The endangered European native oyster *Ostrea edulis (*L*)* and creation of Marine Conservation Zones: a win – win scenario for fisheries and conservation?

Sarah Allison

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Department of Biological Sciences
University of Essex
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For Annie and John, who were there at the beginning, but not at the end.

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Abstract

The abundance and distribution of *Ostrea edulis* and *O. edulis* beds have been contracting for many hundreds of years as a result of anthropogenic factors, leaving behind the legacy we observe today of a fragmented and severely impacted habitat. In 1995, *O. edulis* (and their associated beds) was designated a Biodiversity Action Plan Species and Habitat, and in 2009, as a Feature of Conservation Importance (FOCI) within the UK Marine & Coastal Access Act 2009. To protect the species, a greater understanding of its abundance and distribution and age structure was needed to ensure designation of Marine Conservation Zones (MCZ). Between 2012 – 2015, Essex Wildlife Trust, Blackwater Oystermans Association and the University of Essex undertook a study of density and distribution of *O. edulis* across the 282 km^2 area known as the Blackwater, Colne, Crouch & Roach recommended MCZ (BCCR). This showed that population aggregations were restricted to four main areas. Size structure within two of these four areas showed a significant lack of <40 mm (shell length) individuals. The highest densities and most even size structure for *O. edulis* populations were all located within actively managed harvesting areas. The study also found low concentrations of larvae in the water column during the breeding season (May – October) suggesting that veliger production is limited which may prevent recovery of populations. In 2013, the BCCR was designated as an MCZ, as a result of the study the recommendation was made to set the conservation objectives from 'maintain' to 'recover'. Subsequently, fisheries restrictions have been implemented to retain breeding stock and a management plan of active restoration implemented. The results emphasise the importance of working in partnership with the fishing industry, statutory nature conservation organisations and NGO's to

recognise traditional aquaculture practices as a conservation tool for the restoration of a MCZ protected feature.

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Glossary

BCCR	Blackwater, Colne, Crouch & Roach
BOA	Blackwater Oystermans' Association
CBD	Convention of Biological Diversity
Cefas	Centre for Environment, Fisheries & Aquaculture Science
CHC	Chichester Harbour Conservancy
D	Distance
DE	Dredge Efficiency
Defra	Department for Environment, Farming & Rural Affairs
EMS	European Marine Site
ENORI	Essex Native Oyster Restoration Initiative
EU	European Union
FOCI	Feature Of Conservation Importance
GES	Good Environmental Status
GIS	Geographic Information System
GPS	Geographical Positioning System
IFCA	Inshore Fisheries and Conservation Authority
IUCN	International Union for the Conservation of Nature
JNCC	Joint Nature Conservation Committee
MAFF	Ministry of Agriculture, Fisheries & Food
MCZ	Marine Conservation Zone
MMO	Marine Management Organisation
MPA	Marine Protected Area

MSFD	Marine Strategy Framework Directive
NE	Natural England
NERC	Natural Environment and Rural Communities
NGO	Non-Governmental Organisation
OSPAR	Convention for the Protection of the Marine Environment of the North East Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
PLD	Planktonic Larval Dispersal
Ramsar	Convention on Wetlands of International Importance
SAC	Special Area Conservation
SAGB	Shellfish Association Great Britain
SIFCA	Southern Inshore Fisheries & Conservation Authority
SPA	Special Protection Area
SSSI	Site Special Scientific Interest
T&MCo	Tollesbury & Mersea Oyster Company
TBT	Tributyl Tin
TRaC	Transitional & Coastal Waters
V	Volume
WFD	Water Framework Directive

Chapter 1: Ecology, Life cycle and UK conservation status

Wood engraving on paper by William Ludwell Sheppard, 1872

1. Introduction

The European native oyster *Ostrea edulis*, has a historical range which stretches throughout Europe from Norway to the Black sea (Laing *et al.,* 2004) inhabiting shallow, sheltered, productive marine environments such as bays, inlets, creeks and estuaries in water depths between 0m - ≥ -4m (Laffoley and Hiscock, 1993). Due to its commercial importance as a fisheries species *O.edulis* has seen significant declines in its numbers and range over the last 150 years, primarily due to over exploitation and lack of management. Estimates place the rate of loss in Europe at over 99%, the species is now described as functionally extinct, (Zu Ermgassen *et al.,* 2012) the true historical extent of *O.edulis* beds throughout Europe is largely unknown. Olsen's piscatorial map produced in 1883 indicates broad areas in which oysters were harvested. (Olsen 1883). This information is unquantifiable but it does indicate areas where oysters were present historically, which can be compared to the areas where oysters are found today. Even with the limited historical data we have it is clear that there has been a significant reduction in the extent of oyster beds in Europe. (Zu Ermgassen *et al.,* 2012).

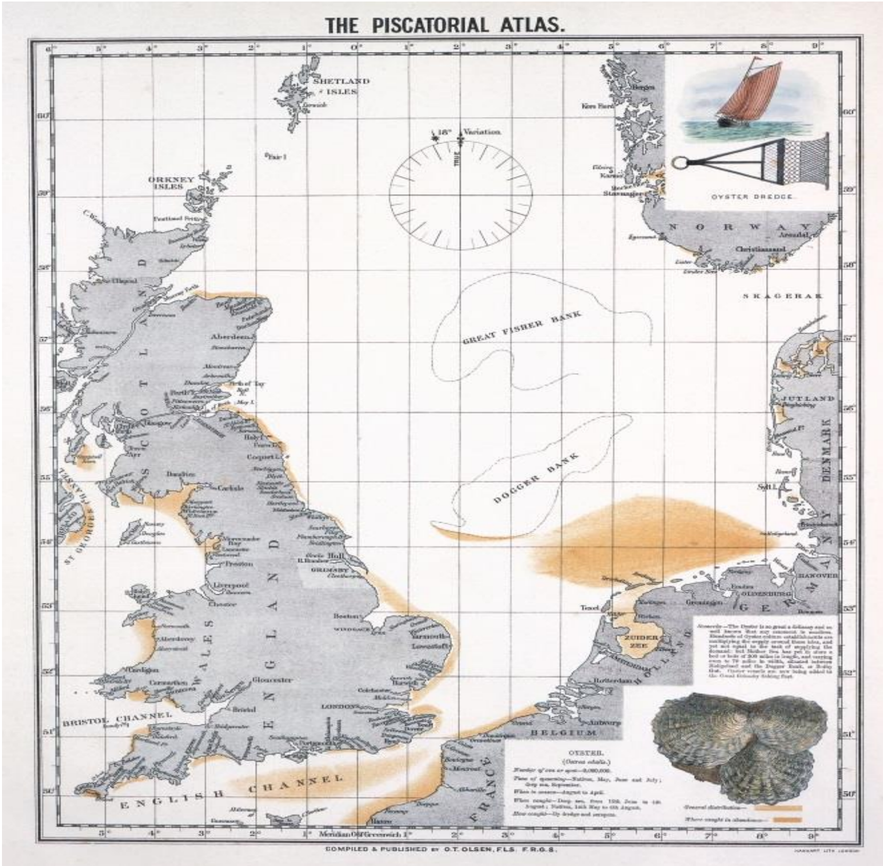

Figure 1 Olsen's Piscatorial Map (1883) - Known *O.edulis* grounds

In a study of the human impacts and shifting baselines of North sea fisheries, Lindeboom (2008) suggests that 20,000 km^2 of oyster beds have been lost since Olsen's 1883 map was produced, significantly altering the biodiversity in the North sea. The reason for the reduction in oyster bed size is generally accepted in the first instance to be as a result of the over exploitation of oysters, subsequent declines were attributed to poor water quality, due mainly to large quantities of sewage entering the inshore estuaries through growing human populations and inadequate provision of sewerage systems, extreme weather conditions and the introduction of pathogens. In the 19th century a burgeoning population, larger boats and an increase in the size of dredging gear meant that extra fishing pressure was exerted onto already severely depleted oyster beds. Such was the demand for oysters that by

1865 oyster beds were so severely depleted that the South of England Oyster Company compiled a report highlighting their concerns. In 1856 Bertram states that '*the natural oyster beds of the United Kingdom are nearly exhausted, for, being free to all comers and from the enormous and increasing demand, the fishermen have dredged them bare'* (Company, 1865). This report is one of the earliest to document the need for restoration through a series of measures including the far-sighted statement that '*private breeding beds are an actual necessity'* and that the natural and artificial cultivation of oysters was necessary to keep the industry open. With the UK oyster populations severely reduced and breeding stock lost, subsequent declines were inevitable. The first of many reports into the cause of the decline was documented by Orton (1920). Lack of recruitment and the onset of disease were recorded (Orton, 1924) and since then new diseases have emerged (Bannister *et al .* 1982, Bannister and Key, 1982, Bucke *et al.,* 1984) with natural rejuvenation of the beds hampered in recent decades by a succession of disease epidemics (Kennedy and Roberts, 1999, Woolmer *et al.* 2011, Kennedy *et al.,* 2011) and severe weather events (Waugh, 1964). From December 1962 to March 1963 an extreme weather event known as 'the big freeze' affected the British Isles and much of Europe. Sea temperatures in the Essex Estuaries dipped as low as -1.8^{o}C, the lowest in recorded history. Temperatures remained below freezing for four months, not increasing until March 1963 (Crisp, 1964). *Ostrea edulis* beds present in the Essex estuaries could not withstand sustained low temperatures and the area suffered significant mortalities with documented losses of between 70-95% of all beds (Waugh, 1964).

The most recent contributor to the decline of *O.edulis* in the UK is the parasitic Haplosporidian *Bonamia ostreae,* first described by Katkansky *et al.* (1969). By 1979 the disease had spread globally due to a lack of biosecurity measures in the buying and selling of live oysters. The outbreak in Europe was attributed to a consignment of infected juveniles imported from California (Elston *et al.,*1986). The initial European outbreak in 1979 caused catastrophic oyster mortality. In France studies reported up to 80% mortality (Comps *et al.,* 1980, Pichot *et al.* 1980, Balouet *et al.,* 1983).

Described as an economically significant protistan parasite (Carnegie *et al.,* 2003) transmission of the disease is direct (Elston *et al.,* 1987) spreading readily throughout dense populations of oysters (Balouet *et al.,* 1983). It is still unclear how the parasite infects the individual oyster but studies indicate the pathway for infection occurs during filtration of seawater for respiration (Bucke, 1988). Studies also suggest that the parasite has the capacity to infect an intermediate host or vector, as well as infecting by direct transmission (Culloty and Mulcahy, 2007, Lynch *et al.,* 2007). Recent observations indicate that infected adults may infect larvae during development in the trochophore stage and into the motile veliger stage of the life cycle, thus spreading infection further (Arzul *et al.,* 2011).

Van Banning (1990) demonstrated that even if an area was cleared of *O.edulis* and left fallow for several years, reintroduced *O.edulis*, quickly developed infection, supporting the idea that a reservoir of infection had persisted within the oysters themselves.

1.1 Bonamia introduction to the UK

First detected in England in the River Fal in Cornwall in 1982, *B. ostreae* spread rapidly throughout the UK. By the summer of 1982 it was detected in the River Blackwater in Essex, in 1983 it was discovered in the Helford River in Cornwall and by 1986 it had spread to Poole Harbour and the Solent (Laing *et al.,* 2014). By 1987 the disease was formally reported to be present in Ireland (McArdle *et al.,* 1991, Culloty and Mulcahy, 2007) and in Wales and Scotland in 2006 (Woolmer *et al.,* 2011). Once *Bonamia* is present in an area eradication is not possible the only option is control (Culloty and Mulcahy, 2007).

In France, management practices such as decreased densities of cultured stocks have been employed with some success (Baud *et al.,* 1997). Elsewhere, such as in Scotland, techniques have been employed such as growing oysters in deep water where temperatures are lower and infection is less virulent as a result (Culloty and Mulcahy, 2007). Current oyster husbandry techniques employed in Essex are derived from a study conducted by Robert *et al.,* (1991) which suggests rotating oyster beds and adhering to a short term 1 year culture period to reduce the likelihood of mass oyster mortalities. Essex Oystermen destroy all remaining stock stored in the creeks at the end of the oyster season (May – August inclusive) and keep stocking densities artificially low to avoid infection from neighbouring individuals. In a recent study undertaken by Centre for Environment Fisheries and Aquaculture Science (Cefas) in Chichester Harbour, *O.edulis* displaying low level infection rates were laid in high densities and within a year infection the rate had increased to 30% and high mortality was observed. (unpublished 2016) The study also concluded that oysters kept at a density of 1.6 oysters/m² could keep the infection rate to as low as 1%-3% of the population. This is a husbandry technique that has recently been employed in Essex (ENORI meeting minutes).

1.2 Water Quality

Water quality is a key component to healthy shellfish beds. Many anthropogenic inputs into the marine environment deleterious to shellfish health have contributed to their past decline. One of the best documented is TBT (Tributyl tin). TBT was first developed in the 1960's as a way of managing bio-fouling on ships and boats. By the 1970's it was widely used throughout the world as a marine biocide. Negative impacts of TBT were suspected from as early as the late 1960s when it was found to leach into the water column, affecting non-target species.

Research into the decline in productivity of brood stock areas of the non-native aquaculture species Pacific Oyster *Crassostrea gigas* in the Bay of Arcachon in France found TBT to be a major contributing factor (Alzieu *et al.,* 1986, Alzieu, 1991). Studies conducted into the effects of TBT on *O.edulis* found a reduction in digestive capacity, reduced somatic growth and shell abnormalities (Axiak *et al.,* 1995).

Shelbourne (1957) used Dog Whelks (*Nucella lapillus)* to show TBT to be an endocrine disruptor causing masculinisation in females and widespread population decline. By the mid 1980's research had shown TBT to be of major concern to the UK shellfish industry. By 1986 the shellfish industry along the east coast of England reported abnormalities in both the Pacific Oyster *Crassostrea gigas* and *O.edulis* (Thain and Waldock, 1986, Waldock *et al.,* 1987) and the link to TBT was made soon after. Legislation to ban TBT globally was finally agreed in 1999 at the 43rd meeting of the Marine Environmental Protection Committee (Meyer *et al.,* 1997).

The link between TBT and shellfish is conclusive; it is one of the best examples of the input of a substance into the marine environment with catastrophic consequences. The impact of TBT on marine ecosystems was identified and it was banned. However, TBT still present in the environment continues to have an effect on marine life. There are additional anthropogenic inputs entering the marine environment that have the capacity to exert a cumulative effect. *e.g.* anthropogenic contaminants that have the ability to degrade water quality over a number of years, altering the marine environment and contributing to sub lethal effects exerted on species and marine communities. A study by Tornero (2016) examining anthropogenic input contaminants, describes heavy metals, antibiotics, antifouling biocides, PAH's all having lasting significant effects on the marine environment.

Odum (1970) describes this phenomenon perfectly in his book as the 'insidious alteration of the estuarine environment'. The study also details the productivity and sensitivity of the estuarine environment that 'greatly enhances its vulnerability to subtle alteration'. This phenomenon could certainly be argued to be taking place in the estuaries in Essex. In Colchester alone there was an increase in human population of 12.8% in the 11 years between 2001 and 2012 and The Office of National Statistics projects a 10% increase in the population in Essex by 2022, making Essex the fastest growing county in the UK. This population growth increases pressure on the marine environment by adding run off from housing, industrial development and roads and increased quantities of waste water discharged from sewage treatment works and sewage overflow systems into the Essex estuaries. Intensive agricultural practices in Essex lead to the loss of nutrient-rich soils, with run off into estuaries further altering the estuarine environment. The detrimental impacts of increased loadings of treated sewage effluent in hypernutrified waters within shellfish estuaries are relatively well understood (Miller, 2009) but the sub lethal effects of these additional stresses on oyster populations are less well known, especially when assessing these in combination with other human activities in estuaries.

1.3 Ecology of *O.edulis*

Ostrea edulis is a sessile filter feeding bivalve, in the order *Ostreoida*, it is associated with highly productive estuarine or shallow water environments and is found predominantly sub-tidally throughout its range. The species is a known sequential hermaphrodite, a concept first proposed by Orton (1927) and later reviewed by Coe (1932), meaning that following every successful breeding season an individual oyster has the ability to change from one complete gonadal cycle to the other. Nelson (1928) and Hutchins (1947) suggested that temperature is the primary reason behind the geographic extent of the organisms range. Laing (2004) furthers this by suggesting that reproduction is intrinsicly linked to temperature, where spawning and reproduction is triggered by temperatures exceeding 15^{o}C.

This temperature cue initiates the spawning process prompting males to release spermatozeugmata into the water column. This adaptation holds sperm within a carbohydrate matrix allowing it to survive longer in the water column. It is also heavier than seawater enabling the ‘parcel’ to sit lower in the water column nearer to a potential receptive female enabling the female to retrieve the ‘parcel’ on the gill filaments and move to the brood chamber located behind the gills for internal fertilisation and brooding. (Foighil, 1989)

The reproductive strategy *of O.edulis* and the development of the motile larval stage known as the veliger has interested biologists since the development of the earliest microscopes. The first study by Horst (1884), was constrained by the limitations of early microscope technology and focused on the later stages of veliger development. Since then with advances in microscopy many studies have focused on understanding the reproductive process in increasingly finer detail. Several authors: Amemiya, (1926), Orton, (1921), Orton, (1927), Cole, (1941), Cole, (1942), Korringa, (1952), Hickman and Gruffydd, (1971) were all influential in the development of our understanding of the reproductive process, but the most comprehensive study which is still used today is Waller (1981), which documented reproductive development through detailed drawings, photographs and text of each stage of development and its observed characteristics.

Fertilised females retain the fertilised eggs in a brood chamber for up to 10 days where the initial cleavage develops into trochophore, and then into a shelled veliger (Figure 2).

Veligers are ejected and float freely in the water column for up to 15 days (Hedgecock *et al.,* 2007). Studies have indicated that the overall time a veliger spends in its planktonic phase can be directly correlated with diet (Marshall *et al.,* 2010) and temperature (Filgueira *et al.,* 2015). One further metamorphosis occurs, the development of a muscular foot changing the veliger into a pediveliger immediately before settlement. The settlement process, documented by Cranfield (1973) also examines the importance of the presence of 9 specific glands within the muscular foot each contributing to the cementing of the individual to a fixed position where it will remain for the rest of its life.

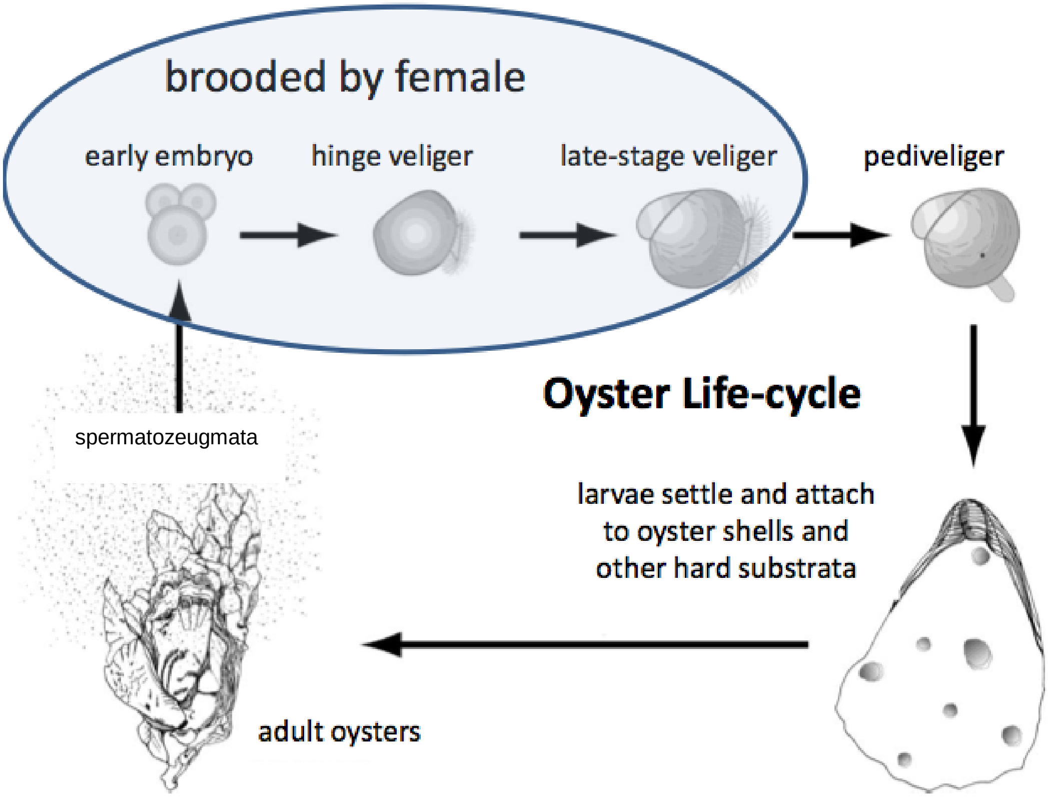

Figure 2 Reproductive cycle of Ostrea sp. (PCW, 2010)

1.4 Settlement and habitat creation

The settlement behaviour of *O.edulis* larvae was first characterised by Prytherch (1934) who described how the muscular foot is used to seek out a suitable settlement location. While all oyster species are known to settle on and attach to many different types of substrata, the biological and environmental cues (both endogenous and exogenous) and the specific relationships between these factors that drive an individual to settle have been a topic of research for many decades (Coon *et al.,* 1985, Bonar *et al.,* 1990).

