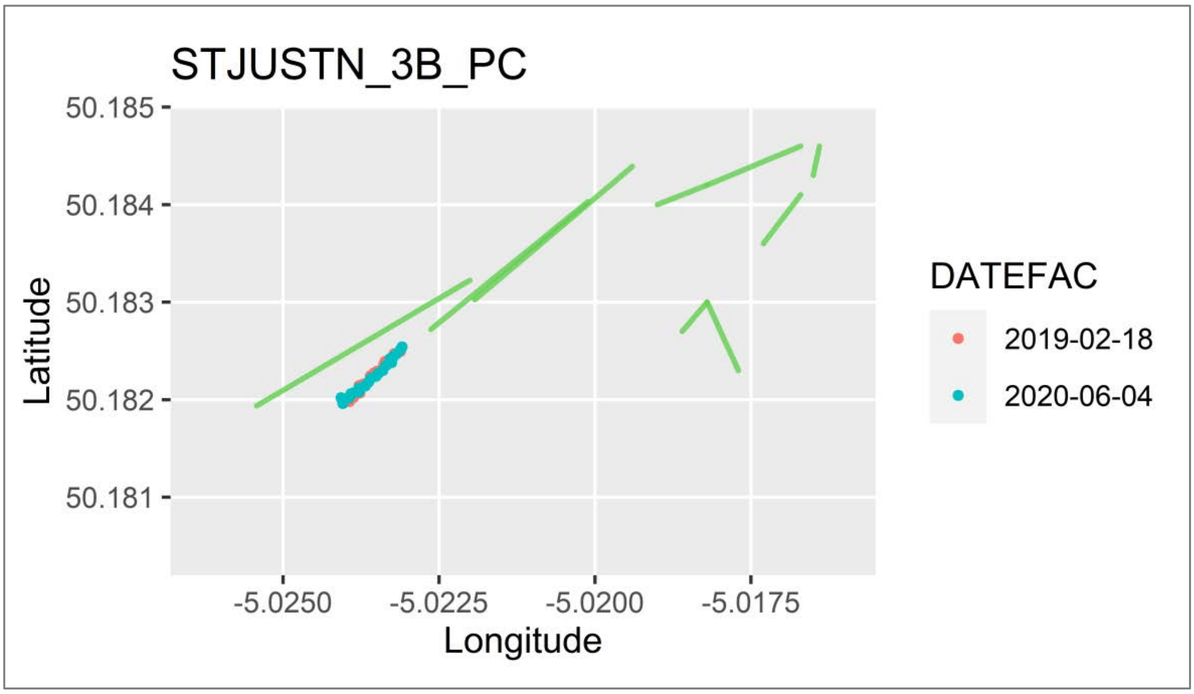


Figure 59: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)



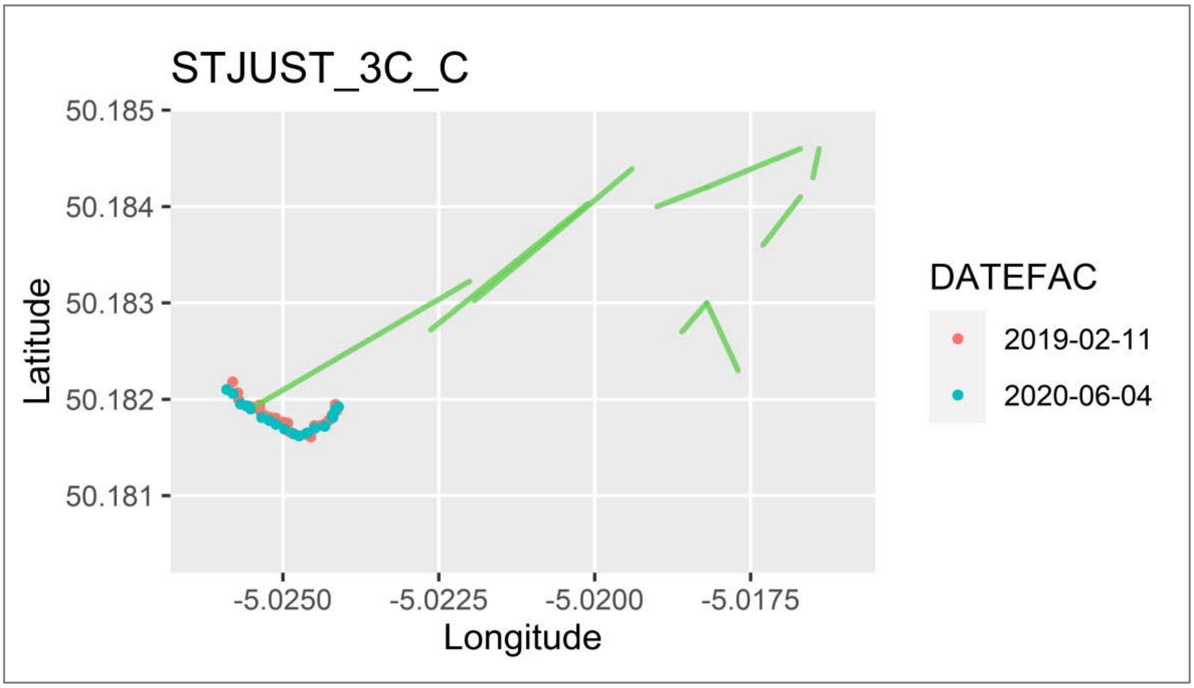


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Figure 60: Quadrat points for this combined analysis group, in relation to cull lines for this site

Site 4: Restronguet Creek, Fal Estuary

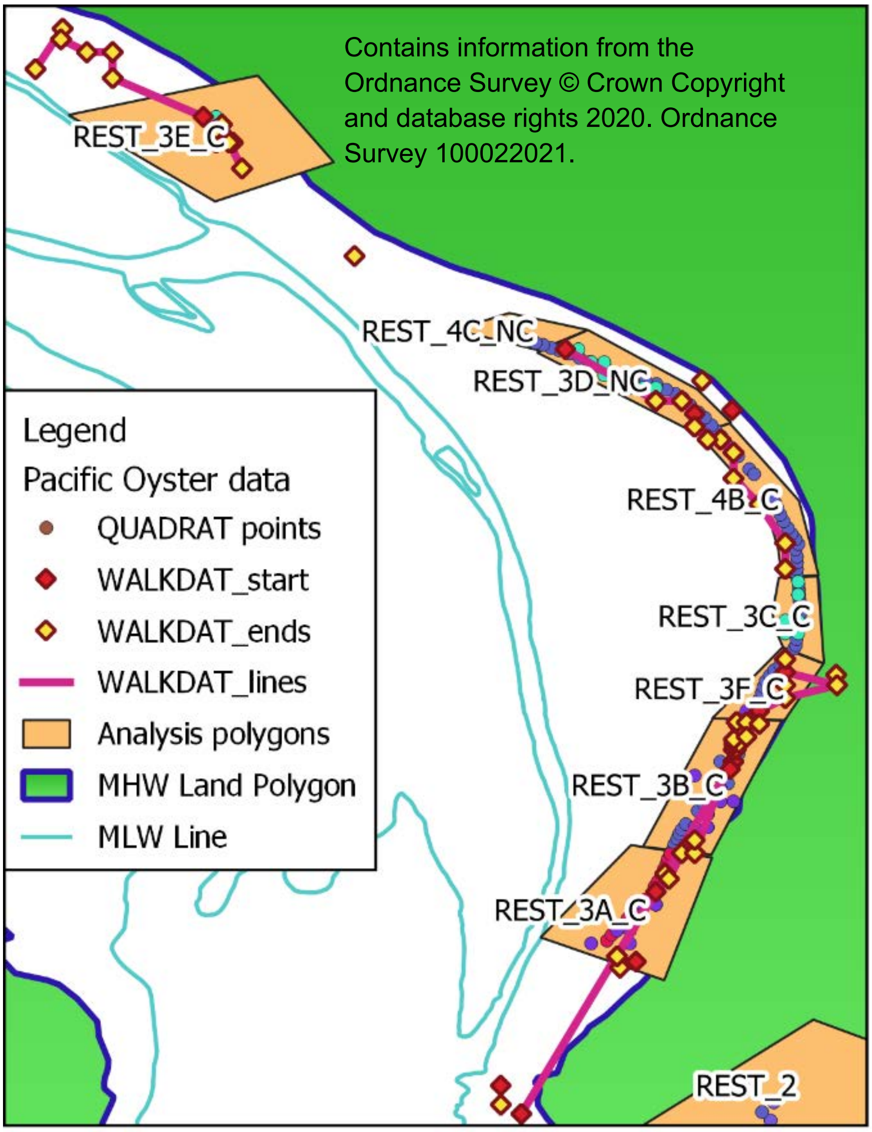


Figure 61: Quadrats, walkover start and end points and analysis polygons mapped in QGIS, at Restronguet Creek, Fal estuary