Table 1 Endogenous and exogenous factors known to induce settlement behaviour in *Ostrea edulis*

Endogenous	Exogenous
	Temperature
Dopamine pathways	Food
	Light
	Substratum type and aspect
Adrenalin / epinephrine (L-DOPA)	Dissolved compounds i.e. ammonia
	Microbial films

These studies both describe in great detail the chemical cues that lead an individual to settle. Coon (1990) describes the first cues immediately pre-settlement that are primarily led by the dopamine pathways of the central nervous system. It is to these first cues that the 'seeking out' of existing settlements of adult individuals by an individual oyster has been attributed. The second phase of the settlement process is controlled through the adrenal pathways leading to metamorphosis and the cementing of the individual to the location in which it will stay for the rest of its life.

The instigation of these endogenous pathways was described by Pawlik (1992) who suggests that chemical components naturally occurring in seawater are detected by an individual's chemoreceptors. This ties in with the observations of Coon *et al.,* (1990) suggesting that the presence of ammonia is a key cue responsible for inducing the dopamine pathways described above.

The ecological preference for gregarious settlement of the genus has long been observed. Initial studies into the phenomenon began in the 1930's in America.

Pawlik (1992) suggests that settlement inducing compounds released by post-metamorphosed individuals stimulate settlement of larvae. Turner *et al.,* (1994) goes further, describing the presence of biofilms, in particular the assemblage of microorganisms that are present on the surface of shells as an important factor in this process. The presence of bacteria within the biofilm adds to the chemical cues released into the water column. This would certainly seem to agree with the findings of Coon (1990) who has suggested that ammonia released by bacteria could be considered as an external cue for stimulating the pathway towards settlement. Turner *et al.,* (1994), concluded that the presence of enzymes; trypsin hydrolysates and a tri-peptide arginine were significantly effective in inducing larval settlement even at low concentrations.

The definitive trigger for gregarious settlement remains the subject of debate after over 80 years of study. Physical cues such as temperature, salinity and light availability seem to play a contributing role in triggering settlement but they seem not to be the primary inducer and it appears that chemical cues seem to play a larger role in initiating the settlement process. It is likely that a key combination of several physical, chemical and biological factors are responsible for settlement of veligers.

It is the gregarious nature of the genus that leads to the creation of oyster beds that form such an important marine habitat. The ability of oysters to build large beds over generations creates a biogenic habitat composed of their own physical structure (Bonar *et al.,* 1990). This increases habitat diversity in the marine environment that is utilised by other species, e.g. increasing the availability of physical refuges (Purchon, 1977, Jones *et al.,* 1994).

This ability to provide structure and shelter for other species means that *O.edulis* can be described as an ecosystem engineer. The complex three dimensional structure that is formed from generations of oysters preferentially settling in the same location provides an emergent hard substratum on otherwise flat soft-sediment estuary or sea bed (Wells, 1961), this hard substratum allows for cryptic or more structurally complex habitat to develop. Menge and Lubchenco (1981) and Jones *et al.,* (1994) describe how oyster beds provide nursery grounds for many species while Wells (1961), Zimmerman and Center (1989), Gutiérrez *et al.,* (2003) and Kostylev *et al.,* (2005) describe the way in which the gaps between individual oysters provide vital spaces for juveniles to seek refuge within thereby reducing the risk of predation (Grabowski, 2004). The shell itself also acts as a habitat, providing a firm substratum for attachment of epifauna (Wells, 1961), further increasing community structure and biodiversity (Mills, 1969).

1.5 Shellfish beds and the Ecosystem services

Ecosystem services have been described as, the direct and indirect contributions of ecosystems to human wellbeing. In simple terms it aims to calculate an economic valuation for the goods and services an ecosystem provides. It aims to bring forward the hidden costs and services into view and more importantly, to bring them to the attention of decision-makers who can incorporate ecosystem services into decision-making frameworks. (Williams and Davis 2018)

The ecology and bed-forming abilities of *O.edulis* have been studied for many years. However, it is only comparatively recently that the ecosystems created by oyster beds have begun to be described and their ecological and environmental value quantified (Zu Ermgassen *et al.,* 2013a. Zu Ermgassen *et al.,* 2013b). This new area of research has brought a fresh dynamic to shellfish restoration. Historically the emphasis of shellfish restoration has been based on fisheries and aquaculture, the value of shellfish being that of the fished product rather than the value of the ecosystem service the unfished bed provides.

By presenting the wider argument on the value ecosystem services provided by shellfish beds, it is possible to demonstrate the value of shellfish restoration beyond fisheries and aquaculture. Studies of the societal benefits provided by biogenic reefs show that they play an important role in water filtration, nutrient removal, shoreline protection and fish habitat provision (Beck *et al.,* 2009, Baggett, 2014). Studies show that the presence of oyster beds increases species diversity, (Menge and Lubchenco, 1981, Bolam *et al.,* 2002, Taniguchi *et al.,* 2003) and that fish biomass increases with the size of oyster beds, (Wells, 1961, Zimmerman, 1989, Coen *et al.,* 1999, Posey *et al.,* 1999, Gutiérrez *et al.,* 2003).

Water clarity is increased in areas surrounding oyster beds as a result of the filtration of water by oysters (Zu Ermgassen *et al*., 2013, Zu Ermgassen *et al.,*2013a) and nutrient uptake and the assimilation of organic nitrogen into inorganic nitrogen gas is a process that is elevated with increased numbers of filter feeding bivalves (Ryther and Dunstan, 1971), Newell, 2004, Newell *et al.,*2005). Furthermore, large numbers of oysters can act as coastal sea defences by helping to dissipate wave energy creating more stable conditions, thereby helping to protect both freshwater and terrestrial habitats, farmland and homes from tidal inundation (Meyer *et al.,*1997, Piazza *et al.,*2005, Beck *et al* 2011).

Table 2– Societal goods and services provided by the presence of shellfish beds and bioreefs, in particular *Ostrea edulis*, Modified table based on William and Davis, 2018

Type of ecosystem service	Types of benefit obtained
Direct services	Commercial and recreational fisheries
	Aquaculture / food production
	Fertilizer and building materials (lime)
	Materials (shells) for building aggregate for jewellery
Regulation services	Enhanced Water quality through filtration
	Coastline protection (storm surges)
	Reduction of shoreline erosion
Supporting Services	Nursery habitats for commercial fish species
	Carbon sequestration
Cultural services	Tourism and recreation (improving recreational fisheries and water quality for tourism)
	coastal heritage

1.6 Fisheries management measures

1.6.1 The importance of *O.edulis* as a fishery.

The history of the *O.edulis* fishery is important, oysters having become a cheap and nutritious staple food for many people in the 19th century. The demand for oysters and their subsequent exploitation when combined with a lack of understanding of the ecology of the species ultimately led to its downfall. In 2002, less than 0.2% of the total global production of oysters came from *O.edulis*, (Culloty and Mulcahy, 2007). However, with 0.2% of global oyster production being valued at approximately £15 million per year it is unwise to ignore the fisheries value of *O.edulis* when discussing cultivation and restoration efforts.

Proposals for the cultivation and managed extraction of *O.edulis* around the UK are becoming more frequent, for example in The Solent in Hampshire, the Mumbles fishery in South Wales, the Blackwater in Essex, Loch Ryan in Scotland and Strangford lough in Northern Ireland. It is important that future exploitation of *O.edulis* is managed in such a way that stock security and future production are not jeopardised (Donnan and Heritage, 2007).

1.6.2 Current fisheries management measures

The sustainable management of a fishery is key to its long-term success. Fisheries management is based around two main concepts: limits and targets (Laing, 2005). Limits are restrictive measures designed to maintain stock levels and include catch quotas, reduced fishing effort and return to the environment of undersized individuals. Targets are an example of positive conservation management, they define clear desirable outcomes and are designed to actively increase stock density and limit impacts of fishing to non-target species. It is important for a fishery to have prescriptive management outcomes and clear objectives to be able to relay these to those working in the fishery (Laing, 2005).

Areas such as the Solent, which until recently had no management plan or harvesting restrictions for *O.edulis,* quickly become depleted. (Williams and Davis 2018) Other areas such as the Blackwater, Fal and Loch Ryan fisheries have been enhanced through a series of management measures designed to maintain and enhance populations of *O.edulis* while enabling a commercial fishery to function. These measures restore habitats, secure stock areas, remove pests and manage disease (Woolmer *et al.,* 2011).

Table 3 Management measures: Table adapted from Laing (2005) shows management methods adopted by the Essex oyster industry to ensure sustainable harvesting practices. Management measures seek to limit damaging activities, or activities likely to reduce *O.edulis* stocks and promote positive activities likely to maintain or enhance stocks

	Catch Quantity	Fishing effort	Stock Abundance	Gear types	Closed periods	Minimum landing size	Returns	Removal of cultch	Cleaning	Maintain brood stock	Remove predators	Return non target by catch
Limit	Y	Y		Y	-	-	-	Y	-	-	-	-
Target	-	-	Y	-	Y	Y	Y	-	Y	Y	Y	Y

1.6.3 Regulation and stipulation

Two of the most widely accepted fisheries management measures are minimum landing size and closed seasons. Minimum landing sizes are one of the most common technical measures in managing fisheries (Waldock *et al.,* 1987 cited Donnan and Heritage, 2007). The intention of this measure is to allow an individual oyster to reach sexual maturity and breed at least once before being harvested in an attempt to retain parent stock (Waugh, 1966) and management practices which cite seasonal closure of certain fisheries are also standard practice. With regard to the management of *O.edulis* in the Blackwater estuary, the combination of the two measures are designed to protect stock and reduce fisheries exploitation during the critical months of the oyster breeding season in June – August to allow for stock regeneration. For sessile species such as *O.edulis* the seasonal closure of the fishery is imperative in allowing natural regeneration of oyster beds.

1.6.4 Bylaws and regulating orders

As well as temporal restrictions relating to the removal of oysters, there are also spatial restrictions that can theoretically control levels of extraction. There are numerous types of spatial restrictions;

1. Several Order
2. Regulating Order
3. Hybrid Order
4. Common Law, Right to Gather

Numbers 1-3 are legislated under the Sea Fisheries (Shellfish) Act 1967.

1. A Several Order is the most commonly used regulation in oyster cultivation and is designed to allow a person or company sole rights to develop a fishery for a specific species over the long term. It is commonly coupled with a Regulating Order.
2. A Regulating Order when coupled with a Several Order gives the rights to fish for the named species to a group of individuals or an association. This way the group regulate the fishery, imposing their own restrictions such as no take zones, closed seasons and size limits. The fishery species becomes a common shared resource and any

activities that contravene the agreed measures can result in the individual being banned from fishing. For example, in Essex the Tollesbury and Mersea Oyster Company (T&MCo) own a Several Order that covers the River Blackwater. The Blackwater Oysterman's Association pay an annual subscription to the T&MCo giving them the rights to extract native oysters from within the Several Order boundary. The Association is made up of a group of individual oystermen, but they agree management measures as a collective and are bound by them. Contravening the management measures means risking losing the rights to fish the most productive and profitable areas.

3. A Hybrid Order is intended for use where there are overlapping fisheries boundaries, for example one or more Several Order areas, private grounds and Regulating Order areas.
4. Common Law, Right to gather, is more commonly referred to as a public fishery and is within the remit of the Crown Estate and regulated and enforced by the Inshore Fisheries and Conservation Authority who are responsible for creation and enforcement of fisheries bylaws designed to protect stocks from over fishing. Common law also known as public fishery allows harvesting of a species unless it is within private ownership, tenanted or within the remit of an existing several order. There are no limits on the amount of *O.edulis* that can be harvested within these areas, fisheries stipulations refer only to the size of individual (over 70mm).

1.7 Restoration efforts

First described by Bertram (1865), attempts to restore populations of *O.edulis* have continued throughout the 20th and into the 21st centuries. Sporadic, haphazard attempts at increasing oyster numbers have been undertaken and in some areas have been successful at increasing populations of *O.edulis* to such an extent that they can support a productive fishery, e.g. Truro Oyster fishery in the Fal in Cornwall and the Blackwater Oysterman's Association in the Blackwater in Essex.

Restoration attempts in these areas have been predominantly fisheries management driven. Recently however, restoration in some areas has been more conservation minded, with initiatives in the Solent and Chichester Harbour launched that have met with varying degrees of success.

1.7.1 England – Solent

Until the 1970's, when a large population of *O.edulis* was found, the Solent had not featured significantly as a national native oyster fishery area. A Ministry of Agriculture, Fisheries and Food (MAFF) document titled; *A review of the development of the Solent Oyster fishery 1972 -80* produced in 1981 shows that the area was not of national significance as a fishery, but sporadic oyster harvesting had been present in the area for many years. The report documents that 1862 – 1864 were two particularly productive years, with large spat fall. In subsequent years fishing became increasingly intense coupled with the removal of large quantities of cultch (Oyster shell or other suitable shell substratum on which veligers settle and cement) to be relayed in Bosham and Emsworth. This was compounded by the predation of spat by the Oyster drill *Urosalpinx cinerea* which removed up to 90% of the years spatfall.

By 1910 numbers had decreased so significantly that oysters were brought in from other oyster fisheries areas. The annual report on sea fisheries for England and Wales 1910- 1938 (Anon 1912-1940) shows that Essex was one of the main contributors to restocking the Solent. In 1915, 8,427,000 oysters were relayed into the Solent from Essex oyster fisheries, then again in 1917 when 3,104,000 were extracted from Essex stocks to be relayed into the Solent.

Mass mortalities of Oysters across Europe in the 1920's stopped extraction from neighbouring oyster fishery areas and no substantial landings were recorded from the Solent until the 1970's when a large naturally established population was found. Once again extraction commenced, landing 650-850 tonnes per year by 1979 and during this time several management measures were put in place in an attempt to manage over extraction. The months when the fisheries were permitted to be open were reduced to 7 months and the minimum catch size was increased from 50mm to 63mm in 1976. However, by 1986, stocks had declined dramatically due to over exploitation and the introduction of *Bonamia* (SAGB internal report, 1990). Populations continued to decline over the next 10 years and the fishery, no longer profitable, ceased. Stocks continue to remain low, due to lack of breeding stock.

In an attempt to restore stocks, the Chichester Harbour Oyster Partnership Initiative (CHOPI) was created. Chichester Harbour is connected to the Solent and the oyster population here is thought to be a meta-population of what was once the larger Solent stock. Formed in 2010, the Partnership is made up of the Southern Inshore Fisheries and Conservation Authority (SIFCA), Chichester Harbour Conservancy (CHC), Natural England (NE) and representatives from the oyster industry. The initiative has re-laid oyster stock in the Harbour at a density of $40m^{-2}$, this is far in advance of the $5m^{-2}$ OSPAR definition of an oyster bed. The aim of this high density laying is to rejuvenate brood stock areas.

Unfortunately this has been unsuccessful due to the presence of *Bonamia*, most recent observations suggest a 30% infection rate and high oyster mortality (Essex Native Oyster Restoration Initiative meeting minutes 2015).

1.7.2 Scotland - Loch Ryan

Scotland supported a strong oyster industry until the late 1800’s. A decline in oyster populations began to be apparent in the mid 1880’s, with over extraction once again the dominant factor. West coast fisheries remained operational but in a reduced capacity for many years. While other areas were being depleted through exploitation, the Loch Ryan oyster fishery remained viable due to positive management and oyster cultivation. Peak production was reached in 1913 when it was reported that 30 boats were landing 130 tonnes annually. However, over subsequent years landings diminished and continued to fall until 1957 when the fishery collapsed (Millar, 1968). In 1961, Millar conducted an audit of oyster populations and stock densities between 1946-1958 in an attempt to locate the best areas for potential oyster restoration and establishment of a viable fishery. Loch Ryan was identified as the best probable option and thousands of juvenile *O.edulis* were imported from Brittany and relayed in the Loch to bolster the population that remained (Millar, 1963).

Tenancy of the fishery was granted in 1976 and cultivation began. Cultch was relayed and the ground was cleaned annually (Donnan and Heritage, 2007). In 1978 a large spat fall occurred, which helped boost restoration efforts. By 1987, oysters were relayed with an annual self-imposed restriction of 15 tonnes. Cleaning and cultivation remained under the Colchester Oyster Fishery Co. until 1998 when Loch Ryan Oyster Fishery took over. Today landings are restricted to 10 tonnes annually and management includes returning under sized oysters and shell material (Hugh-Jones, 2003).

1.7.3 Northern Ireland - Strangford Lough

In Northern Ireland oyster activities followed a similar pattern to those in the rest of the UK. As the human population increased so did fishing pressure. Over extraction and the associated habitat destruction left the oyster beds vulnerable to disease and predation and the beds ultimately failed.

By 1877, oyster beds were so significantly diminished that an enquiry was conducted to look at how the decline in the oyster population could be halted.

The Inspectorate for Irish Fisheries limited the open fisheries season by 4 weeks and prohibited the removal of juveniles (Down recorder 1878).

As early as 1683 the Montgomery records states that Strangford lough beds were being dredged as well as hand harvested from the intertidal zone (Smyth *et al.,* 2009). In 1744, Harris states that the Oysters in Strangford Lough were being commercially exploited and by 1833 records show as many as 20 boats working in the area. Lewis (1837) reports that oysters were taken in both the winter and the summer months, and by the mid 1800's a reduction in oyster numbers was becoming apparent. Reports state that the oyster harvesters had stopped the extraction of oysters in the summer months. This is the first report of a self-imposed closed season for oyster harvesting.

Due to the observed reduction in oyster stocks, the inspector for fisheries conducted an inquiry in 1877 and made recommendations to halt the decline. His recommendations were to shorten the open season and prohibit extraction of juveniles (Down recorder, 1878). Despite new regulations and controls the populations continued to decline and by the end of the century the fishery collapsed (Went, 1961, Smyth *et al.,* 2009). There was an attempt to revive the shellfish industry in Strangford lough in the 1970's when *Crassostrea gigas* spat was imported and seeded onto rafts before being laid out in the Lough (McErlean *et al.,* 2002). This was not uncommon, and importation of *C. gigas* spat was undertaken in many areas that once supported an oyster industry. *C. gigas* is a hardy species that grows quickly and can be harvested within 2 years, and as it is a non-native species fisheries restrictions did not apply and MAFF hoped that it would prop up the failing oyster industry in the UK.

In 1997 prior to an oyster restoration attempt in the Lough a survey of the status of *O.edulis* was undertaken in Strangford Lough (Kennedy and Roberts, 1999). This survey summarised that a small population did still exist but the locations of individuals were too dispersed for the oysters to interact successfully. Availability of cultch was also a limiting factor. In 1998, the European Union funded the development of a project to reintroduce *O.edulis* to Strangford Lough. Seventy five tonnes of cultch were installed at 5 locations, 3,000 resident adult oysters from the lough were collected to act as parent stock and 250,000 oyster spat were relaid (Kennedy and Roberts, 1999).

A follow up survey conducted between 2002 – 2005 suggests that the restoration attempt had little long term success. A population estimate following the 1997 surveys suggested a stock of approximately 100,000 individuals. In 2002 this had increased to 1 million and in 2003 it increased again to 1.2 million. Sadly, in 2004 the survey showed a loss of >300,000 and in 2005 another loss of >300,000. The lough in 2006 was estimated to hold <600,000 oysters. The loss was attributed to unregulated harvesting (Smyth *et al.,* 2009) with areas that were more readily accessible showing the most dramatic decline initially and the less accessible areas declining later.

1.8 Limiting factors to restoration success

1.8.1 Cultch availability

The abundance of bivalve shell (cultch) represents a vital consideration for the health of an oyster population since it determines the amount of potential settling substratum for recruiting oyster larvae (MacKenzie, 1996). Oysters today, especially in areas with an active fishery, are distributed over a wide area, not in elevated reefs off the sea floor.

Ostrea edulis larvae require clean hard recruitment surfaces on which to settle (Laing, 2005). Availability of clean cultch is imperative to the continuation of *O.edulis* beds and lack of settlement sites for emerging veliger larvae is a major limiting factor to recruitment (Rimler, 2014). In highly mobile and sedimentary environments such as the Essex estuaries, one of the major factors potentially limiting recruitment is availability of clean cultch (Laing *et al.,* 2006). The main aim of cultch management is to remove mud and silt and make buried cultch available for larval settlement (Woolmer *et al.,* 2011).

The act of restoration involves the harrowing of the sea-bed using chains and dredges. This liberates the sediment into the water column which is taken away with the tide, leaving behind a clean surface for oyster settlement (Waugh, 1972). There is very little data to demonstrate that removal of sediment through harrowing or bagless dredging is the best option for restoration. Kennedy *et al.,* (2011) explored this option when assessing restoration attempts using *Crassostrea virginica* in the U.S, concluding that increasing the available shell through addition rather than cleaning proved most successful. However, this study does state that post work monitoring was not sufficiently robust enough to draw any final conclusions on the effectiveness of the practice. Buzan *et al*. (2015) make an interesting point when assessing harrowing or bagless dredging to liberate oysters smothered as a result of tropical storms when they suggest that '*Paying or allowing commercial oystermen to voluntarily pull bag-less dredges has positive social and emotional value. It actively engages the commercial industry in the process of trying to improve both the ecological and economical condition […]. It engages them in doing something positive for their community'*. It could be argued that the source of the study (Western dredging association) is biased, as it is by default predisposed viewing dredging as the only answer. However, the sentiment is correct, involving the community in the act of oyster restoration is a positive act, reconnecting people with their marine environment to re- establish bonds and a sense of custodianship of the species which is essential for the long term success of any oyster restoration initiative.