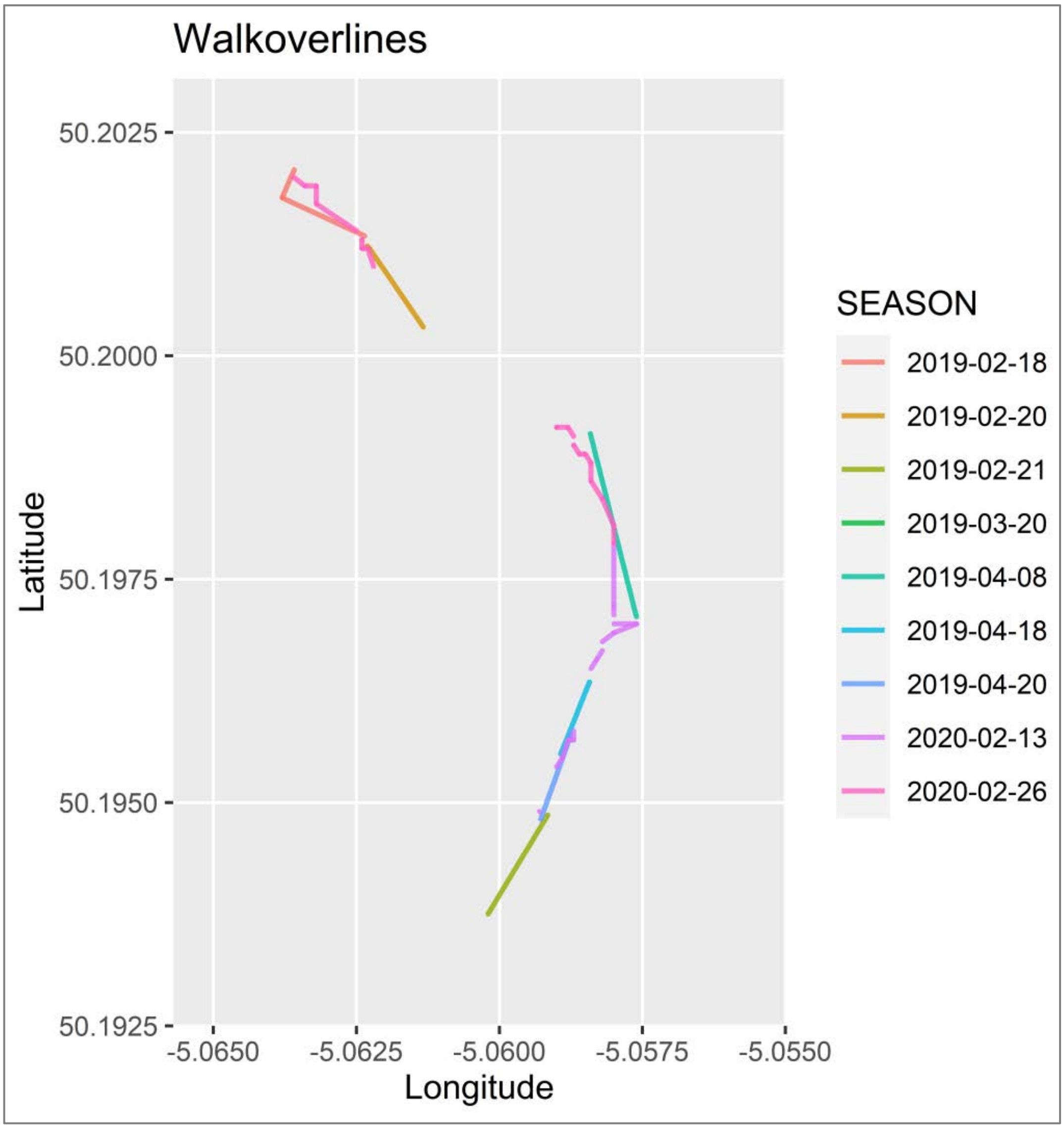


Figure 62: Cull lines mapped in R, at Restronguet Creek, Fal estuary

Model 8: Results for REST3_C

The model REST3_C contains data from 3 years of survey with a two and then one year interval (combined dates 18/01/2019 and 23/01/2019 (n=41), and 13/02/20 (n=35)). There were lines indicating culls on a cull on 07/12/2018, 21/02/2019 (small overlap), 08/04/2019, 18/04/2019, 20/04/2019. A further cull occurred afterwards on 13/02/2020. All model diagnostic thresholds were met. There was a significant (0.02) reduction in population growth of -28.67% per annum.

Results of model 8 REST3_C

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	4.63	3.65-5.62				
COEFFICIENT ESTIMATE	3.17	2.37-3.98	0.02	0.13	5.45	**1.19**

TOTAL GROWTH IN %	-31.56					
ANNUAL GROWTH IN %	**-29.5**					

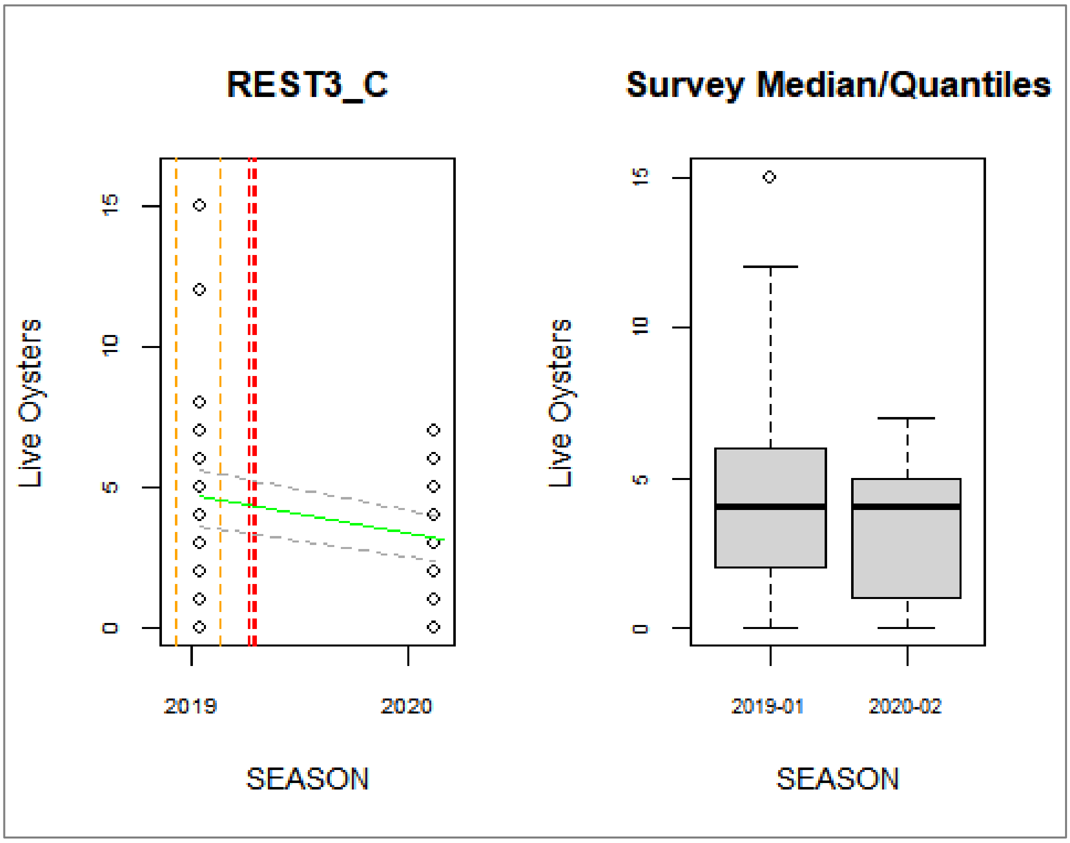


Figure 63: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

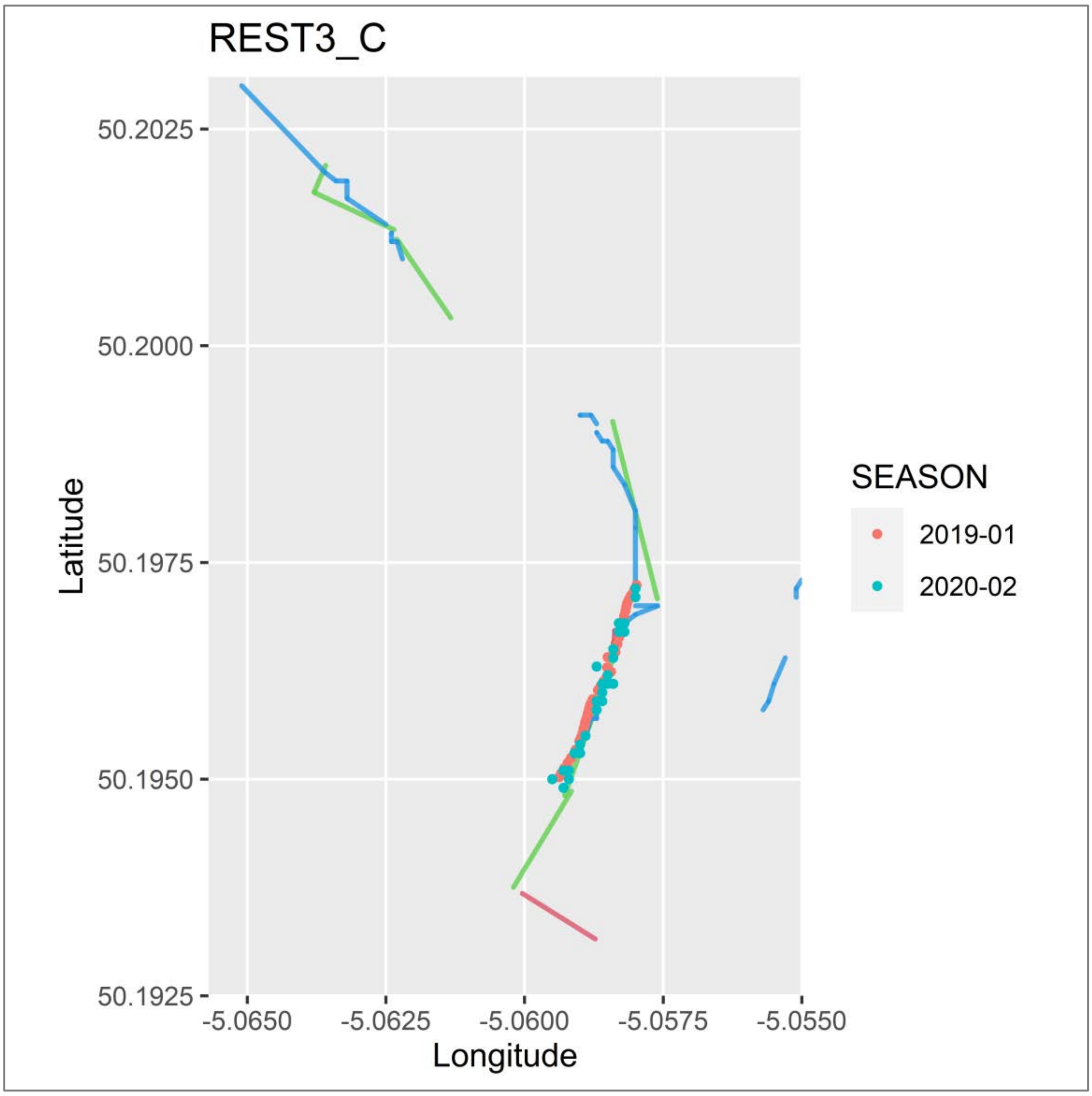


Figure 64: Quadrat points for this analysis group, in relation to cull lines for this site

Model 9: Results for REST3_PC

The model REST3_PC contains data from 2 years with a 1 year interval (combined dates 18/01/2019 and 20/02/2019 (n=35), and 26/02/2020 (n=29)). Points from the 20/02/2019 survey were merged with the 18/01/2019 survey as these jointly covered the area. Initially it looked like these areas were only partially culled, but the data was clearer in R where lines and points indicated a cull occurred on the 08/04/2019. There are also walkover points partially covering these data points from the 13/02/2020 and 26/02/2020, but the information from the Wildlife Trusts indicates there were no culls following these surveys. A population reduction of -22.38% per annum was calculated. All model diagnostic thresholds were met so the trend is likely to be true, but the p statistic showed a 0.14 (14%) probability of no significant difference between years.

Results of model 9 REST3_PC

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	4.17	3.14-5.2				
COEFFICIENT ESTIMATE	3.14	2.23-4.05	0.14	0.38	3.2	**1.05**
TOTAL GROWTH IN %	-24.78					
ANNUAL GROWTH IN %	**-22.32**					

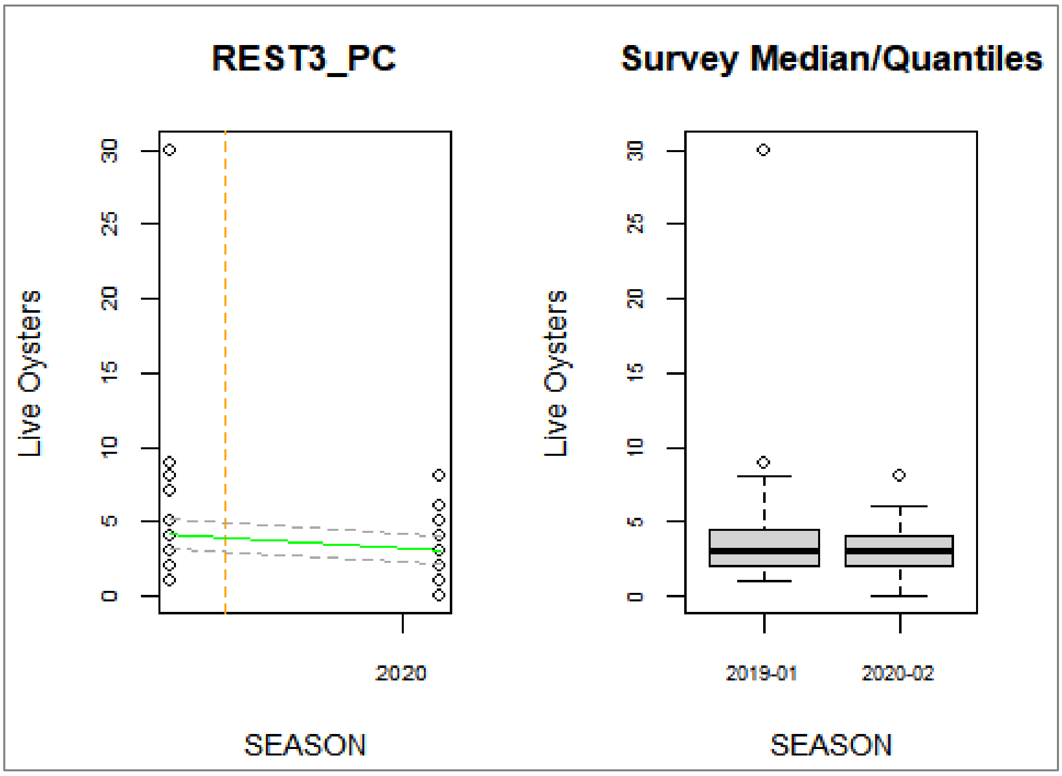


Figure 65: Survey count data, model results (green line with grey standard error lines), and cull dates where they occur (red are full culls, orange are partial / possible culls)