1.8.2 Unlawful extraction

Several attempts have been made to restore habitat and regenerate oyster stocks at sites in Strangford Lough, the Solent and Chichester Harbour. Initial results in some areas have been promising. However, in other areas attempt to restore oyster populations have not been successful. For example Smyth *et al.,* (2009) examined stocks of *O.edulis* in Strangford

Lough and concluded that between 2003 and 2005 stocks had halved declining from 1.2 million in 2003 to 650,000 in 2005. This was attributed to unregulated overharvesting as significant difference in oyster abundance was found between sites that were and were not accessible to fishing with bottom towed gear. Opportunities do exist to try and secure stocks through the statutory route and regulatory orders, and bylaws and permits are all possible under the statutory remit of bodies such as the Inshore Fisheries and Conservation Authority (IFCA), which are responsible for sustainable management of fish and shellfish stocks within the UK. However, these measures need to be agreed at an early stage with the local industry coupled with patrol and enforcement deterrents.

1.8.3 Improvements to Water quality

Various pieces of legislation have been designed and implemented throughout the UK and Europe leading to improvements in the quality of rivers, lakes and coastal waters. Initially these directives were separate pieces of legislation before being combined under the EU Water Framework Directive (WFD; Laing, 2005). (Table 4)

Table 4 European Water Directives consolidated under the Water Framework Directive

Water Framework Directive	European Water Legislation
	Drinking Water Directive
	Fish Waters Directive
	Shellfish Directive
	Bathing Waters Directive
	Ground water Directive
	Dangerous Substances Directive
	Urban waste water treatment Directive
	Nitrates Directive
	Directive for Integrated Pollution and Prevention Control (IPPC)

Delivery of WFD measures for transitional and coastal waters is still at an early stage. It is also unclear what will happen to the WFD (and associated UK legislation the Water Framework Regulations 2003) once the U.K. leaves the European Union. The assessment of Transitional and Coastal Waters (TRaC) in Essex are that they achieve 'Good' or 'Moderate' status under the WFD. For waterbodies assessed as being at 'Moderate' status or below, improvements are required to be made to move them to 'Good' status by 2027. However, it is unclear at this time if the improvements to water quality required under WFD are in line with the original Shellfish Waters Directive parameters and their requirements for oysters and oyster-beds. Laing (2005) suggests '*there should be a presumption in favour of oyster stock restoration* *at sites where the seawater is clean (unpolluted). This is imperative at sites where the stocks are to be exploited but also an ideal where they are managed for conservation reasons, to help ensure a balanced ecosystem'*. However, the parameters of 'clean/unpolluted' are not documented. The scientific literature has a wealth of measurements and calculations on background levels of pollutants in particular heavy metals and their effects on shellfish mortality (Topping, 1972., Bryan, 1976., Copat et al., 2013., Rainbow., 2017) but due to a lack of testing by the Environment Agency we do not know where the water and sediment quality in Essex sit with these parameters, especially given that the presence of Bradwell Nuclear Power Station and more recently the decommissioning of the power station and the discharges associated with the decommissioning process including the dissolution and discharge of waste materials in the form of Fuel Element Debris (FED).

1.9 Introduction to Marine Conservation Legislation

The world's first Marine Protected Area (MPA) was established in Florida in 1935. Fort Jefferson National Monument covered 53 ha of seabed and coastal land. This first marine designated site showed an understanding that the marine environment was not an infinite resource for exploitation but needed safeguarding from damaging activities. This was over 80 years ago - it would be a further 50 years before this understanding of the urgent need to protect our marine environment was recognised globally. The concept of protection of the marine environment on a global scale was first discussed at the International Union for the Conservation of Nature (IUCN) World National Parks Congress, Bali in 1982. The IUCN recognised the importance of Marine and Freshwater habitats and incorporated them into further discussion (IUCN, 1982). Debate topics included the furtherance of MPA's to protect the marine environment and the ecosystem services that marine systems provide including;

- Provision of food and medicines,
- Sustainable advancement of socio-economics of MPA's which included, but was not restricted to, the benefits to the fishing industry, community cohesion and sense of place.
- Importance of MPA's as a significant contribution towards the arts, inspiring painters, authors and poets.

The IUCN congress meeting furthered discussion by considering the approach to protection, and management of these areas. How the concepts could be interpreted and translated from high level academic discussions to 'on the ground' implementation of the concept by a nation state. Unfortunately, discussions on marine issues were at the time restricted to declines in biomass (Craig *et al.,*1982, Rothschild, 1983), showing primarily the impacts of fishing, rather than the concept of protecting the marine environment for its biodiversity value. As such, very few tangible examples of MPA's were taken forward as a result of these discussions; the management and conservation advice remained concepts debated in the world of academia. Ten years later, in 1992 at the next IUCN World National Parks Congress, the concept of designating protected areas of the marine environment for their intrinsic biodiversity value was debated again, this time with significantly more urgency than had been the case a decade previously. Terms such as 'conservation biology' and 'biological diversity' coined in 1980's, became more readily used and the concepts associated with them accepted more readily (Norse and McManus, 1980, Irish and Norse, 1996) The concept of MPA's had been studied in much greater detail over the intervening decade and the notion of doing nothing was no longer a viable option (IUCN, 1992). While opinion was divided as to what form MPA's should take these remained the first tentative steps towards delivering marine conservation through the designation of protected sites.

Also during 1992, two key developments were advanced, influencing what would become the fundamental building blocks to the production of

MPA's. These were the Earth Summit: The Convention of Biodiversity (Rio de Janeiro) and the OSPAR convention in Oslo. The Convention of Biological Diversity (CBD) Rio de Janeiro, 1992, informally known as the Earth Summit this was the first time that protection of biodiversity was addressed by a binding global agreement. One hundred and seventy two participating nations were brought together to discuss sustainable economic development and find ways to halt the destruction of irreplaceable natural resources and pollution of the planet (United Nations, 1992). Signatory nations were required to create and enforce national strategies for the progression of biological diversity; this was ratified within the European Union (EU) with the production of the EU Biodiversity Strategy. This strategy aims to halt the loss of biodiversity and degradation of ecosystem services in the EU and help stop global biodiversity loss by 2020, and reflects commitments taken by the EU, following the Convention on Biological Diversity (European Commission, 2011)

The second fundamental development towards the process for the protection and conservation of the marine environment began in 1992 during the Convention for the Protection of the Marine Environment of the North East Atlantic, also referred to as the OSPAR convention (OSPAR, 2003) The convention was attended by representatives from 14 EU member states, including the UK, with the key objective that each of the member states became fully responsible for the protection of their marine environment. The origins of this group were borne from the Bonn agreement, 1969 (Bonn, 1969) and the Paris Convention, 1972 (Hey *et al.,*1993); both of which were responsible for the prohibition of marine pollution and the disposal of industrial waste at sea consecutively. These conventions and agreements were key drivers in beginning to establish good environmental practice to protect water quality in the North East Atlantic.

The 1992 conference had one critical difference to the preceding conventions. For the first time a provision was included for the 'Protection and Conservation of Ecosystems and Biological Diversity'. Documents and agreements ratified under both the Bonn convention and the Paris convention became annex documents to the OSPAR Convention (Oslo & Paris convention). This was progressive a step forward for the establishment of MPA's throughout Europe but the implementation of this piece of legislation was slow, it would be a further six years before the remit of the OSPAR convention came into force. In 1998 the EU member states were charged with;

'Taking the necessary measures to protect and conserve the ecosystems and the biological diversity of the maritime area, and to restore, where practicable, marine areas which have been adversely affected' (OSPAR, 1998)

Uptake of this obligation by member states was again, slow, and five years later in 2003 (eleven years after the convention first put appropriate steps in place for the implementation of MPA's) the OSPAR commission agreed to the inclusion of the 2003/3 amendment which states;

'That the OSPAR Commission will promote the establishment of a network of Marine Protected Areas to ensure the sustainable use and protection and conservation of marine biological diversity and its ecosystems' (OSPAR 2003)

The OSPAR commission understood that the intent from the 1998 ruling for the progression of the protection of the marine environment was failing. The wording which all member states had agreed to was not being implemented and a more rigid framework with targets and deadlines was needed. It took the unprecedented step of imposing a deadline of 2010 for all member states to implement measures to achieve the ecologically-coherent network of well-managed MPAs they had signed up to deliver. Disappointingly, the targets were not adhered to, and in 2008 an amendment to the 2003/3 document was produced stating:

'*that despite the collective efforts by OSPAR Contracting Parties in selecting and establishing marine protected areas (MPAs) in the North-East Atlantic in the period 2005-2010, the network of MPAs in 2010 is not yet considered to be ecologically coherent throughout the entire OSPAR maritime area […] that further efforts are required by OSPAR Contracting Parties to ensure the ecological coherence of the network of marine protected areas in the North-East Atlantic'.*

Again a timeframe for delivery was agreed and ratified by member states, this time in 2012, 10 years after the original agreement. The UK's response to how it would establish the coherent network of MPAs that was required in European law was shaped in legislation that became the Marine and Coastal Access Act ("the Marine Act")

The Marine Act requires the establishment of a new type of MPA, known as Marine Conservation Zones (MCZ) (DEFRA, 2015). The establishment of MCZ's fulfils two legal obligations:

1. UK obligations in Europe under the OSPAR agreement and;

2. To complement the existing network of MPA's, established throughout the UK, by filling the spatial gaps between existing MPA's (for example existing marine Special Areas Conservation (SAC) and Special Protection Areas (SPA) designated under the Habitats and Birds Directives) to create the ecologically coherent network of designated sites that is stipulated in the Habitats Directive legislation (Table 5)

Table 5 - European and National Legislative Drivers – based on and modified from (EEA, 2015)

Selected policy objectives supporting the creation of MPA networks in Europe's seas			
Overarching objective	Sources for target	MPA target	What is happening
Fully implement: Birds and Habitats Directives	EU Biodiversity Strategy to 2020,	Complete the establishment of the Natura 2000 network and ensure good management.	The Natura 2000 network continues to expand. No overview exists determining whether the EU MPA network is well managed
Ensuring biodiversity through conservation of habitats and species	Habitats Directive, 1992; Birds Directive, 1979	Set up a coherent, ecological network of special areas under the title Natura 2000.	The Natura 2000 network continues to expand. After 22 years of implementation some countries are still not considered, 'sufficient' in their designations.
Achieve or maintain GES	Marine Strategy Framework Directive, 2008	To include spatial protection measures contributing to coherent and representative networks of MPAs, adequately covering constituent ecosystems.	Programmes of measures are being put in place, and should be launched by 2016.
European Drivers			
Set up an MPA network consistent with the CBD target for effectively conserved marine and coastal ecological regions	OSPAR Recommendation 2003/3	By 2012, to ensure an ecologically coherent, representative network of MPAs incl. the High Seas; 2) by 2016, to ensure the network is well managed and that the appropriate measures are set up and are being implemented.	Based on the spatial distribution of the MPA network, it cannot yet be considered to be coherent.
National Drivers			
Marine & Coastal Access Act 2009	OSPAR Recommendation 2003/3	To establish a coherent network of marine protected areas. Designation of Marine Conservation Zones to achieve this	Current designations of MCZ do not achieve ecological coherence, Management plans not in place.

1.10 Existing network of MPA's

1.10.1 The Marine Protected Areas

The European commission are one of the leading administrations globally for the development of Directives and guidance for the furtherance of marine protection (Figure 3).

In 1992 the Habitats Directive was formally adopted by the European Commission this piece of legislation was designed to complement the existing Birds Directive (1979). Together the legislation gave rise to Natura 2000 sites, a network of designated sites protecting 18% of the EU's land area and 6% of its marine territory; they are intended to protect seriously threatened species and habitats from across Europe.

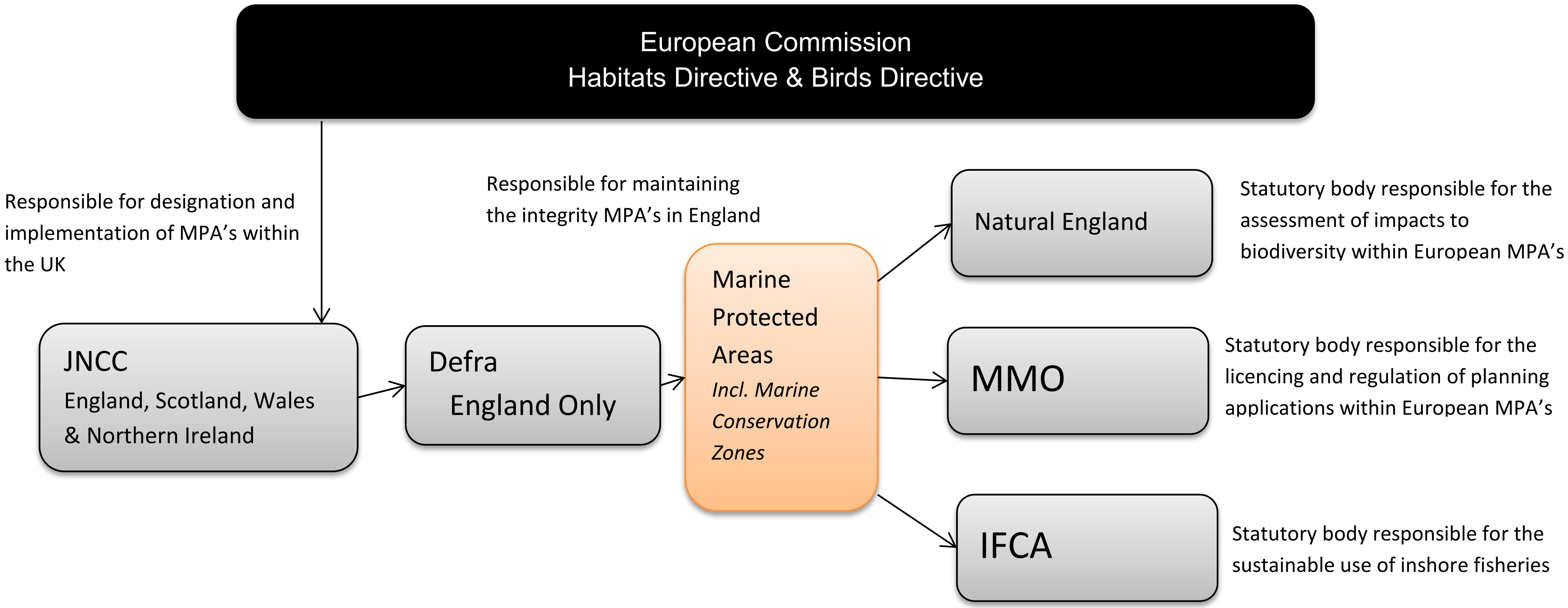

Figure 3: Schematic diagram of the hierarchy of Marine Protected Areas and the statutory bodies responsible for their protection and implementation.

1.10.2 Marine Protected Areas: Europe

2016 represents the 20th year since the adoption of the Habitats Directive whereby EU member states, including the UK, sought to halt the loss of biodiversity across Europe through the designation of large areas of land or seabed noted for its importance and contribution to nature conservation. The result of the Habitats Directive in Essex was the creation of the Essex Estuaries Special Area of Conservation (SAC), one of the largest marine based SAC's in the UK covering an area of approximately 472km^2, protecting subtidal and intertidal habitats including saltmarsh and Mudflat (Natural England, 2016). The Essex Estuaries SAC lies on the East coast of Essex, in the South East of England. It is one of the most highly protected estuarine complexes in Europe, benefiting from a suite of national and international designations. (Figure 4 & Table 6).

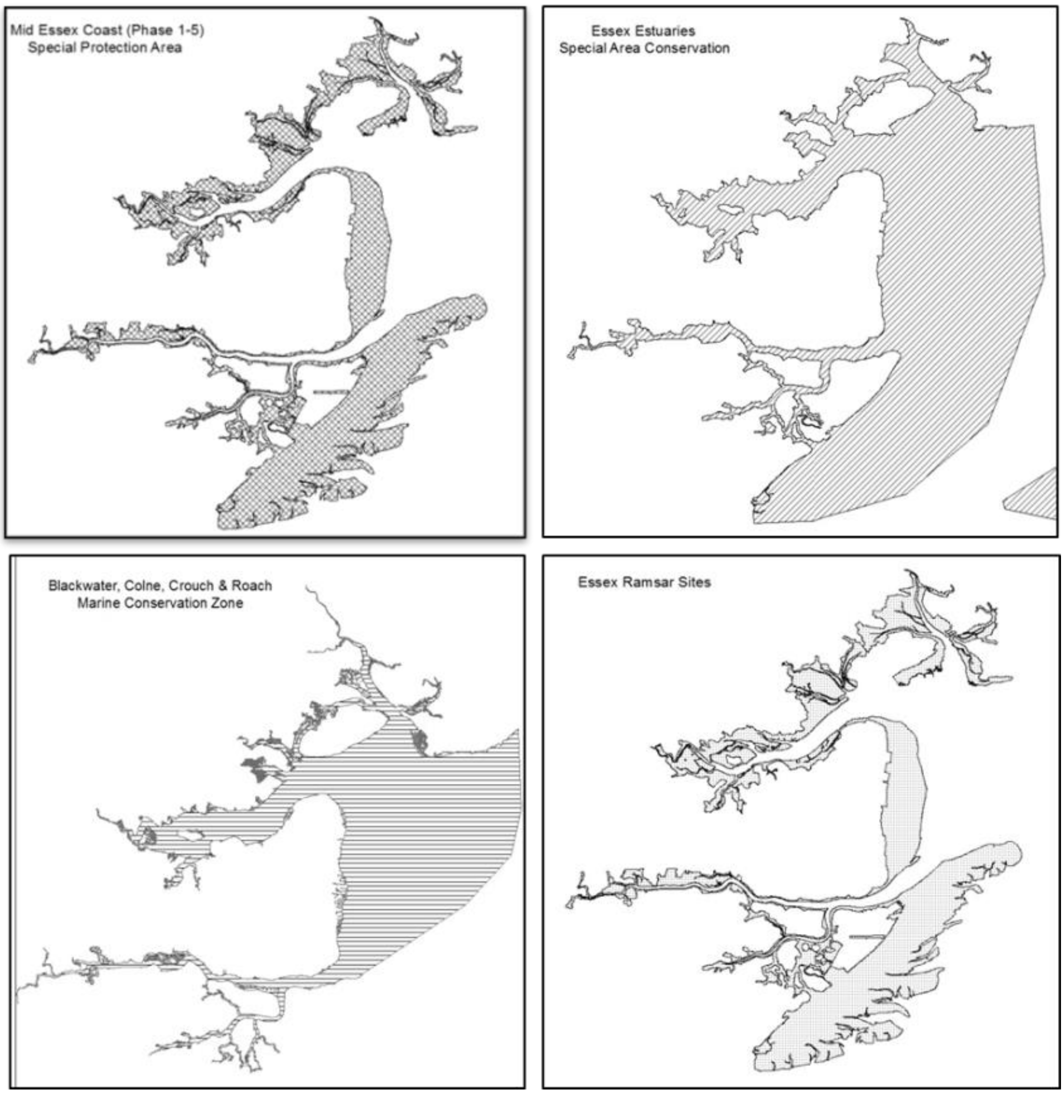

Figure 4 Nature conservation designations with marine components in Essex

Table 6 Designations and supporting legislation protecting the Colne, Blackwater, Crouch and Roach Estuaries and the surrounding coastal waters.

Name	Designation	Legislation	Date of designation	Designation wording
Blackwater Colne Crouch Roach Foulness	Site of Special Scientific Interest	Wildlife & Countryside Act	1990	Protects sites of special interest by reason of any of its flora, fauna, or geological or physiographical features'.
Ramsar	Ramsar Site	EU Natura 2000	1995	Under the Convention on Wetlands (Ramsar, 1971), each Contracting Party undertakes to designate at least one wetland site for inclusion in the List of Wetlands of International Importance (the “Ramsar List”).
Mid Essex Coast Phase 1-5	Special Protection Area	Directive 79/409/EEC later amended in 2009 to Directive 2009/147/EC	Phase 1 – Dengie 1994 Phase 2 – Colne 1994 Phase 3 – Crouch & Roach 1998 Phase 4 – Blackwater 1995 Phase 5 – Foulness 1996	Member States shall take the requisite measures to preserve, maintain or re-establish a sufficient diversity and area of habitats for all the species of birds
Essex Estuaries	Special Area Conservation	Council Directive 92/43/EEC	1996	Conservation means a series of measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favourable status
Blackwater, Colne, Crouch & Roach	Marine Conservation Zone	Marine & Coastal Access Act	2012	Halt the deterioration of the state of the UK’s marine biodiversity and promote recovery where appropriate, support healthy ecosystem functioning and provide the legal mechanism to deliver our current European and international marine conservation commitments

It is designated for its importance as an intricate mosaic of marine habitats and the associated species they support. The list of qualifying features is long (Table 7). These interwoven habitats include, sub tidal, intertidal and saline influenced terrestrial habitats such as shingle ridges, saltmarsh, saline lagoons and tidal flats and it is the variety of these complementary and productive habitats supporting a high biomass of highly specialised species that make estuarine systems of great nature conservation importance. (Davidson,1991).

Table 7 Essex Estuaries Special Area Conservation (SAC) qualifying features

Essex Estuaries SAC feature	***Salicornia* and other annuals colonising mud and sand**
	Spartina swards (Cordgrass swards)
	Atlantic salt meadows *(Glauco-Puccinellietalia*
	Mediterranean and thermo-Atlantic halophilous scrubs *(Arthrocnemetalia fruiticosae/Sarcocornetea fruticosi)*
	Estuaries – overview of the estuaries feature.
	Estuaries – bed clay communities (littoral rock – soft rock notable communities)
	Estuaries – Intertidal boulder and cobble communities (littoral – cobble and boulder communities)
	Estuaries – Subtidal mixed muddy sediment communities (sublittoral mixed sediment)
	Estuaries – Subtidal muddy sand communities (sublittoral sand)
	Estuaries – Subtidal mud communities (subtidal mud)
	Estuaries – Seagrass *(Zostera marina)*
	Intertidal mudflats and sandflats – littoral mud
	Intertidal mudflats and sandflats- littoral sand and muddy sand
	Intertidal mudflats and sandflats - sand and gravel communities
	Intertidal mudflats and sandflats – Seagrass *(Zostera noltii)*
	Sandbanks which are slightly covered by seawater all the time

1.10.3 Marine Protected Areas: UK

Each member state is required to ratify European Directives into domestic legislation to ensure obligations are met. Any additions to marine environmental legislation are usually as a result of failings by the member state to adequately implement policy, to fill gaps in protection, build on existing practices or correct deficiencies in previous instruments. (Boyes *et al.,* 2016).

In 2003 the commission ruled that member states had not adequately implemented the necessary legislation required to protect the marine environment (Ospar, 2003):

'that further efforts are required {…} to ensure the ecological coherence of the network of marine protected areas in the North-East Atlantic'

The UK's response to how it would establish the coherent network of MPAs that was required in European law was shaped in legislation that became the Marine and Coastal Access Act 2009.

1.10.4 Marine & Coastal Access Act 2009

In 2009 the Marine and Coastal Access Act (hereafter 'The Marine Act') was passed in England and Wales. The Marine Act details how the government and its devolved powers will manage the demands we put on our seas, improve conservation and enable the management of human activities and conflicting objectives in a way that benefit both the health of ecosystems and human well-being, for the benefit of current and future generations (Appleby and Jones, 2012).

The guidance to The Marine Act goes further, stating the need for adoption of the precautionary principle in marine management. In order to achieve the remit laid out in the new legislation the Marine Act has reformed some of the UK legislative structures and created some new ones. The Marine Act contains within it measures to;

- Create a Marine Management Organisation (MMO) for English waters
- Create a structure for marine planning
- Reform marine licensing
- Reform inshore fisheries management
- Create Marine Conservation Zones

Although the first three points are fundamental to a sustainable marine environment, assessing impact both in isolation and in combination, it is the latter which is particularly pertinent to this study and which therefore will be focussed on in detail.

1.10.5 Creation of Marine Conservation Zones

Designation of MCZ areas are designed to complement existing Marine Protected Areas currently protected under existing legislation such as Special Areas of Conservation (SAC) designated under the EU Habitats Directive and the Special Protection Areas (SPA) designated under the EU Birds Directive. (Table 5)

The distinguishing features of MCZs are that they are designed specifically to protect marine species, something the existing legislation does not do. When all three designations (SAC, SPA, MCZ) are viewed together they should form 'an ecologically coherent network' designed and implemented to protect vulnerable species and habitats.(Fletcher *et al.,* 2012) Designation of an area as an MCZ depends on the presence of certain qualifying species and habitats referred to as Features of Conservation Importance (FOCI).

5.1.6 Colne, Blackwater, Crouch & Roach Marine Conservation Zone

The Blackwater, Colne, Crouch & Roach Marine Conservation Zone (BCCR) was designated in 2012. The FOCI includes amongst others native oyster and native oyster bed (DEFRA, 2013) (Table 8).

Table 8 Blackwater, Colne, Crouch & Roach Marine Conservation Zone qualifying features

Colne, Blackwater, Crouch & Roach MCZ designated features	**Native Oyster Ostrea edulis**
	Native Oyster beds and associated communities
	Mixed Subtidal sediment
	Lagoon Sea Slug Tennelia adspersa

Ostrea edulis has been identified as being a species in need of protection, historically the species has not benefitted from protected status, coupled with its value as a fisheries commodity the *O.edulis* has declined throughout its range, resulting in small fragmented populations vulnerable to loss. As such it became one of the qualifying features for the designation of an MCZ under the Marine Act for both its presence as a species, the habitat it forms and the associated species that habitat supports in turn. This newly acquired conservation status means that for the first time there is an obligation under UK law to actively seek restoration of this species.

In order to progress the recovery of *O.edulis* in the BCCR MCZ, a non statutory group of scientists, NGO's, oyster cultivators and government bodies came together to form The Essex Native Oyster Restoration Initiative (ENORI), the remit of this collaborative group is to develop innovative restoration techniques, aid communication and understanding, develop protocols and work through any potential conflicts.

Aims of this thesis:

To provide scientific underpinning to the Marine Conservation Zone (MCZ) designation in Essex for the restoration of the European native oyster, *Ostrea edulis*.

Thesis Objectives:

- Determine the effect of the MCZ designation on stakeholders from the fishing and conservation community
- Determine the presence, distribution, density and age structure of *O. edulis* within the MCZ
- Determine the factors which may limit successful restoration, including substrate and larval availability

- To provide scientific underpinning for the designation of a Marine Conservation Zone in Essex for the European native oyster, *Ostrea edulis* through the provision of data to the UK government.
- Design and initiate an effective restoration project, as a means to test the implementation of the legislation.

Chapter 2 - An anthropological approach to Marine Conservation.

European (Habitats and Birds Directives) and UK domestic law (Marine & Coastal Access Act) define Marine Protected Areas as;

'One of the tools that can help us to protect the marine environment, whilst also enabling its sustainable use, ensuring it remains healthy and contributes to our society for generations to come'.(JNCC, 2017)

Since their inception European-implemented MPAs have caused significant confusion, debate and controversy (Fletcher *et al.,* 2012, Caveen *et al.,* 2014). This is because the legislation that creates them, Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora, better known as the Habitats Directive 1992 and transposed into UK law as the Habitats Regulations in 1994, has been interpreted in different ways by different user groups regarding how MPA's can be used and how they should be managed. This confusion is understandable as European MPA's were not designed nor intended to be highly protected nature reserves where all human activities are excluded (Gibbs et al., 2007). Article 2 (3) of the Habitats Directive states that the Directive shall take account of economic, social and cultural requirements as well as the regional and local characteristics of individual protected areas. In allowing this provision, achieving a fair and sustainable balance between economic activity and nature conservation within an MPA becomes a very difficult task. The ability to assess impacts on the interest features of an MPA from human activities against the wider conservation objectives for the site can be almost impossible, especially when viewed in combination with Article 1 (d) of the Habitats Directive which states that MPAs are first and foremost for the 'protection of priority natural habitat types in danger of disappearance' (European Union, 1992). Given that the legislation gives provision for economic, social and cultural activities while requiring the protection of priority natural habitats how do we ensure both of these objectives are delivered in a mutually beneficial way?

Individual MPA's and the network of designated sites they create are recognised as one of the most effective tools we have available to protect our marine biodiversity (Fletcher *et al.,* 2012). In response to pressure from the European Union, the UK government began in 2012 to progress the designation MCZ's (Boyes *et al.,* 2016). As with the Habitats Regulations MCZ's are regarded as 'multiuse socio-ecological designations (Rodríguez-Rodríguez *et al.,* 2015), in which the social, cultural and historical practices that relate to a particular designated site or network of sites are required to be taken into account alongside the primary purpose of the MCZ, the conservation of biodiversity.

While MPA's have for many years been accepted by many marine stakeholders they are often still viewed with suspicion by the fishing industries, who believe that restrictions will be imposed on them with the designation of an MPA. This may be the case for fishing activities that are deemed to be having a significant effect on the designated features protected under the Habitats Regulations (for example trawling within an area of *Zostera* beds). However, the approach taken by the UK government towards the designation of MCZ's includes close working with all relevant stakeholders being at the heart of the designation process. This is an approach that is at odds with that of existing European marine designations that have implemented habitat protection through a 'top down' proscriptive rather than a 'bottom up', inclusive approach. Designation of MPA's predominantly fall into two types; those that are top down, science led, government implemented and those that are bottom up, science guided stakeholder implemented (Caveen *et al.,* 2014). The choice of approach is key to the long term success. While the designation of MCZ's are a legislative requirement for the UK government, the form and management of these areas have been designed to be negotiable within broad parameters. This approach allows stakeholders to be a key part of the decision making process from the outset, working together to find a middle ground, one that will provide a win – win for all of the stakeholders.

2.1 Top down vs Bottom up.

The application of top down, science based, government led implementation of marine protection can be problematical. Science based decision making is often exacerbated by a lack of empirical evidence when it comes to MPA's (Jones, 2002, Reed and Del Ceno, 2015). Nationally, there is a notable lack of data on location and extent of marine species and habitats even within designated areas, and government departments are reluctant to make decisions without supporting evidence, which can create tensions among interest groups and stakeholders (Redpath *et al.,* 2015). To conservationists the designations do not deliver adequate levels of protection for marine habitats and species to combat the damage being done to these features by human activities and they have been seen as 'paper parks' (Monbiot, 2012). To some in the fishing industry they are a means to control and restrict fishing activity. Sanctions, bylaws and closed areas designed to allow the recovery and restoration of marine biodiversity will invariably reduce the area available to fishing and can displace inshore fleets, potentially moving them on to less profitable fishing grounds, causing significant conflict within the local community (Defra, 2012). In 2009 as a result of the implementation of the Marine Act a new government body was established. The Inshore Fisheries and Conservation Authority (IFCA) was created, this newly created government body incorporates the responsibilities of the previous Sea Fisheries Committee to ensure the sustainable exploitation of the sea fisheries resource and develops the role and responsibilities further to include the conservation objectives of MCZ's. Initial conflicts between stakeholders can also lead to situations where the management of the MPA delivers positive results for both the marine environment and economic, social and cultural interests. By opening up and maintaining the debate and lines of communication a middle ground can often be sought. This approach to the development of multiuse MPAs as a stakeholder led, science guided, bottom up approach is based on communication, co –operation and compromise was initially trialled in 1989 in the territorial waters around the Isle of Man. Ramsey Marine Nature Reserve was the first in the UK to be developed in partnership between government, scientists, conservationists and the fishing industry (Gell, 2015). For an MPA to function and succeed as an area for enhanced marine biodiversity whilst also enabling sustainable economic, social and cultural advancement then a base of trust must be established in order to avoid conflict (Redpath *et al.,* 2013).

The process is heavily reliant on close communication, trust and confidence between partners and the achievement of combined successes, and can take many years to develop. This step towards true partnership working is crucial, and clear, open and honest communication, careful deliberation and ultimately the agreement of shared goals and the approach to achieving them is key to the long term success of the stakeholder led approach to delivering marine conservation. (Figure 5)

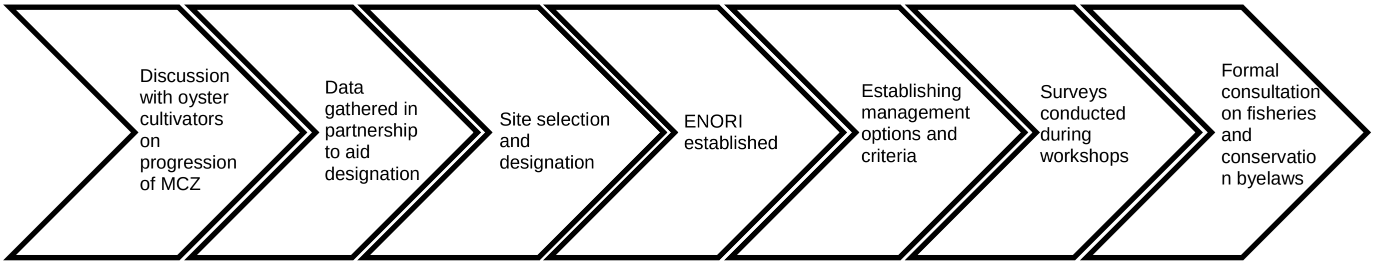

Figure 5 Schematic diagram showing the process undertaken by this study from initial communication with the shellfish industry (2009) through to the designation (2013). The subsequent establishment of Essex Native Oyster Restoration Imitative (ENORI) (2014) a stakeholder group of statutory bodies, NGO's, Oyster industry representatives responsible for developing conservation objectives and management options for the progression of the site, through to formal consultation on management options of the BCCR MCZ (2017). Diagram based on Ranger *et.al.* 2016

Some conflict is inevitable as fishing industry and conservation bodies can have opposing views on how an MPA should progress and this needs to be managed in an open and honest way for the partnership to develop. For example, representatives from the fishing industry may be concerned about potential fishing catch quota restrictions, a reduction in fishing activity, the establishment of closed areas or total bans on fishing and the impacts these can have on livelihoods and traditional ways of life in often isolated maritime communities. Disputes over the status of information and data, frustrations over timescales to deliver results and differences in opinion are all obstacles which must be overcome. Resolution to disagreements must be based on the transparency of regulators and clear, open and honest communication between stakeholders (Figure .6). Successfully managing conflicts between nature conservation and economic, social and cultural issues requires all stakeholders to understand early on what the issues are and how they are likely to emerge and develop. By understanding these complexities, obstacles can be overcome effectively enabling long term solutions to become much more effective (Redpath *et al.,* 2013).

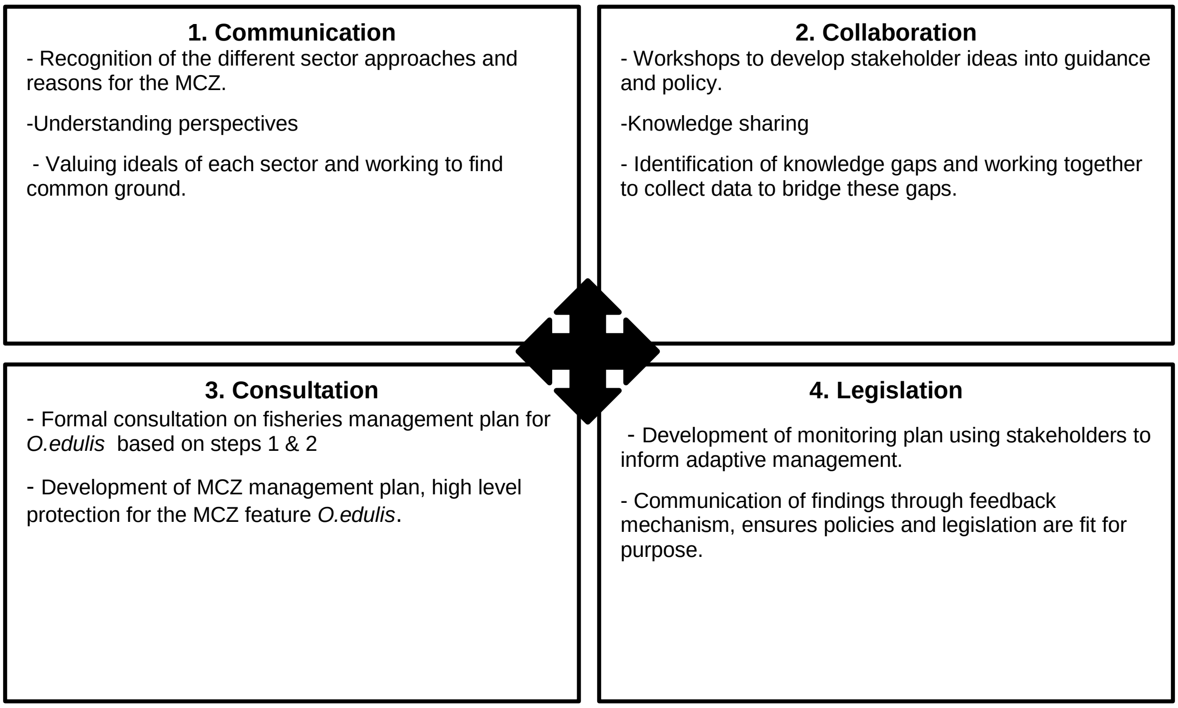

Figure .6 - Schematic diagram showing the process stakeholders undertook to ensure values and opinions of each sector were taken into account during the development of the legislation and management options for the Blackwater, Colne, Crouch and Roach MCZ

This inclusive approach to designation provides a framework for stakeholders to participate in group communication and has been extremely successful. Examples of where this approach has been used to great effect include the successful establishment of Ramsey Marine Nature Reserve and in 2000 the creation of the Lyme Bay marine reserve. In both cases the use of effective communication and the development of group cohesion as a tool to reduce future conflict and secure positive working relationships has been critical. (Colyvan *et al.,* 2011, Peterson *et al.,* 2013, Elston *et al.,* 2014)

1.2 Building stakeholder relations-the Blackwater Estuary partnership.

The relationship between the local oyster industry in the Blackwater estuary in Essex (Blackwater Oysterman's Association) and the conservation sector (Essex Wildlife Trust) began in 2001 through a coastal seawall managed re-alignment project. The partnership between the two bodies formed during the design of the seawall re-alignment at Abbotts Hall on the Blackwater estuary and evolved out of work undertaken to ensure that there were no detrimental impacts from the re-alignment on the adjacent oyster beds. Following this initial work, several other collaborative projects were undertaken between the two organisations including a response to the planned nuclear power station located on the Blackwater at Bradwell on Sea in 2007. The creation of the Marine Act 2009 providing the opportunity for the creation of MCZ's. Included within legislation was the ability to protect *Ostrea edulis* and *Ostrea edulis* beds. This opportunity gave the partnership a new focus. Would it be possible to find enough common ground in which the partnership could pursue a conservation designation for native oysters whilst also maintaining the integrity and future viability of the oyster fishery in the Blackwater estuary?

Initial discussions regarding the potential for an MCZ designation in Essex for *O.edulis* began in 2009. It was clear from initial communication that the primary motivations of the two sectors (oyster industry and conservation sector) were different. The primary driver for the oyster industry was economic. A lack of regulation in the industry left resident oystermen vulnerable to unregulated harvesting of oyster stocks from nomadic fleets. In pursuing the MCZ designation, the legislation could potentially put in place a series of measures that would mitigate the risk of unregulated harvesting. Whereas the primary driver for the conservation sector was to increase numbers of *O.edulis* for their inherent value as a species and the ecosystem services they provide. However, it was clear from initial communication that both sectors shared two common values; both wanted increased protection for populations of *O.edulis* already present in Essex and both wanted to increase these numbers to more sustainable levels.

While MPAs are advocated as tools to protect wild species and habitats, they are primarily concerned with regulating human behaviour and activity and inevitably have impacts on individuals and communities, especially in the busy inshore sea areas (Ranger *et al.,* 2016). As a result of the Blackwater Oysterman's Association (BOA) and Essex Wildlife Trust (EWT) working in partnership in the preceding years and coming to either consensus or compromise on a wide range of issues, a strong foundation of trust had become established. The basis of this trust comes through sharing opinions and expert knowledge between the two organisations that led to the mutual understanding that the partnership could achieve more together than by working alone. Early stage communication with additional stakeholders including Natural England, Kent & Essex IFCA, followed the process reviewed by (Reed, 2008) whereby decision making is from mutual agreement, transparency and shared values. Forums, meetings and communication focused initially on a single shared value, both sectors wanted to see an increase in native oysters in the Essex Estuaries. The process in which this would be achieved differed, never-the-less work began in partnership to collect the data necessary to progress the designation of the area as an MCZ. In November 2012, following the submission of data (to follow in Chapter 3) to the UK government, the Blackwater, Colne, Crouch & Roach MCZ was designated in November 2013. The designation of the MCZ was the first step, in order for the MCZ to fulfil a remit of a designation for fisheries and conservation, then debate and communication needed to continue. Following the designation, EWT and the BOA undertook wider stakeholder engagement, opening lines of communication in order to encompass principle user groups, statutory bodies, NGO's and academics. Communication was formalised under the Essex Native Oyster Restoration Initiative (ENORI). The group is responsible for developing and delivering conservation objectives contained within the designation whilst also consolidating opposing views on how this is achieved. This cross sector collaborative approach to conflict resolution allows a progressive approach to restoration of the MCZ feature whilst taking into account the socio-economic impact.

2.3 Aim

Obtain effective ‘buy in’ from the Essex Oyster industry and other stakeholders affected by the designation of the BCCR MCZ.

2.3.1 Objectives

- Determine opinion from a range of stakeholders of the effects the designation of a marine conservation zone would have on fisheries and conservation in Essex.
- Assess effective approaches to community engagement and interaction throughout designation, restoration and management.
- Assess the process of designation, restoration and management of a Marine conservation Zone in Essex.

2.4 Methodology

2.4.1 Surveys

Surveys were developed in conjunction with the University of Essex Social Sciences Department, following the Japec 2015 model and were designed to explore the views and opinions of stakeholders engaged in the designation of the Blackwater, Colne, Crouch & Roach Marine Conservation Zone area. The survey was developed using Groves 2009 (Figure 7). A pilot study was developed and implemented prior to the commencement of the main study for the following reasons; To ensure questions were robust and non-leading, to check that participants are familiar with terminology, to ensure the questionnaire can be completed in an appropriate time frame, to allowed for appropriate adjustments to be made. Developmental stages included a test pool of individuals who trialled the survey and structure in advance of the final version. All individuals asked had previous experience of designing and conducting surveys of this type.