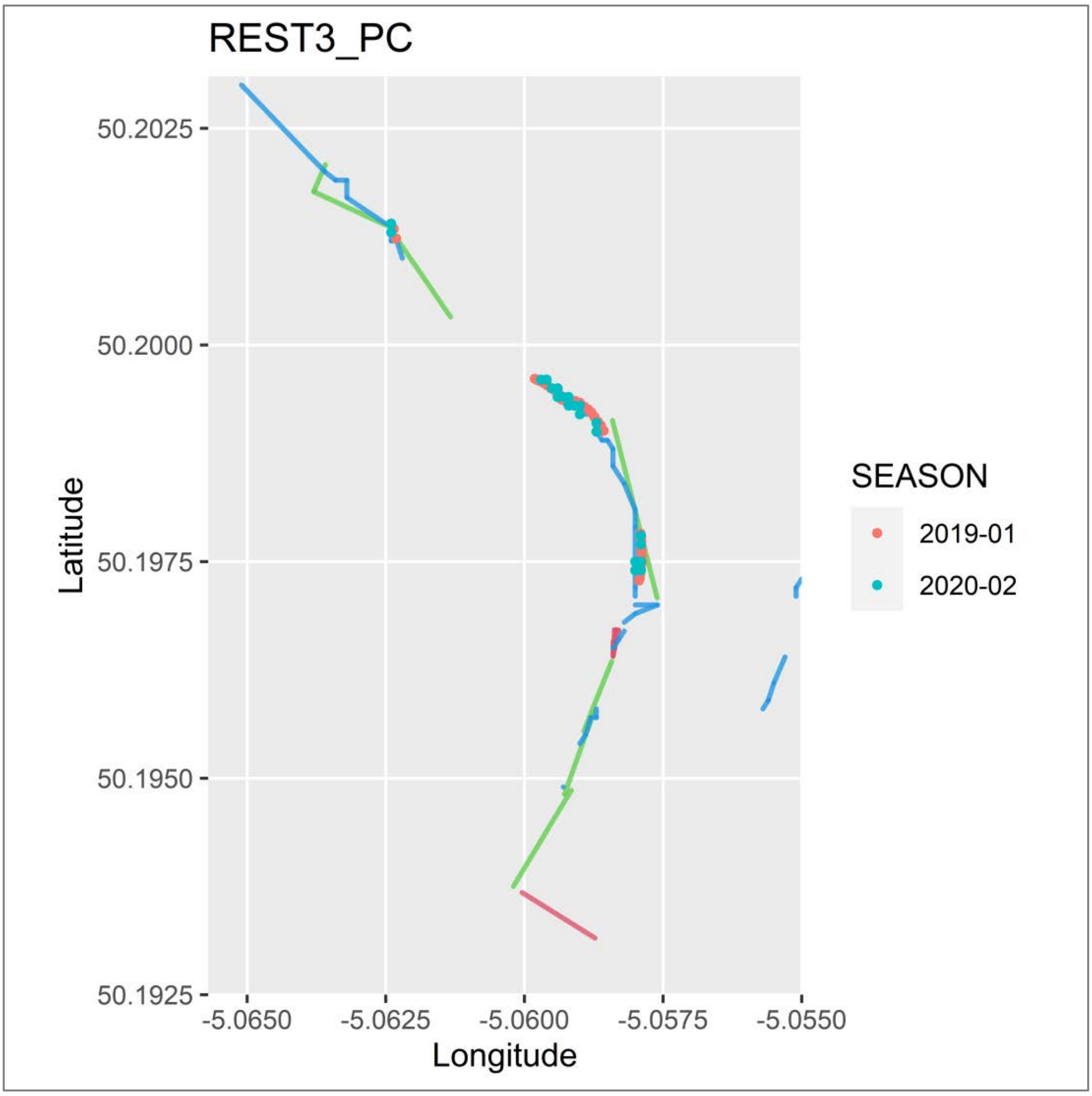


Figure 66: Quadrat points for this analysis group, in relation to cull lines for this site

Sites 5 and 6: Noss Mayo and Newton Ferrers (The Yealm Estuary)

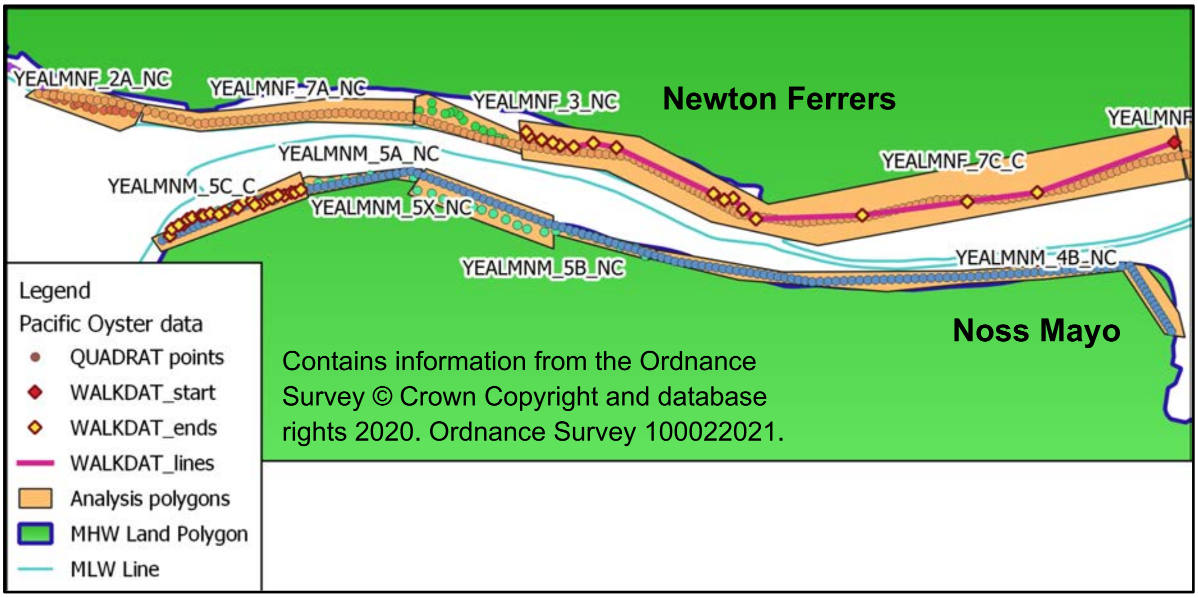


Figure 67: Quadrats, walkover start and end points and analysis polygons mapped in QGIS, at Noss Mayo and Newton Ferrers, Yealm estuary

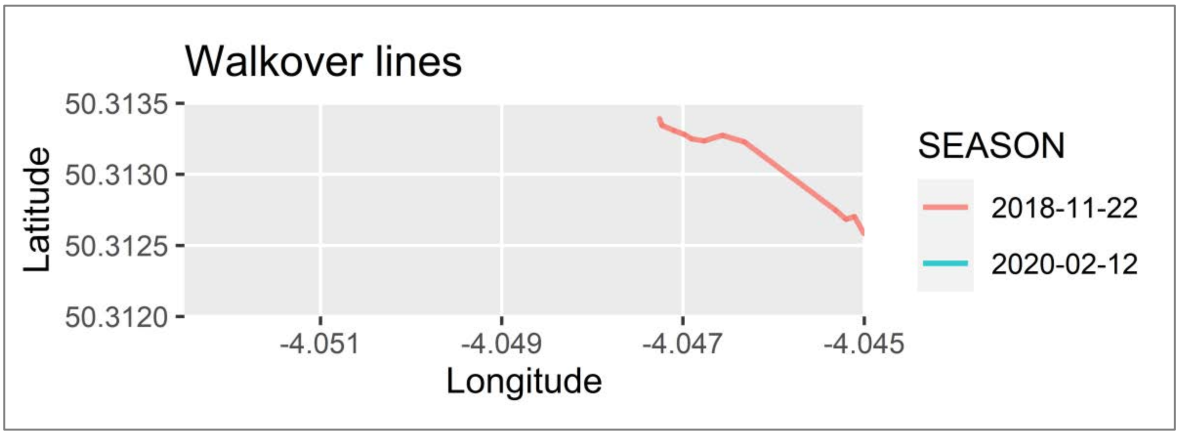


Figure 68: Cull lines mapped in R, at Noss Mayo and Newton Ferrers, Yealm estuary

Model 10: Noss Mayo 1: Results for YEALMNM_5_CB

The YEALMNM_5_CB model contains data from surveys of two years, almost three years apart (10/05/2017 (n=18), 23/03/2020 (n=26)). There are end points from a walkover survey, but no start points so cull lines were not identified in R. However, a cull training day was confirmed by staff at Natural England, which occurred on 01/02/2017 before the quadrat surveys. All goodness of fit measures were met but the model was slightly over dispersed at 1.23. The data in this model is from the same surveys as the next model YEALMNM_5_NC but the conditions in this group differ as it was culled during the NE training day prior to surveys. There was a significant (0.018) growth in population in between the surveys which both took place after the training cull, calculated at 20.34% per annum.