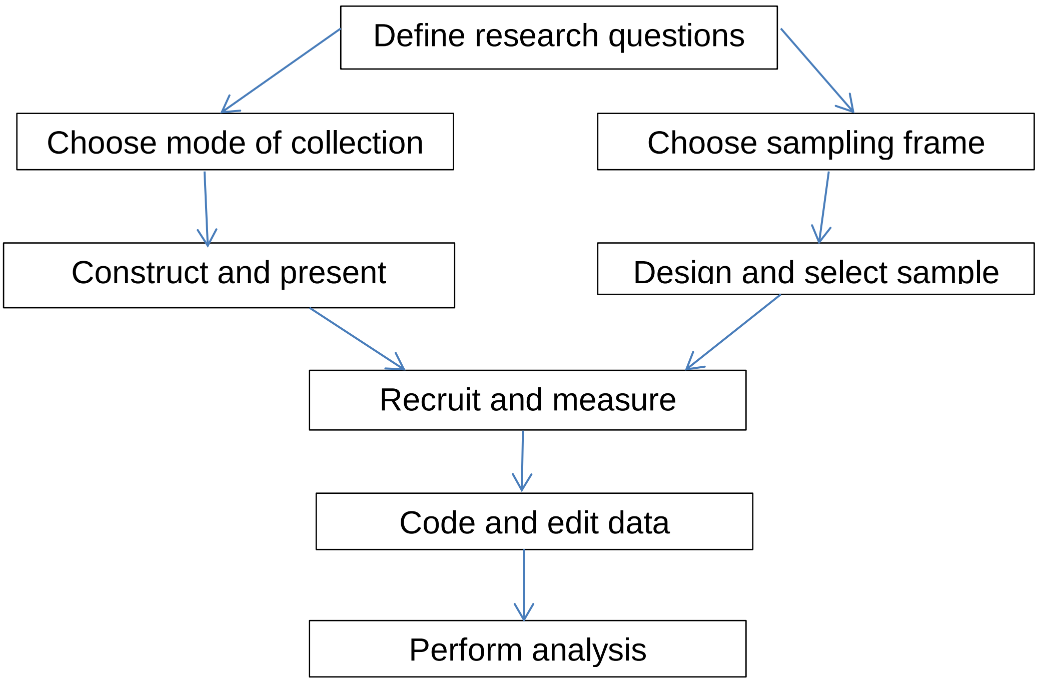

Figure 7 Schematic diagram showing design and development of the stakeholder questionnaire based on Groves *et al* (2009)

The study focused on groups of stakeholders that have been influential in the development of the MCZ project. Oyster growers/cultivators, regulatory bodies, nature conservation NGO's and academic/research bodies. The surveys were conducted during Feb-May 2017 during regular meetings of the ENORI group and at additional meetings containing additional stakeholders active within the MCZ area. Surveys contained structured questions to ascertain age, locality and the individual groups represented, ranked semi structured questions to ascertain preferred attributes and unstructured questions to gain their views on marine conservation, ecosystem priorities (De Juan *et al.,* 2017) and their attitude towards the process and the project.

(Bird, 2009) (Table 9) Interpretation of unstructured questions were homogenised to facilitate interpretation. All Questionnaires were anonymous, surveyed individuals were over 18. All volunteers that participated were provided with information on how and where the information would used, a full brief of the survey questions and their definitions (see section 2.4.2) were provided before taking part. A wider stakeholder group of 34 attended the workshop, participants included those instrumental in the designation and development of the BCCR (Blackwater, Colne, Crouch & Roach) MCZ including regulatory bodies, fishing industry, nature conservation NGO’s and academic institutions. Surveys were undertaken during workshops and meetings, responses were collected after the meetings and workshops or submitted later by post or email. Thirty four attendees were present at the workshop, 34 questionnaires were distributed one to each attendee, Twenty questionnaire responses were collected either immediately after the workshop or by email or post following the workshop (n=20). Of the participants 6 were from Nature conservation NGO’s, 8 were from the fishing industry, 4 were statutory or regulatory bodies and two were independent academics (Table.10).

2.4.2 Definitions

All participants were briefed on definitions of specific wording within the context of the survey.

Legislative – Application and administration of the Habitats Directive and the Marine & Coastal Access Act in reference to the restoration of *O.edulis* within the BCCR.

Active management – Actively restore *O.edulis* and *O.edulis* habitat to the BCCR MCZ through a series of fisheries based cultivation methods. i.e. Bagless dredging, harrowing of the seabed, removal of predators, this method requires continuous management and annual monitoring.

Passive management –No active intervention, recolonization of *O.edulis* through natural regeneration. This is a hands off approach to restoration (monitoring required).

Restoration activities for conservation – Actively restore *O.edulis* to the BCCR MCZ through a series of conservation based methods. i.e. Installation of suitable settlement substratum, establishment of brood stock areas, this method requires one off intervention for installation and monitoring.

Other – This gives the participant the opportunity to suggest any additional thoughts on the subject matter. Any ‘other’ suggestions were collated and analysed.

Table 9: Questionnaire distributed to stakeholders that have been influential in the development of the MCZ project, including Oyster growers/cultivators, regulatory bodies, nature conservation NGO's and academic/research bodies. Surveys were conducted Feb-May 2017 during regular meetings of the ENORI group and at additional meetings containing additional stakeholders active within the MCZ area.

Structured					
What sector are you representing?	Conservation	Fisheries	Regulatory body	Other	
What is your age?	25-35	36-45	46-55	56-65	65+
How many years have you been involved with the Oyster industry	0-10	10-20		20+	
Do you live	locally	Within 10 miles	Within 20 miles	More than 20 miles	
Why do you support the Marine Conservation Zone for native oysters	Fisheries	Conservation	Both	Neither , I don't support the designation	
Do you want more or fewer or the same number of native oysters in Essex?	more	fewer	The same		
Semi structured (ranked)					
How do you feel about the process so far?	(1) extremely negative – (5) extremely positive				
How do you feel about the ENORI partnership	(1) extremely negative – (5) extremely positive				
Were there any barriers to overcome to progress the project?	Legislative	Individual personalities	Communication	Other	
If you do want more oysters, why?	Conservation	Economic benefit	Cultural/ historical interest	Cultivation	
How do you want to increase the number of oysters in Essex	Active management	Passive management	Restoration activities for conservation	Other	
Unstructured questions					
Are there any frustrating aspects you have found with the process?					
What are the advantages of working in partnership?					
What are the disadvantages of working in partnership?					

Table.10: Characteristics of respondents who participated in the survey (Table 9) : sector, age, locality, and number of years involved in the MCZ project .

	Overall %	By sector		
		Conservation %	Fisheries %	Statutory/Regulatory %
Sector				
Conservation	30			
Fisheries	40			
Independent	0			
Statutory/Regulatory	30			
Age				
25-35	30	50	12	33
36-45	30	33	25	33
46-55	25	16	25	33
56-65	0	0	0	0
65+	15	0	37	0
Years involved with Oyster industry				
0-10	75	100	37	100
10-20	5	0	12	0
20+	20	0	50	0
Years involved with Blackwater				
0-10	63	80	25	100
10-20	0	0	0	0
20+	36	20	75	0
Area of residence				
Local	45	0	75	50
Within 10 miles	10	16	0	16
Within 20 miles	15	16	0	33
More than 20 miles	30	66	25	0

2.5 Results

All participants (n=20) were asked if they wanted more, fewer or the same number of *O.edulis* in Essex, all of those who took part in the survey agreed that they wanted to see an increase in native oysters in the Essex. Participants were then asked to rank in order their primary motivations for this: conservation, economic benefit, cultural and/or historical interest, cultivation and aquaculture. Overall, half of all participants (50%) ranked conservation as the primary driver for wanting to see an increase in *O.edulis* in the BCCR MCZ (Figure 8).

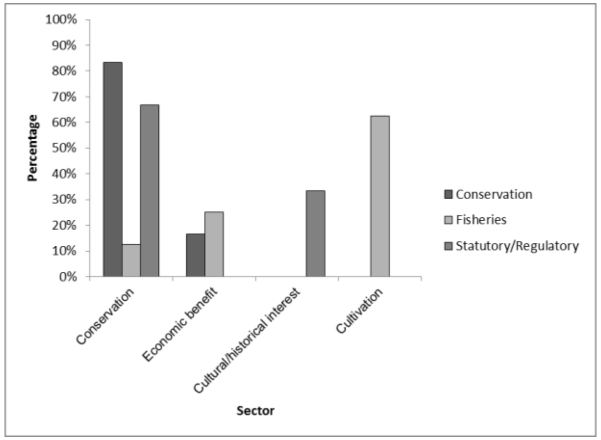

Figure 8 Primary motivation- 50% of all stakeholders across three sectors stated the most important driver for the increase of *O.edulis* within the BCCR MCZ was for the benefit to conservation

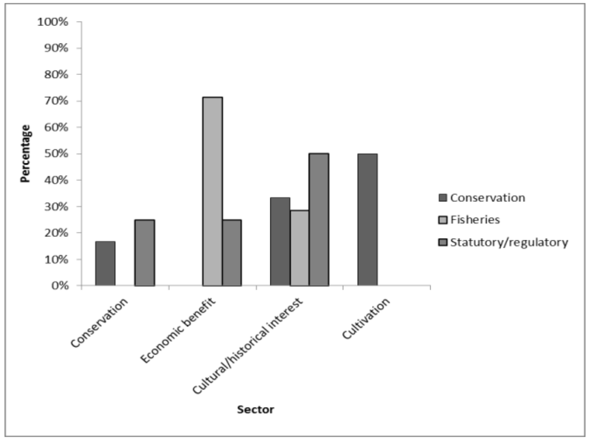

Figure 10 Second most important driver for the increase of *O.edulis* within the BCCR MCZ. Overall equal weighting was given between economic drivers (35%) and cultural/historical interest (35%) as the secondary motivation of the group for the increase of *O.edulis*

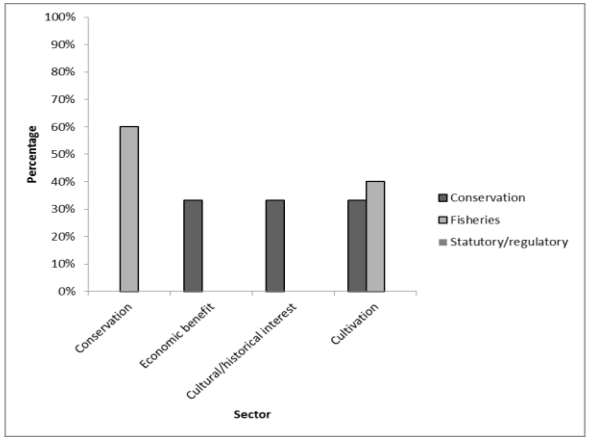

Figure 9 Third most important driver for the increase of *O.edulis* within the BCCR MCZ. Overall Cultivation (41%) was cited as the third most important driver for increasing *O.edulis* within the BCCR MCZ

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Overall equal weighting between economic benefits and cultural/historical significance was given as the second overall most important driver for the stakeholders. When broken down into sectors, 50% of the conservation sector cite cultivation as their second most important driver for the increase of *O.edulis* within the BCCR MCZ, whereas 71% of the fishing industry cite economic benefit as the second most important driver for the increase of *O.edulis* within the BCCR MCZ.

When broken down into responses from sectors, differences in primary drivers emerge. Conservation NGO's and statutory nature conservation bodies cite conservation as their primary reason for wanting more native oysters in Essex (83% and 67% consecutively) whereas the fishing industry saw cultivation (62%) as the primary driver (Figure 9). Interestingly conservation NGO's rank cultivation as the second most important aspect (50%) for increasing numbers of native oysters in Essex, and cultural/historical interest (33%) after that. Statutory and regulatory bodies rank conservation as the primary driver (66%) cultural and historical interest in second place (50%). In contrast, the fishing industry regarded economic benefit as the second most important driver (71%); (Figure 10) and conservation as the least important factor (60%) (Figure 8).

Participants were then asked if they supported the designation of the BCCR MCZ and if they did, why. All respondents agreed that they supported the designation with the majority (65%) supporting the MCZ for its contribution to both conservation and fisheries. However, when this figure is broken down into thoughts and opinions of each of the sectors, differences were observed. Most of those in the conservation sector (83%) and statutory/regulatory sector (100%) said that they supported the MCZ for its value to both fishing and conservation, with only 17% supporting the designation for conservation purposes alone. In contrast, in the fishing industry the overall majority (75%) said they supported the designation of the MCZ for its positive contribution towards the fishing industry, while only 25% supported the MCZ for its contribution towards fishing and conservation.

Next, participants were asked to choose one of four options on how they would increase numbers of Native oysters in the BCCR, 1. Active management. 2. Passive Management 3. Restoration activities for conservation 4. Other. Responses showed that overall active management was favoured (65%) with restoration activities for conservation the second favoured option (30%) (Figure 11). When broken down into sector, both conservation NGO's and fisheries shared active management as the preferred option for restoration (50% and 87% respectively), whereas the regulatory or statutory bodies favoured a combination of restoration for conservation first (50%) and active management (50%)

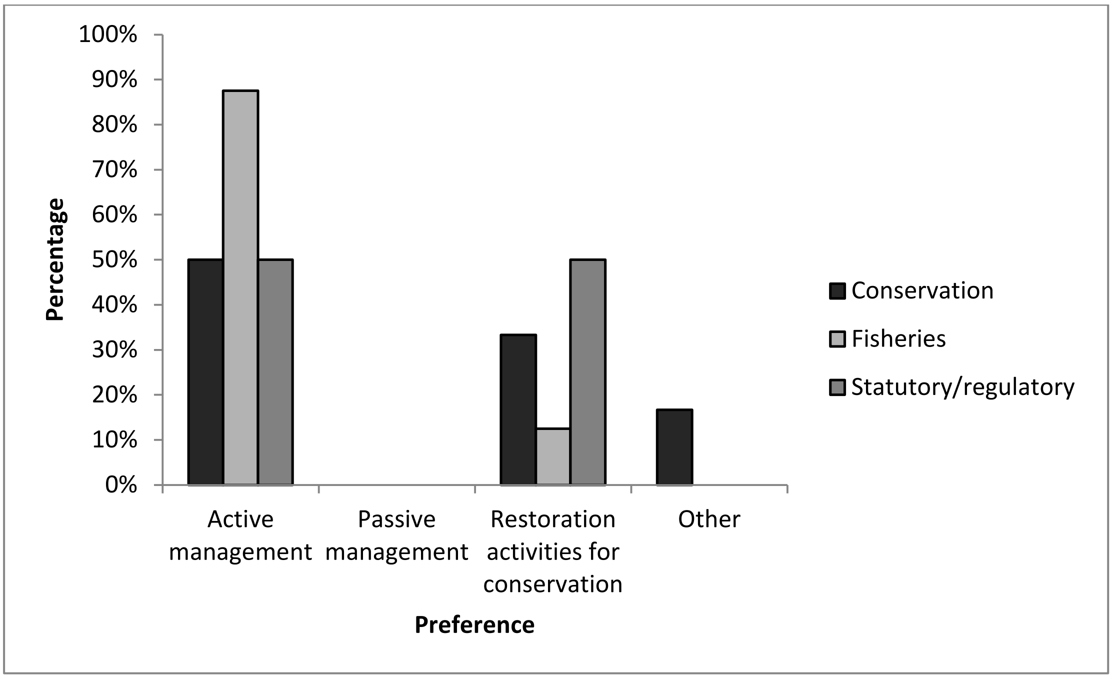


Figure 11 Preference on how to increase numbers of Native oysters in the BCCR MCZ. Overall active management (65%) was the favoured approach by all sectors and restoration activities (30%) was the second most important means to increase *O.edulis* within the BCCR

The survey group were asked to rank in order what they have found to be the biggest barriers to the progression of the MCZ process to date, all sectors agreed (85%) that the primary barrier towards progress had been legislative, this was mirrored in the opinions of both conservation, fisheries and statutory/regulatory bodies where 83%, 87% and 83% consecutively agreed that legislation was a barrier to the management and restoration of the MCZ. (Figure 13). After which, individual personalities was cited as the next largest obstacle encountered during the process (64%). (Figure 12) additional comments (included in other) of barriers to the progress of the MCZ included complexities of the site and how to manage the fishery within a MCZ and communication with those outside of the stakeholder group.

Participants were asked to rate how they felt about the process of designating and implementing management and restoration activities within the MCZ, Categories ranged from 1. Extremely negative through to 5. Extremely positive. Overall 55% of participants found the process to be positive; this was reflected in both the conservation sector (50%) and the statutory/regulatory sector (100%). However, the fishing industry responses were under the overall average with 25% of responders feeling positive about the process or extremely positive (25%) about the process, but 37% of fishing industry participants felt neither positive or negative (neutral) about the process, 12% felt negative about the process. (Figure 14)

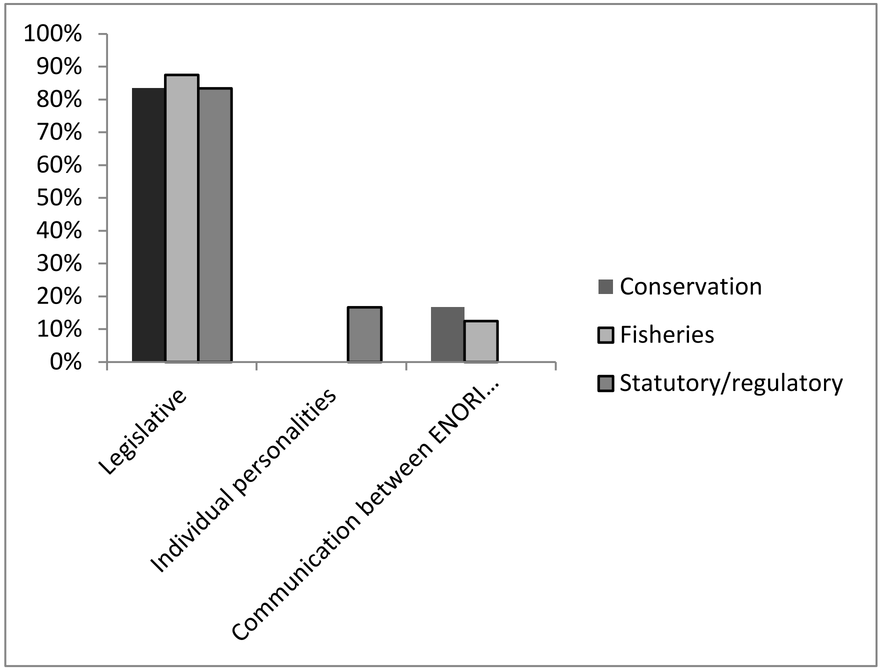


Figure 13: Opinions on greatest barrier to the progress of the BCCR MCZ. Overall (85%) of participants agreed that primary barrier to the progression of the MCZ was the application and administration of the legislation.

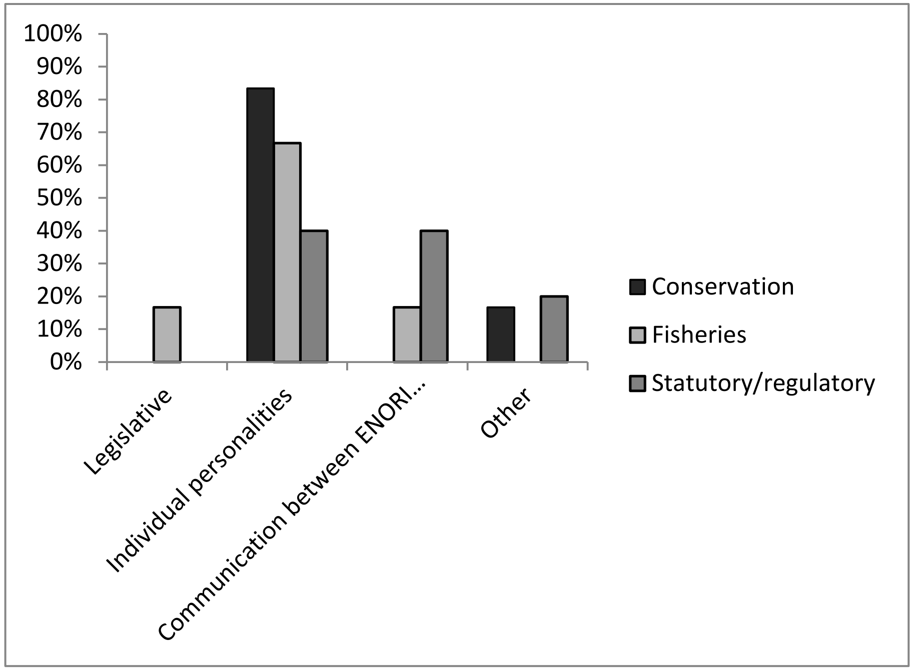


Figure 12 Opinions on second biggest barrier to the progress of the BCCR MCZ. Overall (64%) of participants agreed that the second biggest barrier to the progression of the MCZ was the individual personalities involved.

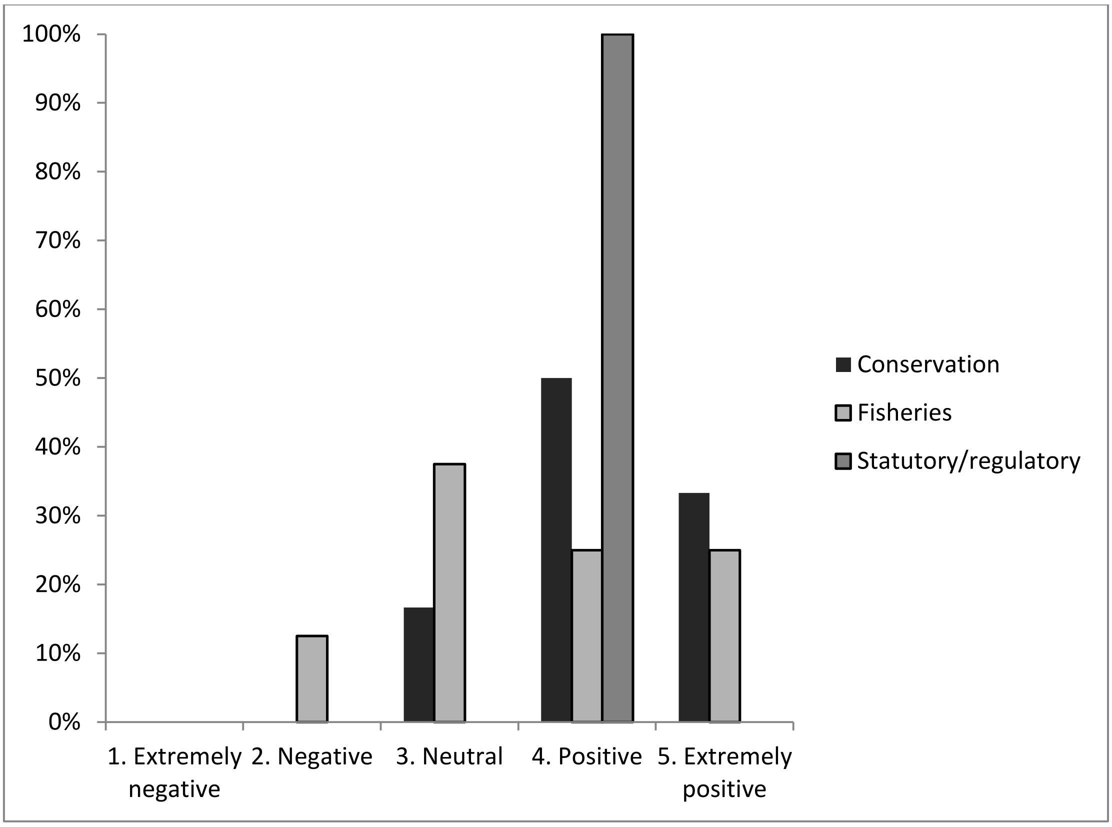


Figure 14 shows participants opinions of the process so far from designation of the BCCR MCZ through to implementation of management options. Overall (55%) of participants felt positive about the process.

Participants were then asked an open ended question to expand on their feelings and experiences about the process from designation through to implementation of management options in particular what they had found to be negative or frustrating. Participant responses varied from funding (5%) and communication through to conflict between partners on implementation of ideas (10%). The most common themes that emerged were length of time taken to come to an agreement between partners on how to proceed, resulting in implementation of the process being drawn-out (30%) and the legislative complexities of the process and the site (25%) both of which were directly attributed to the frustration regarding length of time taken to implement the process.

Despite these frustrations all participants (100%) stated that overall they felt positive about the process (60%). 83% of conservation sector rated the partnership as positive or extremely positive (16%). Fisheries rated the partnership as positive (50%) or neither positive or negative (neutral) (37%). Statutory/regulatory sectors rated the partnership is neutral (33%) positive (50%) extremely positive (16%) (Figure 14). Participants from across the sectors stated that working through problems together as a group was one of the major advantages of the partnership that partnership, communication, sharing knowledge and cross sector learning were overall the most positive aspect of the partnership', that the partnership 'provides an open forum for discussion, brings together stakeholders which is invaluable for the future sustainability of the project and allows personal relationships to be formed'.

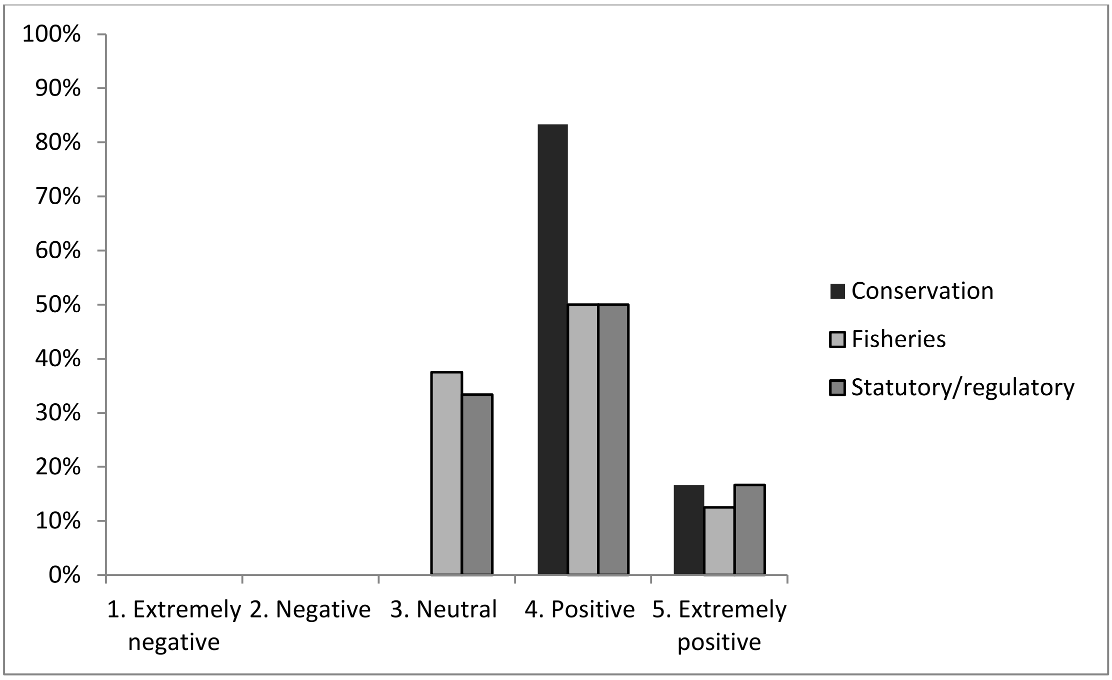


Figure 15 shows participants opinions of the ENORI partnership from designation through to implementation of management options. Overall (60%) of participants felt positive about the partnership.

2.4. Discussion

Overall, these results demonstrate that a process of communication, sharing views, values and knowledge leads to group cohesion and that this cohesion is vital in progressing and achieving long term positive conservation management for the MCZ. Results also indicate that while communication and knowledge sharing is important in achieving these shared goals, the time it takes to discuss and negotiate combined agreement can cause stakeholders to become impatient and frustrated with a perceived lack of progress. While ecological protection is frequently the driver for a conservation designation, it is often social and economic aspects of the designation that is crucial to the success or failure of these conservation designations (Redpath *et al.,* 2013). Long term successes of a project, whereby both the conservation objectives and the socio-economic requirements are delivered effectively, rely on a strong foundation of communication and discussion of options and opinions, which in time lead to mutual agreement and shared values of those involved (Ranger *et al.,*2016). Reed (2008) states that the complex and dynamic nature of environmental problems requires flexible and transparent decision-making that embraces a diversity of knowledge and values. This is certainly the case of the BCCR MCZ, in order to overcome difficulties of conflicting stakeholder opinion, legislative complexities and conflicting management advice, as well as progressing the conservation objectives for the MCZ, an integrated stakeholder led approach is required from the very early stages. This method is becoming more widely accepted as a tool in which to identify and mitigate any conservation conflicts that may arise at the earliest possible stage in the process and using these conflicts as a tool to discuss, share knowledge, gain experience and achieve long term agreement from stakeholders, especially those most affected by a new designation or change in policy (De Juan *et al.,* 2017).

The purpose of the Essex Native Oyster Restoration Initiative (ENORI) was to bring together representatives from a range of backgrounds and interests in order to consolidate views of stakeholders and the groups and individuals they represent. All participants represent the views of their respective groups, the survey methodology is designed to sample a subset of these groups, it is therefore possible to ensure a wider collective of opinion is represented through the group without extensive numbers of participants. Partners and wider stakeholders have met regularly during the 5 years since the designation of the BCCR MCZ to discuss how to progress the conservation objectives for the MCZ and increase numbers of *O.edulis*. Despite stakeholders having differing opinions and perspectives on the mechanisms for the primary delivery of the MCZ, there are common values that can be seen across the stakeholders and the sectors they represent, all participants supported the designation of the MCZ and wanted to see the MCZ deliver an increase in *O.edulis*. Overall all sectors wanted this increase to be for the benefit of both fisheries and conservation. Unsurprisingly the primary reason for desiring an MCZ did differ between sectors, with nature conservation NGO's and statutory/ regulatory bodies wanting to see an increase for the purpose of conserving the species, whereas the fishing industry wanted an increase in abundance primarily for cultivation, however, participants agreed that the second most important drivers for an increase in *O.edulis* were economic and social/cultural. All sectors also agreed on how they would like increased numbers of *O.edulis* in the MCZ, overall all participants wanted to see implementation of active management as the key delivery tool for increasing numbers of *O.edulis* within the MCZ, with additional restoration activities for conservation, further discussion related to the need for a combination of all factors, active management, restoration projects as well as passive management in areas where *O.edulis* have been found historically to ascertain if natural recolonization could occur. These shared values show positive and progressive thinking and aligned values across all sectors surveyed, this helped facilitate formal and informal communication, adding to and building on relationships formed during the designation of the site and development of management options. Stakeholders also agreed that the main barriers to the development of management plans and conservation objectives for the MCZ were primarily due to legislative constraints. (Chapter 5: Introduction to Marine Protected Areas: Critical analysis of implementation in the UK) These legislative complexities were cited as the greatest cause of frustration to the process, with many participant responses stating that they experienced frustration due to the length of time taken to implement positive restoration activities and actions on the ground. This shows that stakeholder participation needs to be underpinned with practical, tangible actions and results that can be taken forward as a group project while continuing to work towards larger or longer term goals to ensure momentum and positive communication, otherwise stakeholders become frustrated. This process of continued communication shows to stakeholders that there is a commitment to learning from each other; it fosters respect for professional opinion and coming together of shared values all of which is reflected in participant responses to open ended qualitative analysis of the survey. A number of new Marine Protected Areas including MCZ's are being designated throughout the UK in the coming years, the majority of which will be designated within six nautical miles of the UK coastline, each experiencing differing socio-economic impacts and pressures. There remains a fundamental need to ensure these areas are planned and managed in a way that fulfils their primary function, for the protection of species and habitats while also taking into account the socio-economic value of the area. The BCCR MCZ has shown that in order to achieve successful long term buy-in and recovery of an MCZ it is imperative that stakeholder engagement is undertaken at the earliest possible opportunity, and that communication is a key tool in breaking down perceptions and sectoral silos and allowing a forum for discussion and disagreement to be voiced, in doing so stakeholders develop understanding, mutual respect and common solution based on shared values.

Chapter 3- Abundance, distribution and size structure of *O.edulis* in the BCCR MCZ.

3.1 Introduction

The Blackwater, Colne, Crouch and Roach (BCCR) MCZ lies on the East coast of Essex, in the South East of England. The designation covers an area of approximately 284 km^2. It is made up of four estuaries;, Blackwater, Colne Crouch and Roach, (Figure 16E) as well as open stretches of coast Dengie, (Defra, 2013).

The Blackwater Estuary is the largest estuary in this complex extending to a length of 21.2km, from its tidal limit at Maldon to the mouth (Hill *et al* ., 1996). Upper intertidal habitats along the estuaries are characterised by extensive swards of saltmarsh; areas vegetated with salt tolerant plants found on low energy coastlines where deposition levels are high (Davidson *et al.,*1991). The importance, extent and composition of these saltmarsh communities are of international importance qualifying as Atlantic salt meadows for their species assemblage and are protected as an SAC designated under the Habitats Directive. (Figure 16B).

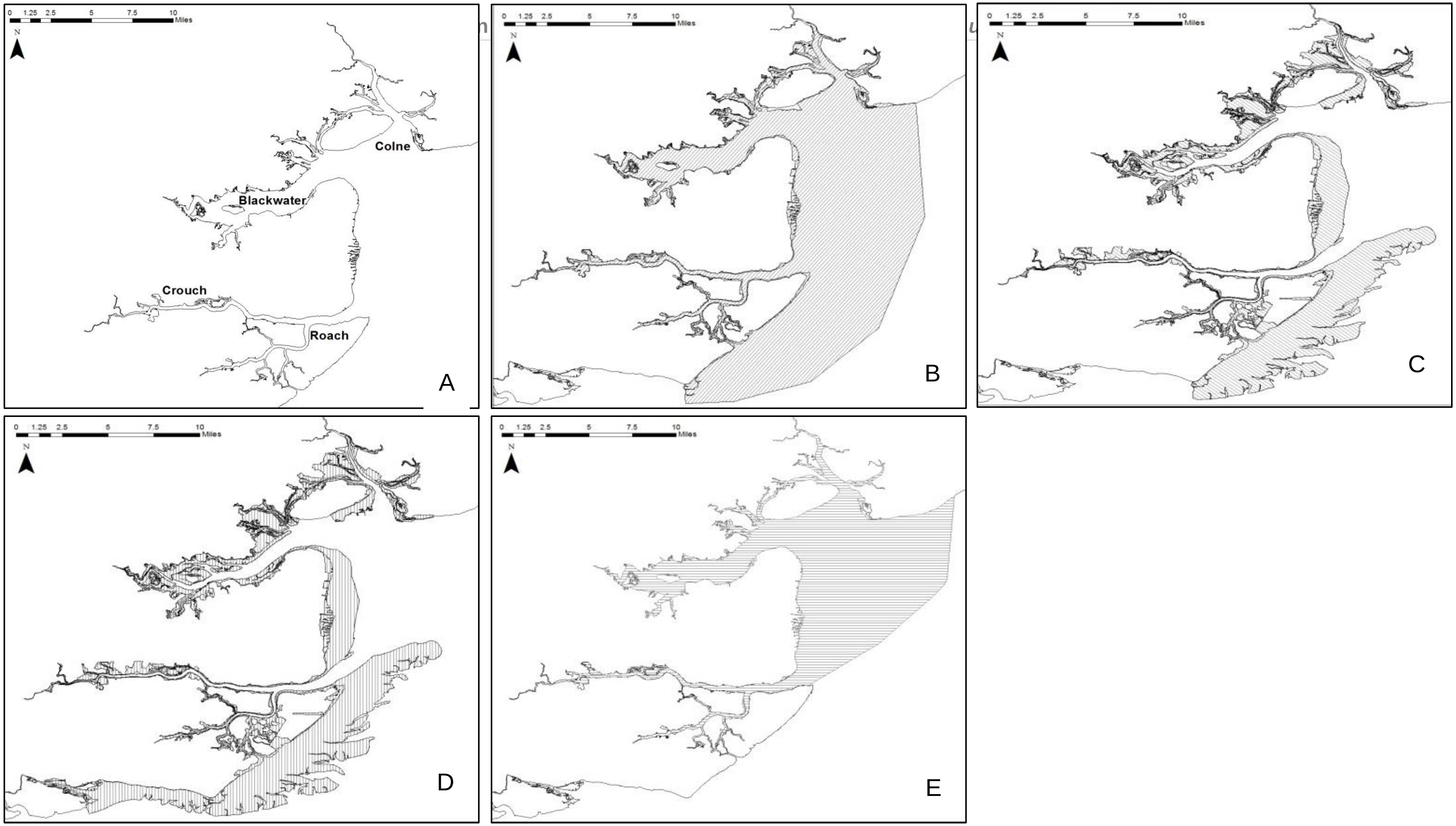


Figure 16 Nature conservation designations of the Essex Estuaries (A) location of Estuaries Colne-Blackwater-Crouch and Roach. (B) Essex Estuaries Special Area Conservation (SAC). (C) Essex Estuaries Mid Coast Phase 1-5 Special Protection Area (SPA). (D) Essex Ramsar sites (E) Blackwater, Colne, Crouch & Roach Marine Conservation Zone (MCZ)

Above high water the majority of the Essex Estuaries SAC is bounded by seawall defences, the most of which have been constructed using clay excavated from the immediate area. This method creates an associated linear pond called a borrowdyke.

The presence of seawalls and the phenomenon of sea levels rising as a result of global warming result is a destructive process known as coastal squeeze. This erosion of the intertidal area is a significant consideration in the Essex Estuaries SAC (Pollitt *et al.,*2003, Collier *et al.,*2005, Holt *et al.,*2012). Cooper (2001) published a study quantifying the loss of saltmarsh in the Essex Estuaries between the years of 1973 and 1998. The study showed that during the 25-yr period, 1000 ha of saltmarsh were lost in Essex, primarily due to coastal erosion, representing a 25% loss of the total saltmarsh area originally present in Essex in 1973. This was extended in 2004 by a study looking at saltmarsh loss over a 50 year period, the study conducted by Hughes & Paramour (2004) estimated loss in the South East of England to be approximately 40 ha y^{-1}.

The lower intertidal zone is dominated by extensive intertidal mud and sand flats equating to over 17000 ha (JNCC, 2000). Closer to the mouth, substratum type gradually begins to change. More exposed shores, higher tidal and wave energy and faster tidal currents usually keep fine sediment in suspension and coarser particle sizes are deposited and result in muddy sand, sand flats and intertidal mixed sediment found along the shores of

Mersea island and the offshore intertidal areas of the Buxey and Foulness, here Cockles (*Cerastoderma edule)*, razor shells (*Phaxas pellucidus)*, sand gaper (*Mya arenaria)* and the banded wedge shell (*Donax vittatus*) all dominate, inhabiting the coarse mud and sand from mid shore to the shallow sub tidal, they in turn are a food source for many over wintering waders and wild fowl (Connor *et al.,* 2004)

In more exposed areas of the estuary, shingle banks may accumulate, these habitats are found along the East Mersea shore and Colne Point. Material is pushed up the beach during storm surges, these rare shelly habitats are important for their invertebrates and assemblages of rare vascular plants such as shrubby sea blite (*Suaeda* vera*)* yellow horned poppy (*Glaucium flavum*), and sea heath (*Frankenia pauciflora*). (Fuller, 1987). Subtidally the mosaic of habitats continues with sand banks found extensively throughout the area. The Buxey, the Knoll, the Swallowtail and the Bachelor Spit sandbanks all support a range of species that are associated with these habitats, including Thornback ray (*Raja clavata)* which use these areas for feeding and breeding (Hunter *et al* ., 2006). Subtidal mud flat communities are dominated by infaunal bivalve molluscs, such as clams (*Mercenaria mercenaria)* and (*Venerupis philippinarum),* cockle (*Cerastoderma edule)*, razor shell (*Phaxas pellucidus*).

3.1.1 Conservation and designation: *O.edulis*

Subtidal mixed sediment is present throughout the estuarine complex. Areas such as the Nass, Knoll and Bench Head are examples of this habitat type supporting a range of species, including aggregations of the bed forming species *Ostrea edulis*. One definition of an oyster bed is the dense aggregations of Cultch (shell) with a veneer of living oysters, the dense aggregations of shell provide rugosity to the sea bed, making the character of the substratum different to that of surrounding areas, supporting both infauna and epifauna, these areas are particularly important for juveniles as it provides shelter from predators. The presence of *O.edulis* within the Essex Estuaries has been known for centuries, first documented in Roman times it has endured and remained until present day. (Zu Ermgassen, *et al.,* 2013)

Until the Marine and Coastal Access Act was passed in 2009, *O.edulis* had very little conservation protection. Though cited as a species of conservation importance in the OSPAR guidelines, (OSPAR, 2003) and also as a Biodiversity Action Plan species cited within the NERC Act, (Nerc, 2006) the level of protection awarded under these two conservation guidance packages is minimal. The OSPAR convention seeks a holistic approach to the protection of the marine environment, compliance is gained through cooperation of member states and is a key factor in the delivery of the UK's Marine Strategy Framework Directive (MSFD), the convention focuses on enhancement of the marine environment through good environmental status (GES) while this holistic approach benefits all marine biodiversity it does not afford protection to individual species, nor does it stop damaging activities which can contribute to the loss of individual species and habitats. The UK Biodiversity Action Plan (BAP) does recognise the rare or vulnerable status of a species or habitat and seeks to address the decline, under section 40 the Act states a 'Duty to conserve biodiversity' however the wording is weak stating

'public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity.'

In 2012 a review of Biodiversity Action Plans were conducted, the audit recognised the rapid decline is species and habitats it was designed to protect, following the review a new UK strategy was developed, known as the UK post 2010 biodiversity framework. The review added an additional 550 species and 16 habitats, and seeks to improve levels of protection

The Marine Act however, increased the levels of protection through the establishment of MCZ's, areas of protection designated for the presence of certain species and habitats such as *O.edulis*. Evidence of its presence was required to secure the site as a MCZ for the protection of *O.edulis* and *O.edulis* beds.

3.2 Aims

- Determine the presence of *O edulis* in the Essex estuaries to enable the designation of a Marine Conservation Zone.
- Determine distribution and density of *O.edulis* in the Essex Estuaries to ensure effective management and restoration.
- Determine density and size structure of *O.edulis* associated with suitable substratum sites to inform management and restoration.