Results of Model 10 YEALMNM_5_CB

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	4.11	2.25-5.97				
COEFFICIENT ESTIMATE	9.87	5.49-14.26	0.02	0.17	15.64	**1.23**
TOTAL GROWTH IN %	58.37					
ANNUAL GROWTH IN %	**20.34**					

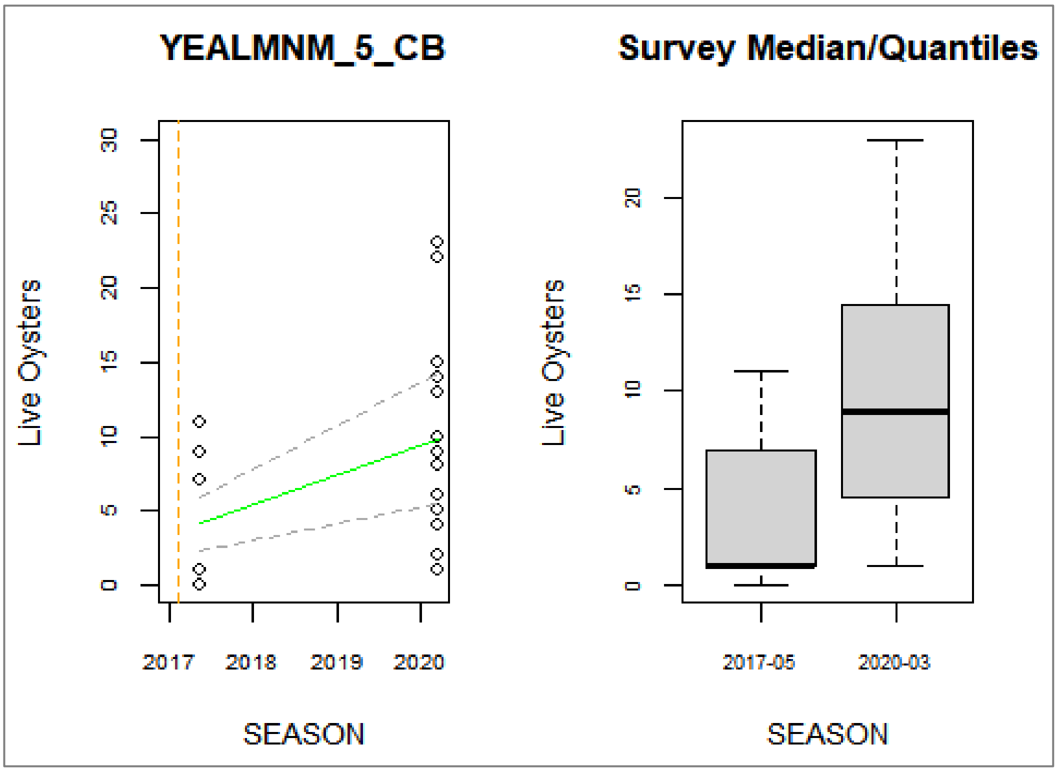


Figure 69: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

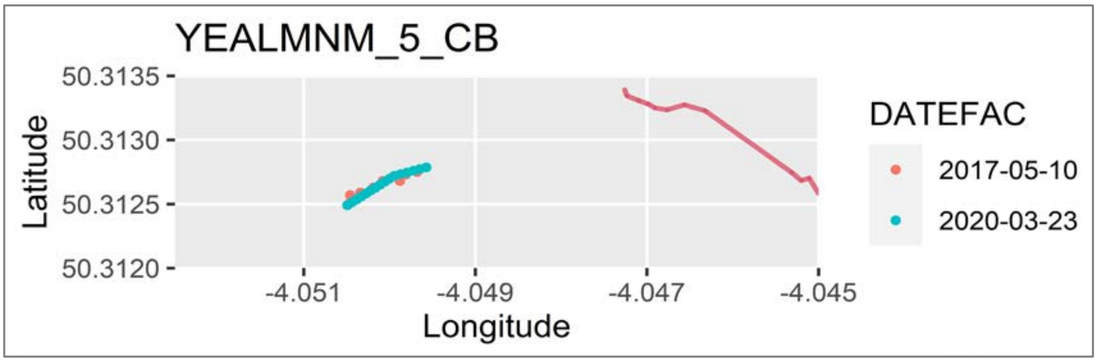


Figure 70: Quadrat points for this analysis group, in relation to cull lines for this site

Model 11: Noss Mayo 1: Results for YEALMNM_5_NC

The YEALMNM_5_NC model contains data from surveys from two years, almost three years apart (10/05/2017 (n=34), and 23/03/2020 (n=31)). The best model was a GLM negative binomial, and all goodness of fit measures were met, but the model is slightly over dispersed at 1.22. The population growth rate is increasing with a growth rate of 6.77% per annum. This is lower than model YEALMNM_5_C (20.33% per annum) which was culled prior to the surveys. This difference is not necessarily an effect from the cull, it could be for example that in this area the population is already approaching a carrying capacity so population growth has slowed, whereas the areas culled had not.

Results of model 11 YEALMNM_5_NC

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT	7.82	5-10.65				
COEFFICIENT ESTIMATE	9.71	6.08-13.34	0.42	0.11	0.86	**1.22**
TOTAL GROWTH IN %	19.43					
ANNUAL GROWTH IN %	**6.77**					

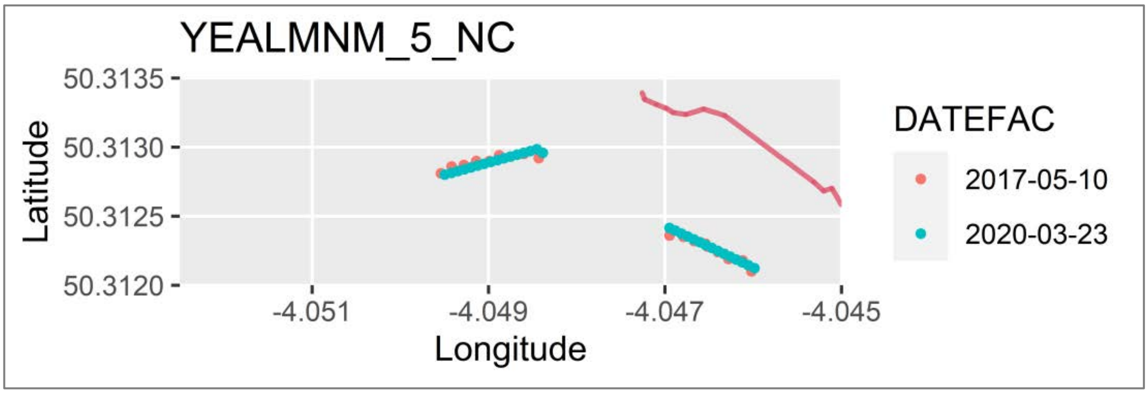


Figure 71: Quadrat points for this analysis group, in relation to cull lines for this site

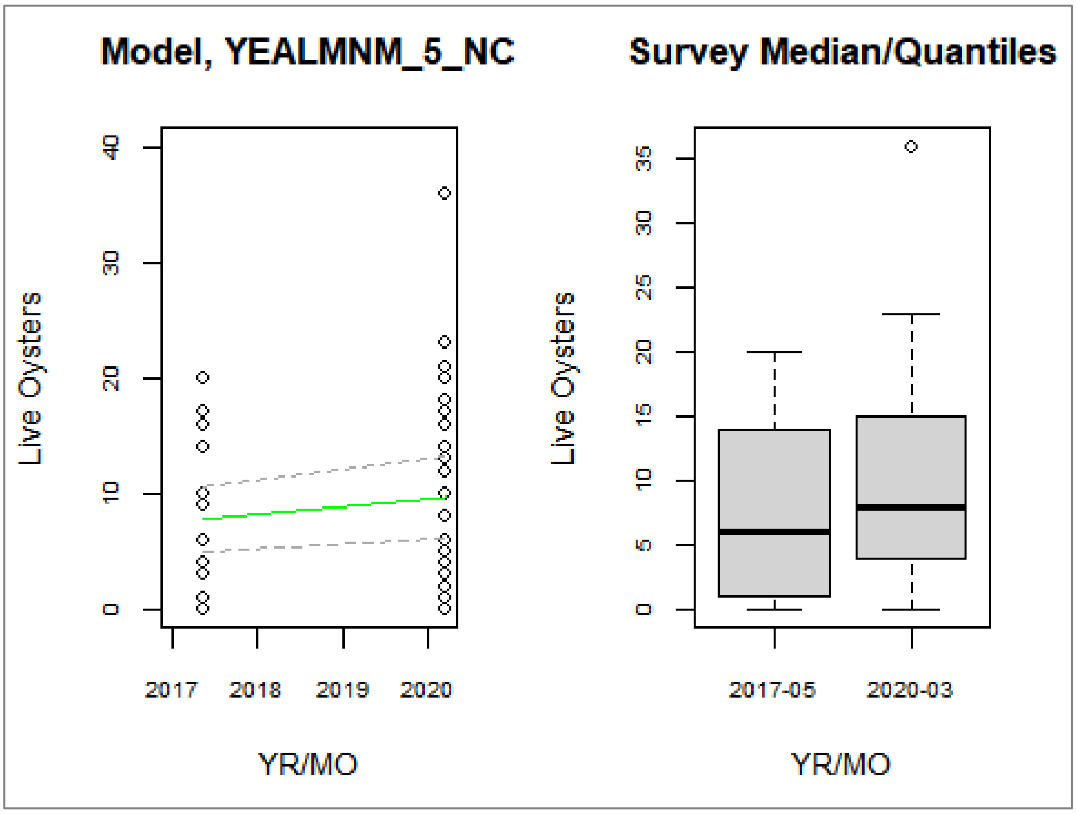


Figure 72: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

Model 12: Noss Mayo 2: Results for YEALMNM_5X_NC

The YEALMNM_5X_NC model has data from the same surveys and conditions as model YEALMNM_5_NC above (10/05/2017 (n=22), and 23/03/2020 (n=20)), but there was some uncertainty around the path taken as points appeared to be above mean high water so a decision was made to treat these separately. Again, this is one of the few sites where there is some certainty that a cull has not occurred. A population growth rate of 13.51% per annum was calculated, and most model diagnostic measures were met, but the model was fractionally over dispersed (1.23). There is also an 11% probability the years are not significantly different.

Results of Model 12 YEALMNM_5X_NC

MEASURE	RESULTS	CI	P_VALUE	CHIS Q	DEV	ODP
INTERCEPT	6.18	3.67-8.69				
COEFFICIENT ESTIMATE	10.1	5.95-14.25	0.11	0.15	5.33	**1.23**
TOTAL GROWTH IN %	38.79					
ANNUAL GROWTH IN %	**13.52**					

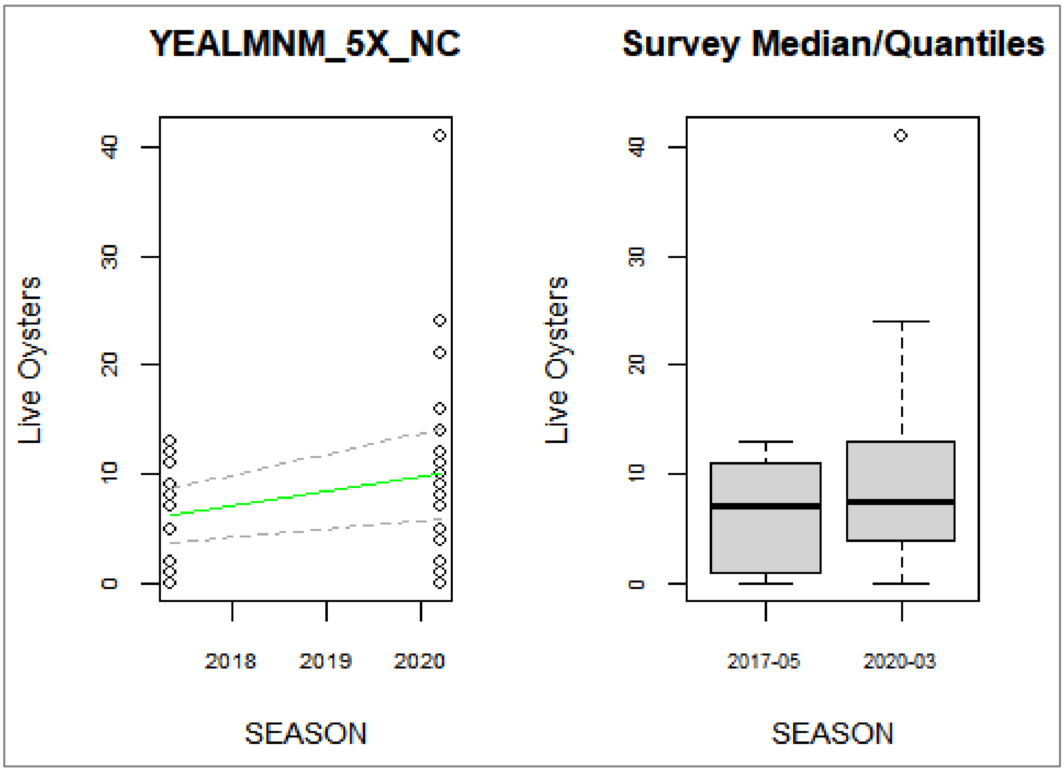


Figure 73: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

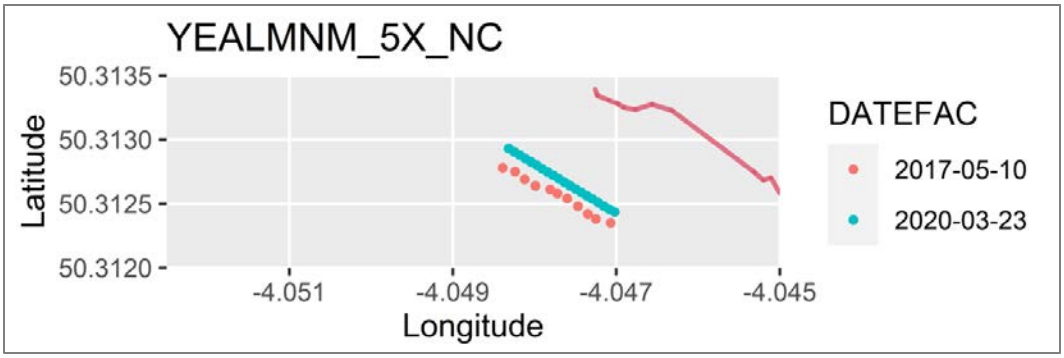


Figure 74: Quadrat points for this analysis group, in relation to cull lines for this site

Model 13: Newton Ferrers 1: Results for YEALMNF_2_PC

This model contained data from two surveys 1.5 years apart (24/01/2019 (n=13), and 04/06/2020 (n=14)). There is no indication of culling at this site in QGIS or in R. A reduction in population growth has been calculated at –28.97% per annum, and all model diagnostics were met. This differs from neighbouring sites in Newton Ferrers and Noss Mayo with the same conditions, where Pacific oysters have increased. It has since been confirmed by the project officers that there has been the removal of Pacific oysters by the general public at this site. A line representing these culls is added to the plot below, but the actual dates and nature of these oyster removal events are unknown.