3.3 Materials and Methods

3.3.1 Study Design – Blackwater

ArcMap GIS software was used map the area of the recommended Marine Conservation Zone. A 200m x 200m grid was created using fishnet software and clipped to the boundary created. Using Seazone mapping software TruDepth data points were imported into the database and depths of ≥ 0 – ≤4m within the boundary were selected. The MCZ fishnet grid was clipped to incorporate only these depths. (**Error! Reference source not found.**). Every 200m grid square within these selection criteria was allocated a value between 1 and 4000 in consecutive order. Numbers were input into a random number generator and 283 were selected, each randomly selected sample point was uploaded into the survey area geodatabase. All surveys took place between November 2010 and March 2011. Survey sites were located using GPS. Each sample location was surveyed using a 1m wide standard oyster dredge fitted with a 45mm ring size.

At each location a 100m tow (determined by GPS linked sidescan sonar (Humminbird 698ci HD, (Humminbird, Eufaula, Alabama) was taken. The contents of the dredge were discharged onto the sorting table and photographed. All *O.edulis* were removed, counted and shell length (mm) of each oyster was measured from umbo to outer shell margin using callipers.

Substratum samples were collected, photographed and allocated a number from 1 – 8. (Table 11) These broad substratum categories were based on EuNIS level 4 habitat type classification (Table 12)

Table 11 Broad substratum categories and their associated substratum code, based on EuNISlevel 4 habitat type classification.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Silt	Clay	Fine mud	Muddy Sand	Sand	Gravel	Shell	Cobbles

Level 4: Biotope complexes - These are groups of biotopes with similar overall physical and biological character. Where biotopes consistently occur together and are relatively restricted in their extent, such as rocky shores and very near-shore subtidal rocky habitats, they provide better units for mapping than the component biotopes, better units for management and for assessing sensitivity than the individual biotopes. They are relatively easy to identify, either by non-specialists or by coarser methods of survey (such as video or rapid shore surveys), thereby offering opportunities for data collection by a wide range of people and without recourse to specialist species identification skills

This type of assessment was adopted due to its rapid methodology, relative ease, ability to be replicated by a wide range of people, including the fishing industry while retaining high level of specificity.

Table 12 Broad substratum categories used and the associated EuNIS code and biotope category description.

Substratum categories	Name	EuNIS code	EuNIS description
1	Silt	A5.34	Shallow sublittoral muds, extending from the extreme lower shore to about 15-20 m depth in fully marine or near marine conditions, predominantly in extremely sheltered areas with very weak tidal currents.
2	Clay	A4.23	This habitat type occurs on moderately wave-exposed, circalittoral soft bedrock subject to moderately strong tidal streams. As this complex is found in highly turbid water conditions, the circalittoral zone may begin at the low water mark, due to poor light penetration
3	Mud	A5.32	Shallow sublittoral muds, extending from the extreme lower shore into the subtidal in variable salinity (estuarine) conditions.
4	Muddy Sand	A5.33	Infralittoral, cohesive sandy mud, typically with over 20% silt/clay, in depths of less than 15-20 m. This habitat is generally found in sheltered bays or marine inlets and along sheltered areas of open coast.
5	Sand	A5.22	Clean sands that occur in the upper reaches of marine inlets, especially estuaries, where water movement is moderately strong, allowing the sedimentation of sand but not the finer silt fraction.
6	Gravel	A5.12	Clean gravels that occur in the upper reaches of marine inlets, especially estuaries, where water movement is sufficiently strong to remove the silt content of the sediment.
7	Shell	A5.42	Shallow sublittoral mixed sediments in estuarine conditions, often with surface shells or stones, enabling the development of diverse epifaunal communities, e.g. *Crepidula fornicata* (A5.422), as well as infaunal communities. This habitat type is therefore often quite species rich, compared with purer sediments.
8	Cobbles	A3	Infralittoral rock includes habitats of bedrock, boulders and cobbles which occur in the shallow subtidal zone and typically support seaweed communities.

In total 401 locations throughout the Blackwater, Colne, Crouch & Roach MCZ were sampled using the dredge method. (Figure 17)

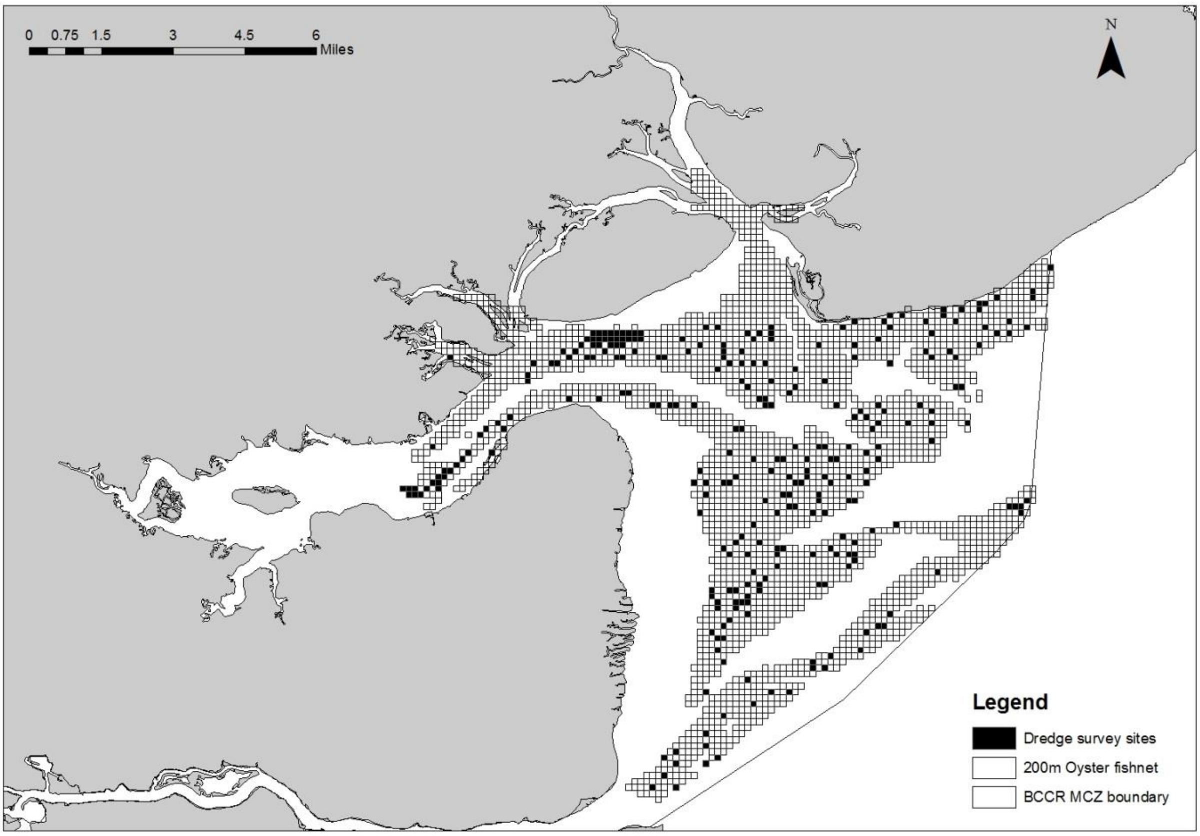


Figure 17 200m x 200m 'fishnet' grid created in ArcMap and clipped to the Blackwater, Colne, Crouch & Roach MCZ. White areas denote intertidal zone and therefore not sampled, Black squares denote random sample area locations, 401 locations were sampled for *O.edulis* using a 100m dredge tow.

3.2.2 Survey Design – Colne Estuary

An additional data set (n= 110) for the Colne Estuary was used to determine spatial extent and distribution of *O.edulis* throughout the Essex Estuaries, an additional 110 survey locations within the Colne Estuary were sampled during January – November 2007 (Hardy 2014) The Colne Estuary was conceptually divided into seven discrete sampling zones, comprising four sections of the main estuarine channel and three major tidal creeks; Geedons, Brightlingsea Creek and Pyefleet Channel. (Figure 18). A stratified sampling design was adopted within which Sampling Zones were assigned on the basis of known variations in salinity, intertidal characteristics, composition of benthic substrata, levels of disturbance through shipping and commercial activity and positions and historical extent of *O.edulis* beds within each Zone. In total 118 locations were sampled. (Hardy,2014)

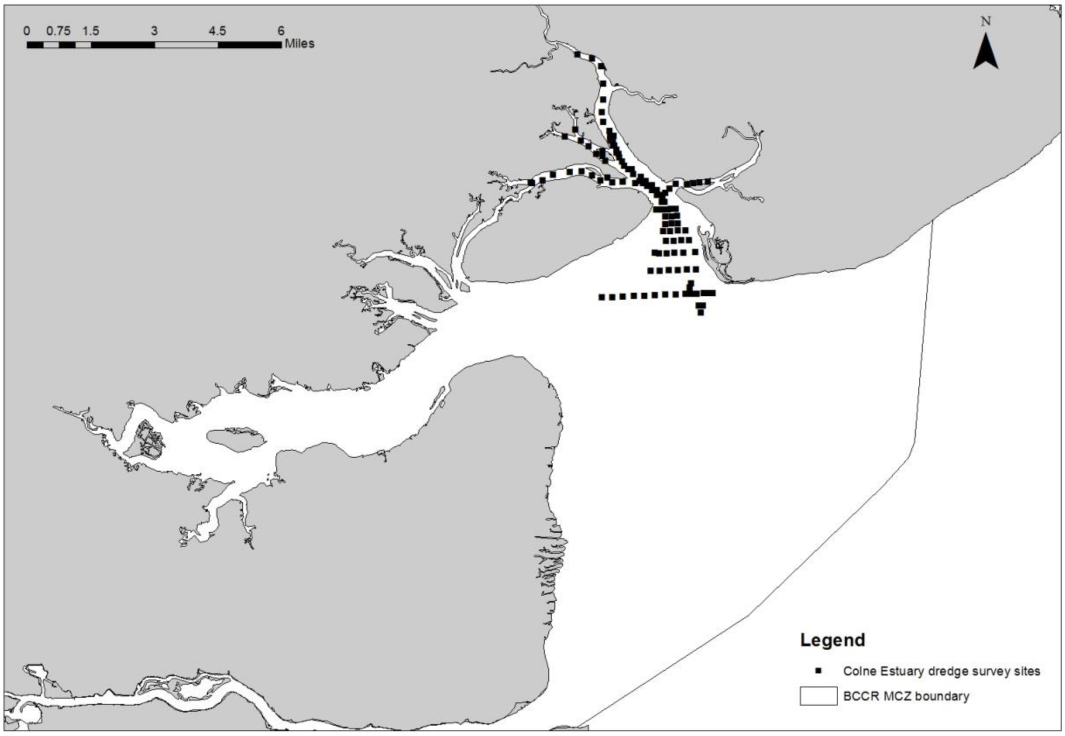


Figure 18 Map of Colne Estuary including 200m x 200m fishnet grid and extent of MCZ area. Map shows M. J. Hardy sampling locations 2009 – 2012

3.3.2 Data Analysis.

All survey data was imported into ArcMap 10.2.2, including presence, number and sizes of *O.edulis* within each sample, and substratum type. The survey area was divided into 5 distinct zones. (1) Blackwater (2) Colne (3) Bench Head (4) Ray Sand (5) Outer Estuary. (Figure 19) based on present and historical management regimes. (Table 13).

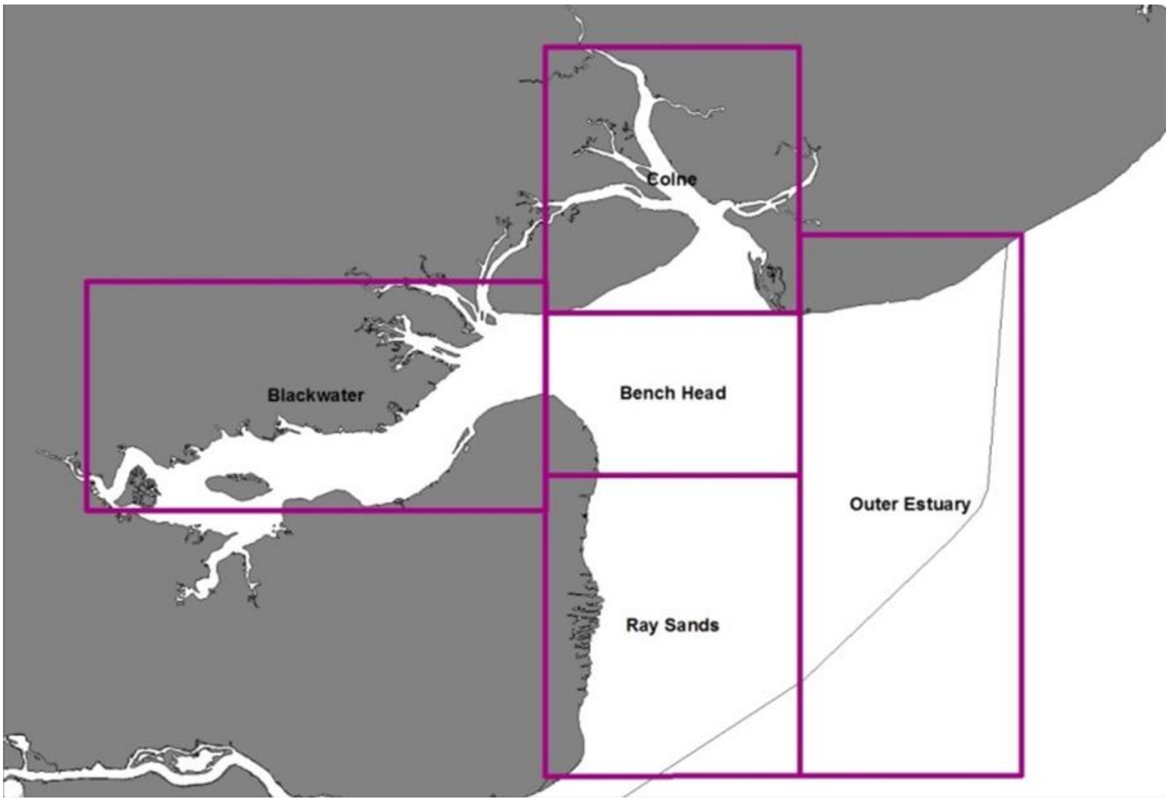


Figure 19 Five distinct survey zones were identified based on historical management practices and fisheries data. Blackwater area has had continuous aquaculture practices since 1972 contains a fisheries several order, is managed and fished by Blackwater Oystermans' Association. Colne is privately tenanted has previously supported a population of *O.edulis* but they are no longer present, Bench Head an area of public ground, open to opportunistic fishing with no formal management known to support a population of *O.edulis*, Ray Sand public ground open to opportunistic fishing, no formal management, population of *O.edulis* known to be present since 1980 and Outer Estuary public ground, no known populations of *O.edulis.*

Table 13 shows fishing and cultivation practices for *Ostrea edulis* within the Blackwater, Colne, Crouch & Roach MCZ.

Area	Activity	Date	Historical land use	Activity
Blackwater Creeks	Private grounds	1800	Privately owned seabed	*O.edulis* relayed in creeks over the summer from 1972 onwards removed for at the end of each summer.
Blackwater	Several order	1972	Owned and cultivated by Blackwater Oystermans Association	*O.edulis* known to be present since 1876, numbers declined dramatically 1962/3 cultivation and relying of cultch seabed since 1972, oyster spat settlement on cultivated grounds from *O.edulis* in privately owned creeks.
Bench Head	Public ground	--	Open fishing grounds	Historically fished by opportunistic fishing boats, no formal management, translocation or cultivation practices
Colne	Tenanted	1952	Leasehold since 1952	*O.edulis* historically present in Colne. Populations declined significantly in 1982 due to the introduction of the parasite *Bonamia ostrea*. Restoration and cultivation began again in 2010
Ray Sand	Public Ground	--	Historically open fishing grounds	Wild population known to be present since 1980. Historically fished by opportunistic boats, no formal management or cultivation practices
Outer Estuary	Public ground	--	Historically open fishing grounds	No *O.edulis* populations known to have populated this area

3.3.3 Statistical Analysis

Statistical analysis of *O.edulis* distribution and density data was undertaken using a two way analysis of variance using a General Linear Model approach, with the data square root (N+1) transformed. Transformed data followed by multiple comparison procedure in Sigmaplot (v.12, Systat. Hounslow, London, U.K.). Analysis compared *O.edulis* counts per 100m dredge sample by survey zone and substratum category. A pairwise multiple comparison procedure (Holm-Sidak method) compared mean values. Principal component analysis of population size structures and estuary zones was conducted using MVSP v3.1, (Kolvec Ltd, N. Wales, U.K.).

3.4 Results

3.4.1 Determining the presence, absence, distribution, abundance and population structure of *O. edulis* in the BCCR MCZ.

One hundred and one of the 401 locations (Figure 17) sampled contained *O.edulis* (Figure 20) Densities ranged from 1 to 150 individuals per sample (100m dredge) (Figure 21). High densities were recorded in the Blackwater and Ray Sand (Figure 22). Number and location of *O.edulis* within the MCZ show significant spatial variability between populations. A Two-way ANOVA revealed significant differences in abundance between sites ($F = 11.434$ $p < 0.0001$; $df = 4$). To determine which sites differ throughout the MCZ area a paired t-test was applied. This showed a significant difference between Blackwater, Colne ($t = 4.651$, $p = < 0.001$), Bench Head and the Outer Estuary zone (t=0.45, p=<0.001) but no significant difference between the Blackwater and the Ray Sand (t= 1.427, p=0.285). A significant difference was also observed between the Ray Sand and the Colne(t= 3.914, p=<0.001), Bench Head and Outer Estuary Zone (t= 0.45, p=0.652). No significant difference was observed between populations when comparing Bench Head populations to the Colne (t= 2.102, p= 0.137) (Table 14).

Table 14 Substratum type and *O.edulis* counts within the Blackwater, Colne, Crouch & Roach MCZ, a Pairwise Multiple Comparison Procedures (Holm-Sidak method of means test revealed a significant difference between the Blackwater, Colne, Bench Head and the Outer estuary.(p=<0.001) But no significant difference between the Blackwater and the Ray Sand.

Comparison	Diff of Means	t	P	P<0.050
BW vs. Co	2.289	4.651	<0.001	Yes
BW vs. Outer	1.465	4.31	<0.001	Yes
BW vs. BH	1.34	4.007	<0.001	Yes
Ray vs. Co	1.797	3.914	<0.001	Yes
Ray vs. Outer	0.973	3.355	0.005	Yes
Ray vs. BH	0.848	2.991	0.015	Yes
BH vs. Co	0.949	2.102	0.137	No
Outer vs. Co	0.824	1.808	0.199	No
BW vs. Ray	0.492	1.427	0.285	No
BH vs. Outer	0.125	0.45	0.653	No

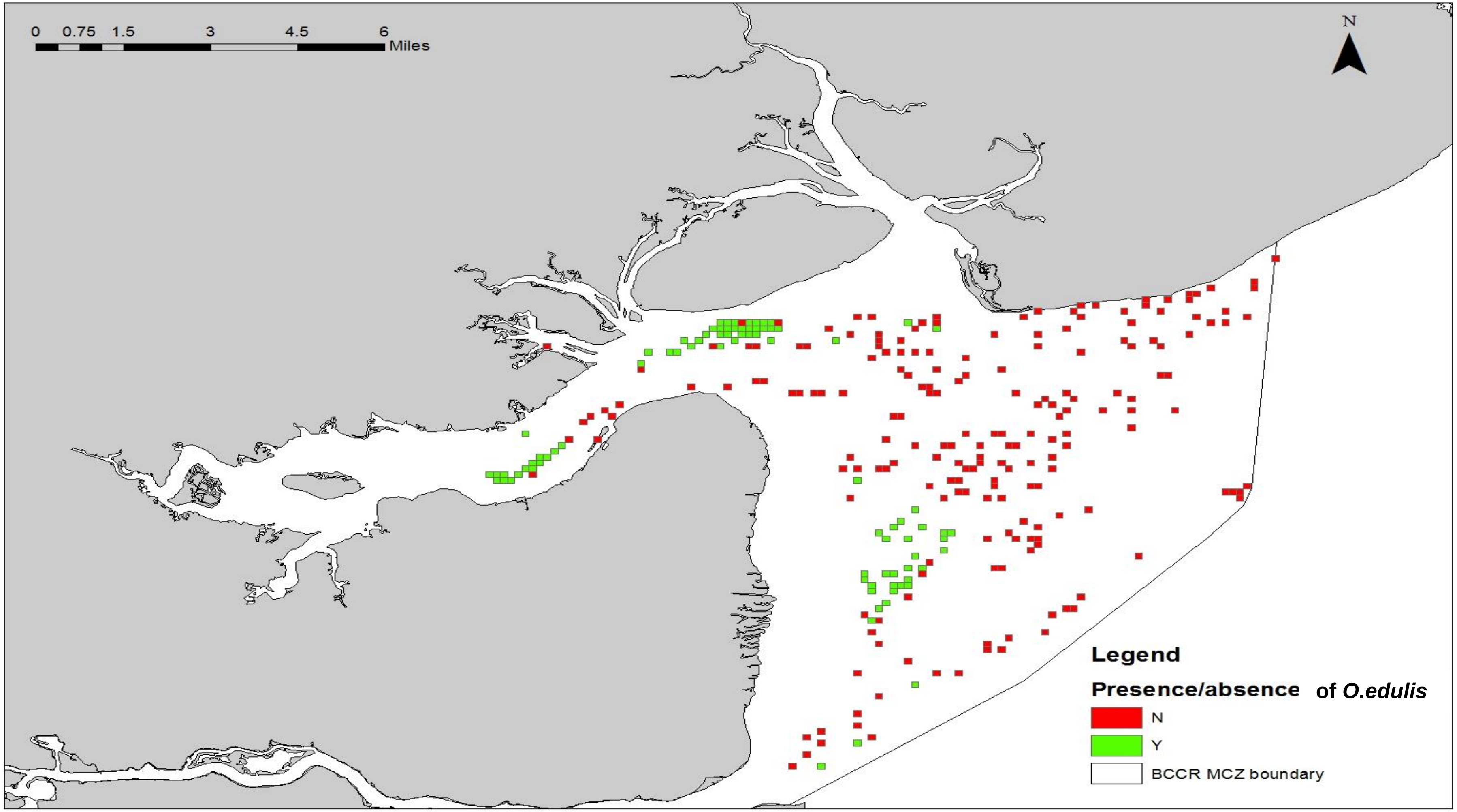


Figure 20 Presence (Green) , absence (Red) and spatial distribution of *O.edulis* within the Blackwater, Colne, Crouch & Roach MCZ. Distribution shows four distinct locations or clusters of *O.edulis* individuals located within the Blackwater, Bench Head, Colne and Ray Sands.