Results of model 13 YEALMNF_2_PC

MEASURE	RESULTS	CI	P_VALUE	CHIS Q	DEV	ODP
INTERCEPT	8.85	5.77-11.92				
COEFFICIENT ESTIMATE	5.36	3.41-7.3	0.06	0.34	12.29	**1.09**
TOTAL GROWTH IN %	-39.44					
ANNUAL GROWTH IN %	**-29**					

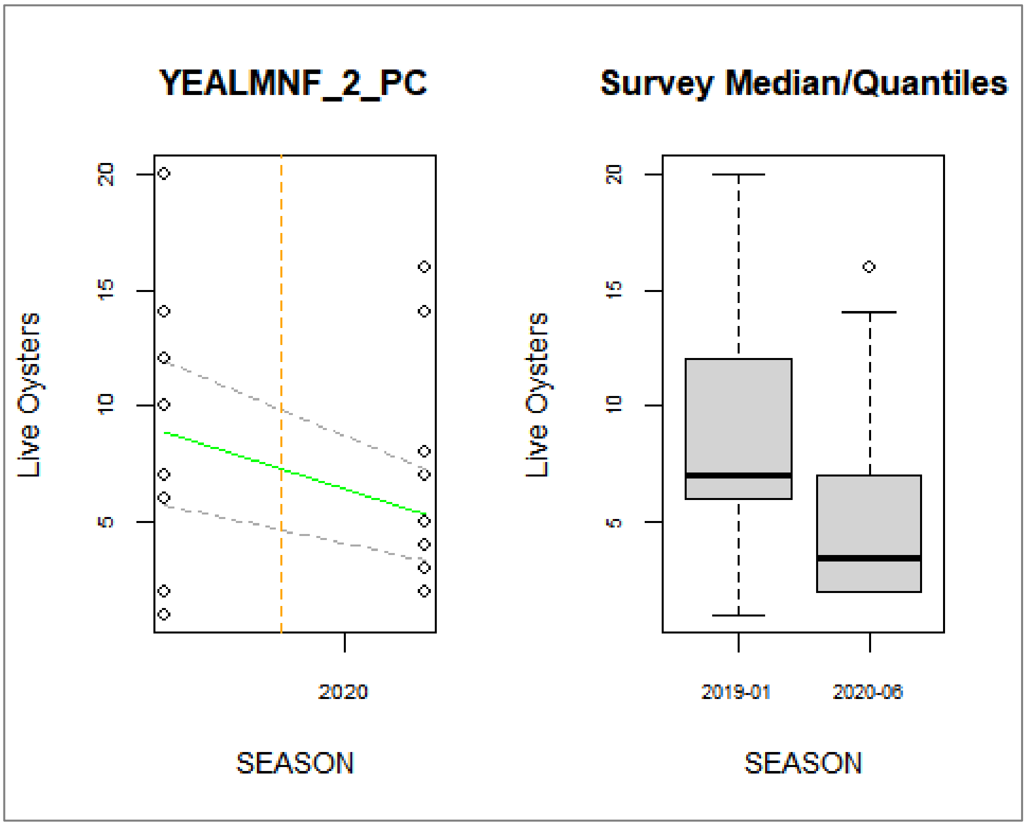


Figure 75: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

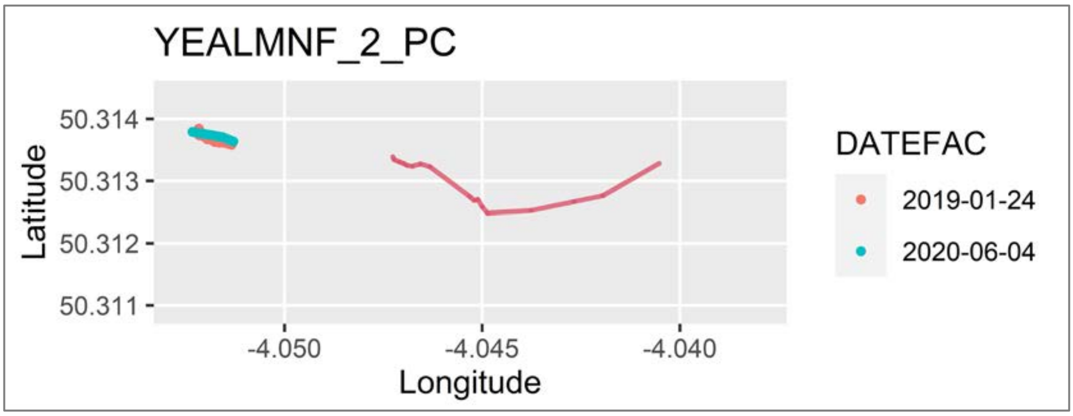


Figure 76: Quadrat points for this analysis group, in relation to cull lines for this site

Model 14: Newton Ferrers 2: Results for YEALMNF_3_NC

The model YEALMNF_3_NC was very close to YEALMNF_2_PC but with slightly different years of survey (22/11/2018 (n=14), and 04/06/2020 (n=16)), and a slightly longer interval between surveys. Whilst the points are very close to a cull line, there does not seem to be any overlap so was considered unculled. A population growth rate of 20.71% per annum was calculated, all model diagnostics were met, but there is a 14% probability the differences are not significant.

Results of model 14 YEALMNF_3_NC

MEASURE	RESULTS	CI	P_VALUE	CHIS Q	DEV	ODP
INTERCEPT	8.36	5.24-11.48				
COEFFICIENT ESTIMATE	12.25	8.13-16.37	0.14	0.32	6.67	**1.1**
TOTAL GROWTH IN %	31.78					
ANNUAL GROWTH IN %	**20.77**					

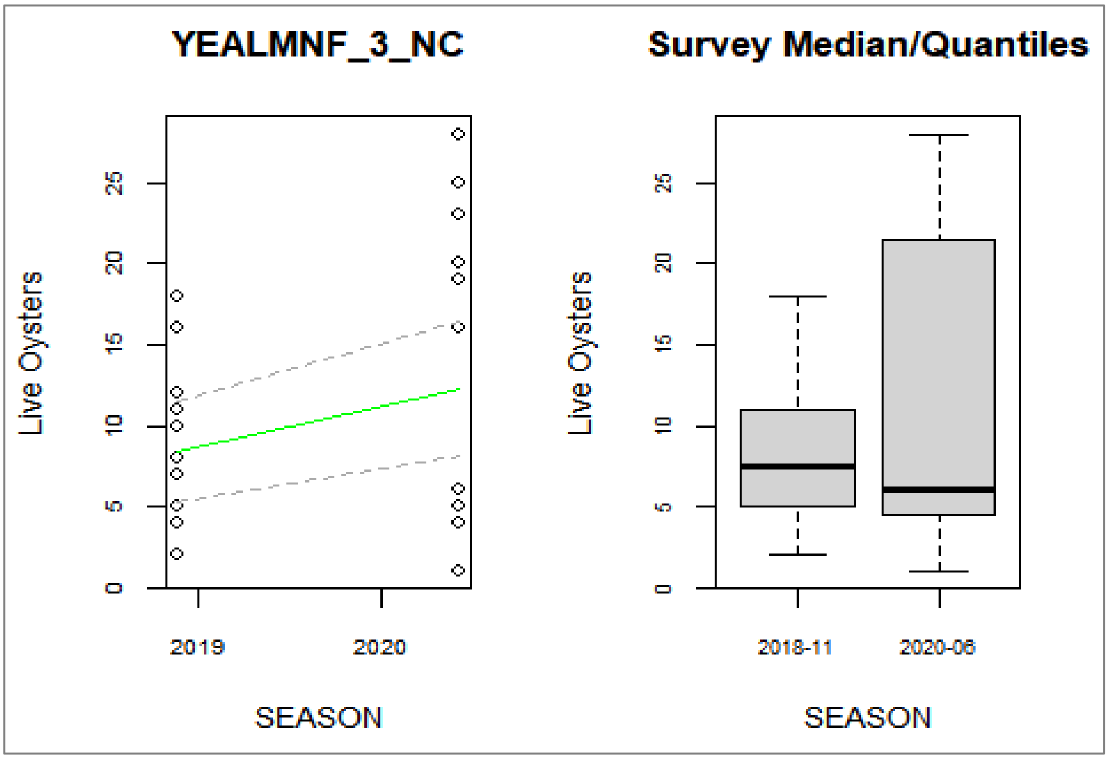


Figure 77: Survey count, model results (green line with standard errors), and cull dates where they occur (red are full culls, orange are partial / possible culls)

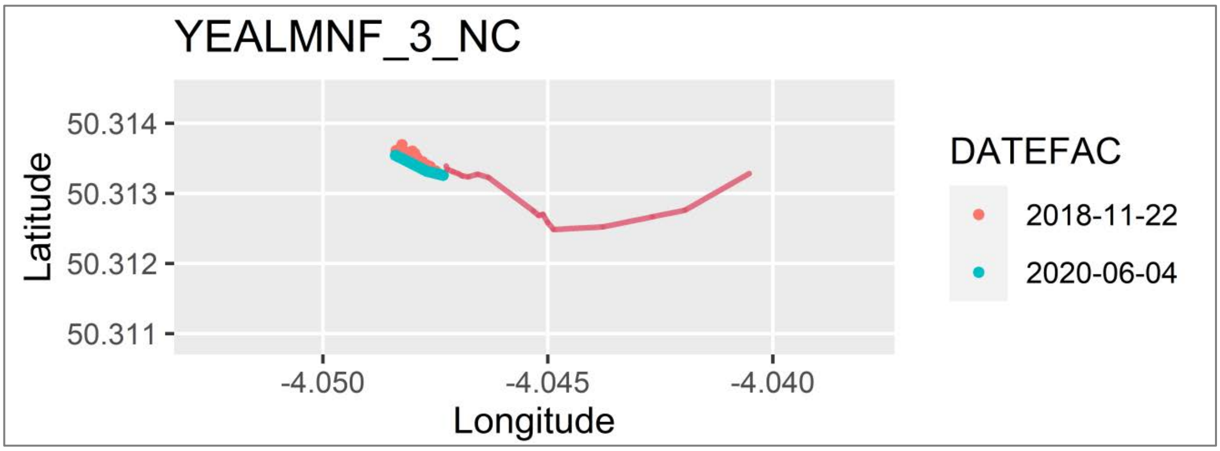


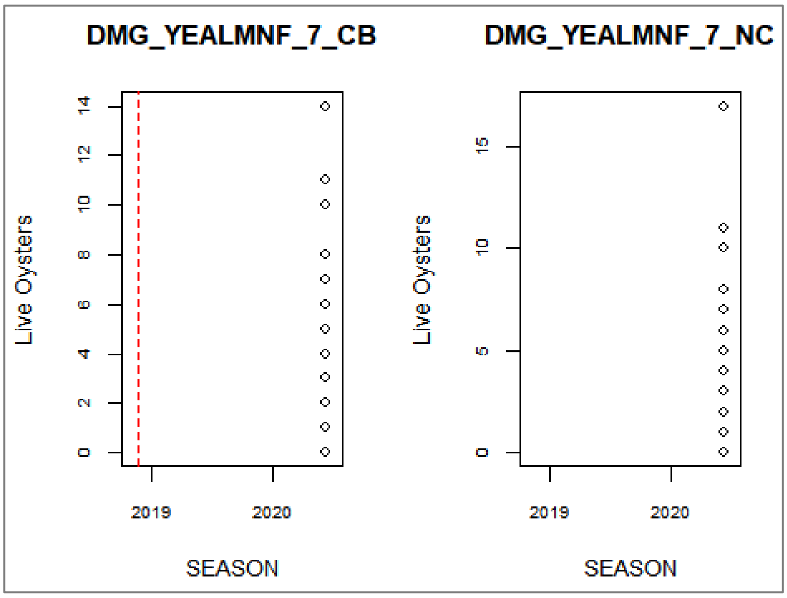
Figure 78: Quadrat points for this analysis group, in relation to cull lines for this site

Model 15: Newton Ferrers 3: Results for YEALMNF_7 (CB & NC)

The data group for YEALMNF_7 is slightly different as it only has one survey year (04/06/2020), but one area was culled before (YEALMNM_CB) the survey on 22/11/2018 (n=101), whereas the other area was not culled (YEALMNM_NC) before (n= 75). This model was dealt with differently as there is no before and after time, so instead of using time as a variable, the areas were treated as factors and the posterior means between the two areas were compared. The model showed that the oyster densities for the two areas were almost identical despite one area being culled before.

Results of model 15 YEALMNF_7

MEASURE	RESULTS	CI	P_VALUE	CHISQ	DEV	ODP
INTERCEPT (	2.16	1.57-2.75				
COEFFICIENT ESTIMATE	2.16	1.47-2.85	1	0.32	0	**1.05**
TOTAL GROWTH IN %	**0.07**					



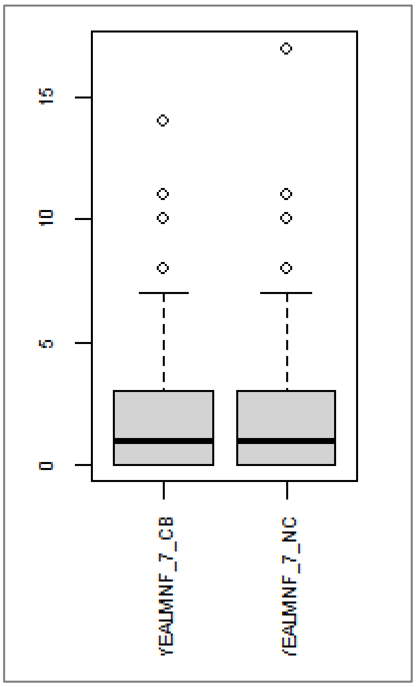


Figure 79: Survey count, and cull dates where they occur (red are full culls, orange are partial / possible culls)

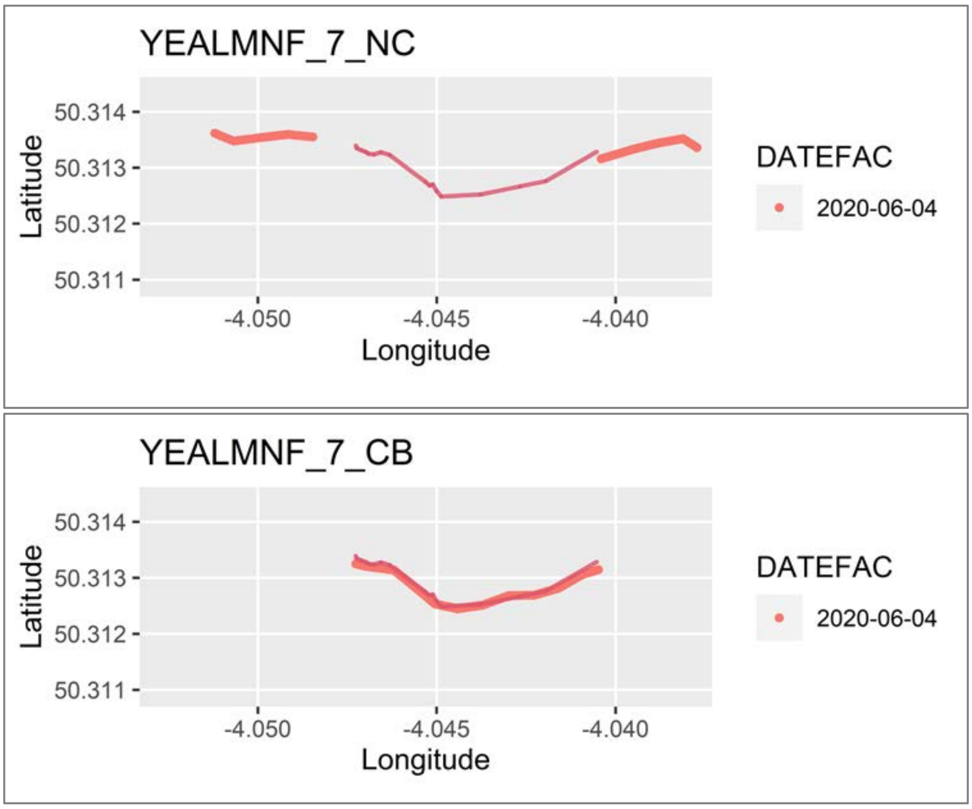


Figure 80: Quadrat points for this analysis group, in relation to cull lines for this site

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