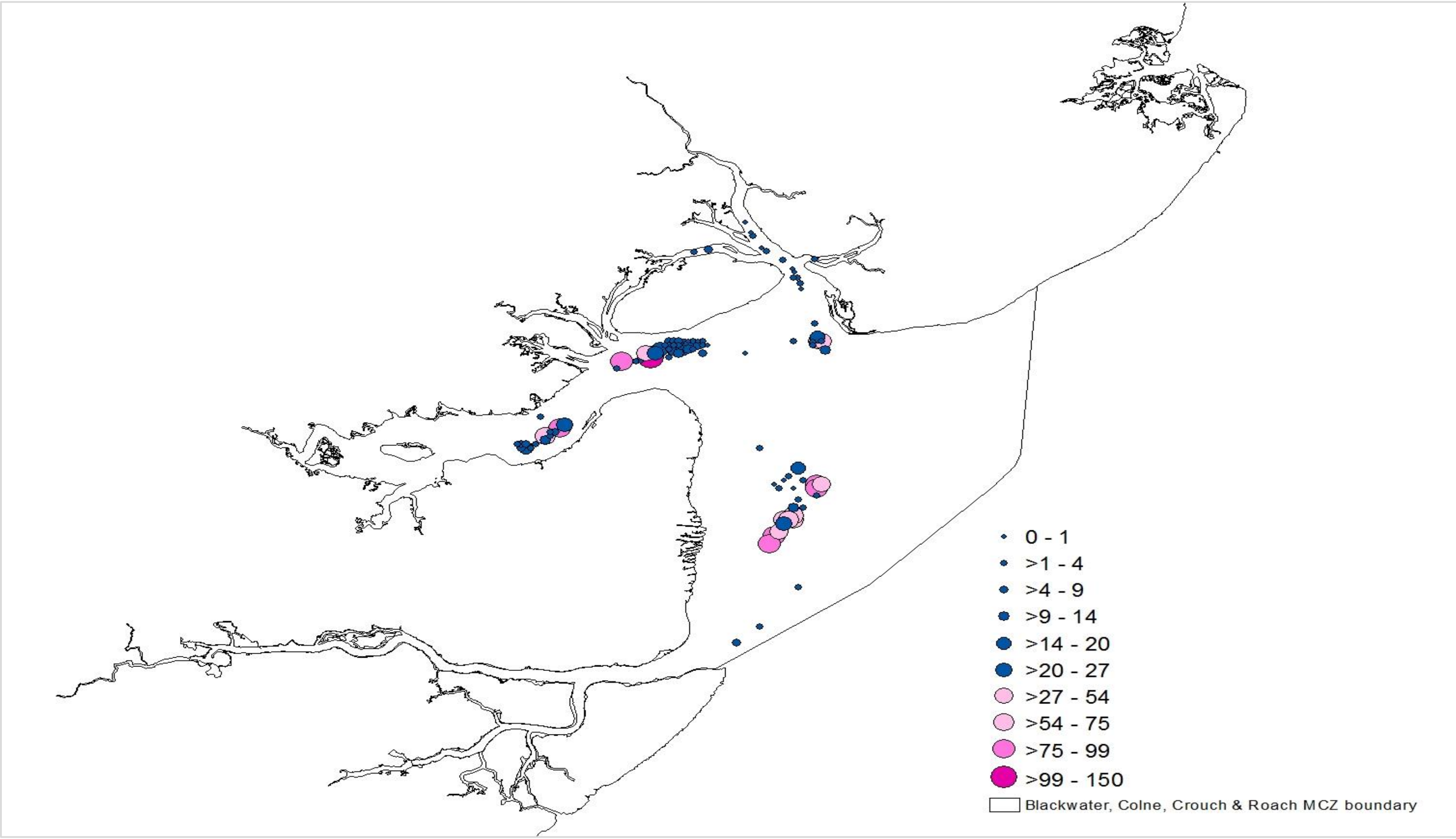


Figure 21 Density and distribution. Number of *O.edulis* per 100m dredge sample throughout the Blackwater, Colne, Crouch & Roach MCZ, Highest densities were located within the Bench Head and Ray Sand survey Zones, lowest occurrence of individuals were found within the Colne Estuary.

3.4.2 *Ostrea edulis* population distribution and age structure within the BCCR MCZ.

Spatial variations of oyster population structure were also compared between survey zones. (Figure 22) Size frequency data revealed changes in population structure between the four survey zones that contained populations of *O. edulis*. (Figure 23) Principle Components Analysis of the size distribution data of all samples containing oysters revealed that primarily the Blackwater and Bench Head survey zones containing a higher proportion of individuals in the smaller size classes, when compared with populations in the Ray Sand and Colne, and a high occurrence of larger individuals (60-100mm) in the Ray Sand compared with populations within the Blackwater & Bench Head which shows a more diverse range of sizes (Figure 24)

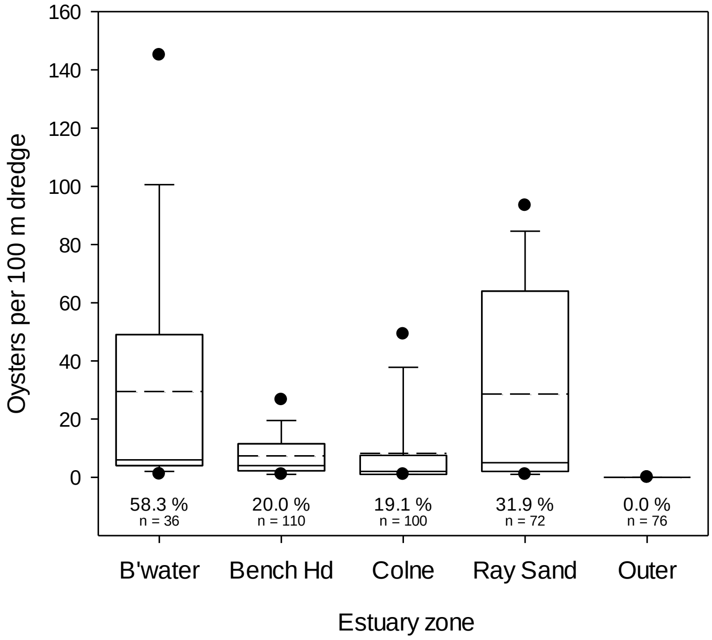


Figure 22 Box and whisker plot (median, 25-75 quartiles, mean value dotted line) Number of *O.edulis* per 100 m dredge sample (n = total number of dredge samples taken in survey zone) % = number of 100 m dredge samples containing 1 or more *O.edulis.*

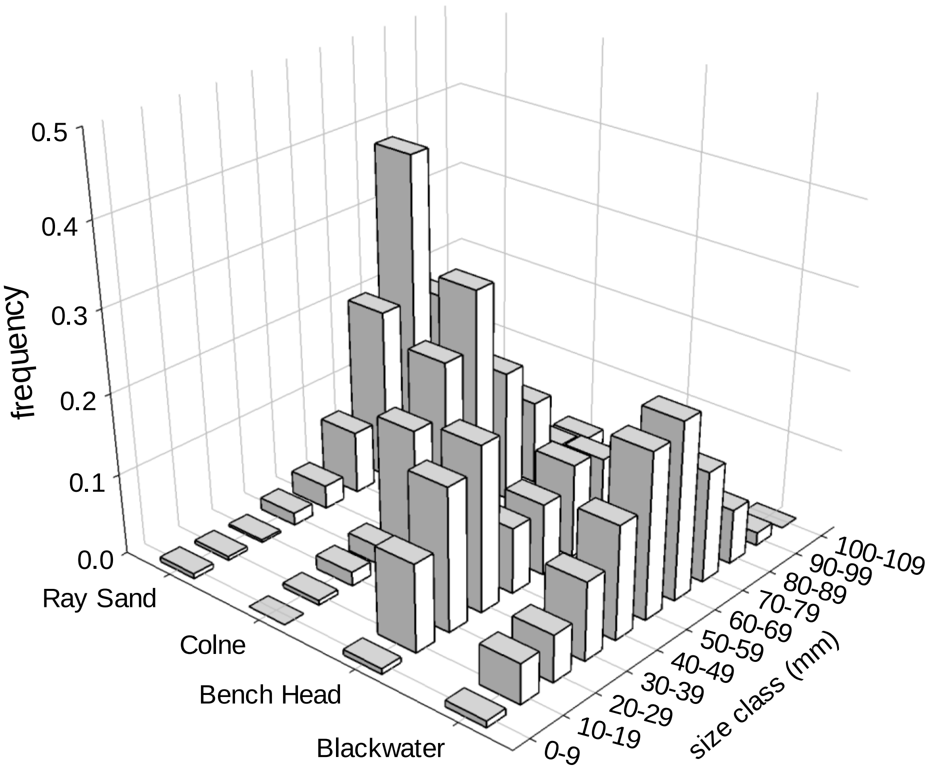


Figure 23 Different age structures of *O.edulis* between four estuary zones; Blackwater, Bench Head, Colne & Ray Sand.

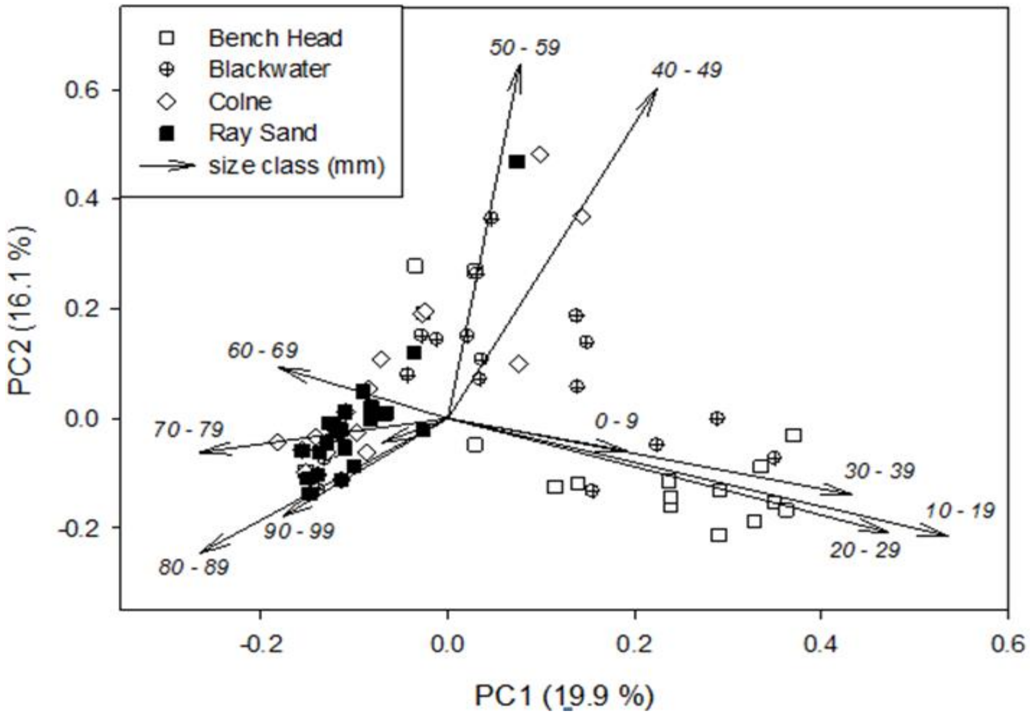


Figure 24 Principal Component Analysis of *O.edulis* population size structure (shell length classes in mm) in the Blackwater, Colne, Crouch & Roach MCZ.

3.4.3 Effect of substratum type on *Ostrea edulis* abundance.

Of the survey locations sampled, 104 of the 401 locations sampled contained the substratum types, Gravel, Shell and Cobble (particle size >2mm) (Figure 25) Only 4 from a possible 110 survey locations within the Colne contained substratum >2mm whereas a 132 out of a possible 283 survey sites within the Blackwater, Bench Head, Ray sand and Outer Estuary contained substratum >2mm

There was a significant difference in population density of *O.edulis* in relation to substratum type within the survey zones (F = 9.119, p = <0.001, df = 7) results show significantly higher numbers of *O.edulis* on shell within the Blackwater Survey Zone. There was also a significant difference between number of oysters found on shell compared to other substratum types regardless of survey zone. (Table 15)

Table 15: The of number of *O.edulis* per 100 m dredge compared between different substratum types.

Comparison	Diff of Means	t	p	P<0.050
Shell vs. sand	1.596	6.826	<0.001	Yes
Shell vs. Silt/Clay	1.479	4.279	<0.001	Yes
Shell vs. Muddy Sand	1.651	3.951	0.002	Yes

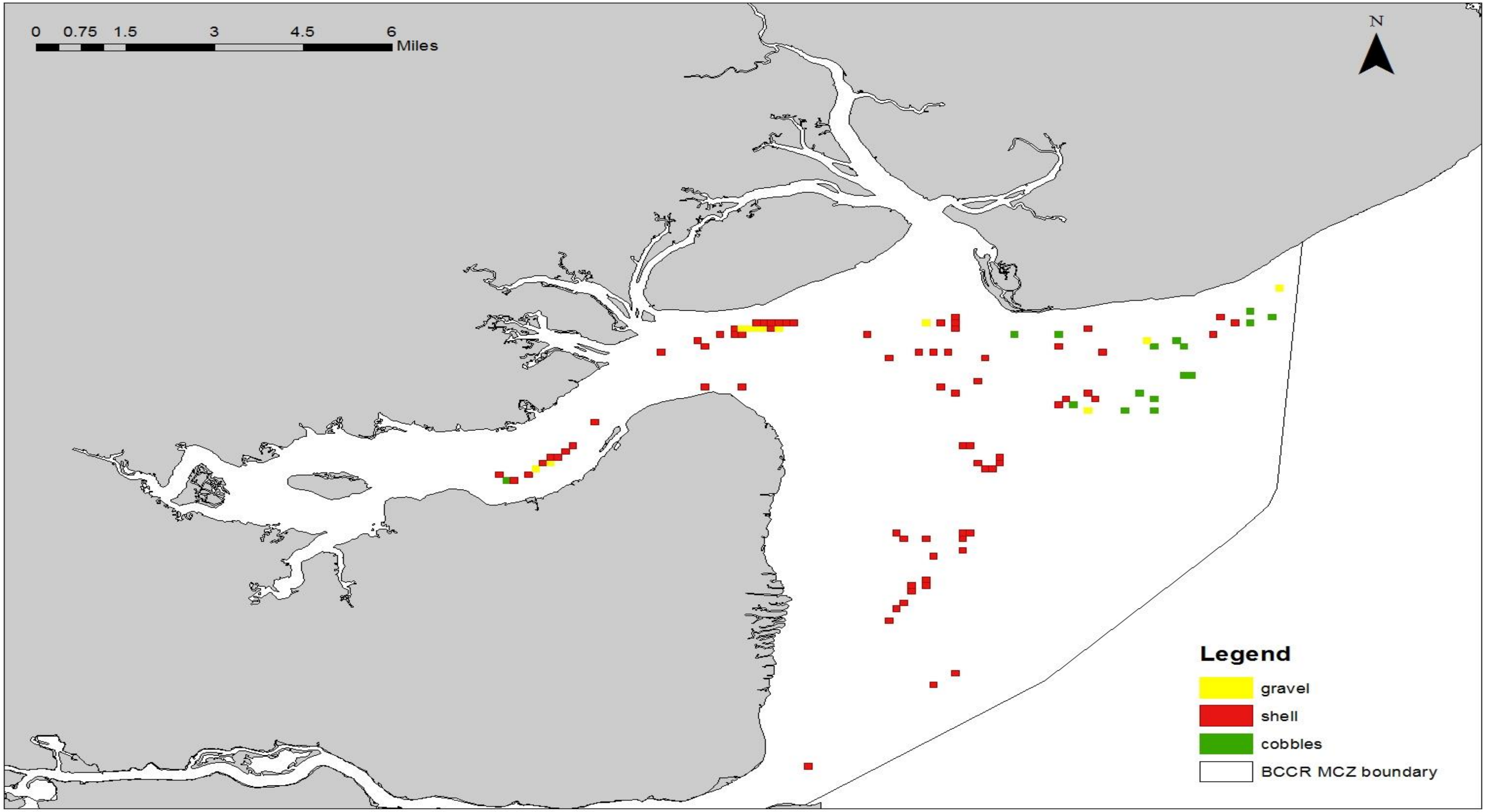


Figure 25 Location and distribution of substratum type throughout the Blackwater, Colne, Crouch & Roach MCZ. (2) Clay (3) Fine Mud (4) Muddy Sand (5) Sand (6) Gravel (7) Shell (8) Cobbles.

3.5 Discussion

While there is historical anecdotal evidence stretching back many hundreds of years of the presence of *O.edulis* within the Essex estuaries, in particular the Colne and Blackwater, there has not to date been any quantified scientific evidence of its presence and distribution throughout the estuaries and surrounding coastal waters and the age structure of these remaining populations. Stocks of *O.edulis* in the Essex Estuaries were significantly affected by the severe weather event of 1962/63 (Crisp 1964), conservative estimates of mortality placed between 50 and 75% loss, leaving only remnant populations (Smyth *et al.,*2009). Since then stocks have increased, probably in part due to the translocation of large numbers of *O.edulis* predominantly from the Fal and the Solent between 1972 and 1997 in the privately owned creeks adjoining the Several order, these *O.edulis* were kept in the creeks over the summer period given an opportunity to spawn before being removed and sold (Bird per comms 2016) During this time the Blackwater Oysterman’s Association (BOA) were granted exclusive fishing rights over the Blackwater grounds in the form of a Several order and proceeded to cultivate the ground and relay cultch and suitable settlement substratum in large quantities. (Haward per comms 2016)

O.edulis does not occur throughout the spatial extent of the Blackwater, Colne, Crouch & Roach MCZ, which due to propensity of the species for gregarious settlement, is to be expected. (Bayne, 1969, Laing & Spencer 2006), instead they form five distinct aggregations, two of which are located within the survey zone Blackwater and two in the survey zone Bench Head, and the fifth in the survey zone Ray Sand. Aggregations located within the Blackwater are contained within the Blackwater Oystermans' Association Several Order. One of the populations located within the Bench Head survey zone immediately abuts the Several order and the other is located 5 kilometres to the East, in the mouth of the Colne where substratum type is favourable for settlement. The fifth population is geographically distinct, located 10 kilometres to the South in the Ray Sand.

Highest densities of *O.edulis* are located in the Blackwater and Ray Sand, with no significant differences between densities in these areas. However, a significant difference is observed when comparing age demographic between these two sites. Age classes within the Blackwater show a significantly higher number of smaller individuals, when compared to the Ray Sand, which displays a higher proportion of larger, older individuals. The age class distribution towards larger individuals contradicts the expected distribution of shellfish stocks which should display a greater frequency of small individuals and a subsequent decline in numbers throughout successive age classes due to mortality and fishing effort. (Roy *et al.,*2000, Orlova & Panov 2004, Gerasimova & Maximovich 2013). A lack of younger *O.edulis* in the Ray Sand survey zone could potentially indicate a lack of recruitment. In 2012 a fisheries bylaw was implemented by the Kent & Essex IFCA prohibiting the removal of *O.edulis* from the Ray Sand and Bench Head survey zones. The retention of breeding adults was an attempt to encourage recruitment. Subsequent surveys have not been conducted to determine if recruitment in the Ray Sand continues to be limited. The size distribution analysis also indicates a potential lack of recruitment in Colne. Historically the Colne has had intermittent *O.edulis* cultivation, management of this area is undertaken by the Colchester Oyster Fishery. Communication with local oystermen suggests that stocks in the Colne declined after the severe weather event of 1962/63 which also impacted on Blackwater populations, after which the accidental introduction of the protozoan parasite *Bonamia ostrea*, and loss of suitable settlement substratum has shown that populations have not recovered, despite minimal harvesting. (Hardy 2014) Habitat loss has been cited as one of the major factors contributing to the decline of *O.edulis* stocks across its range (Laing & Spencer, 2006). Availability of coarse sediment substratum to receive veligers is key to settlement and recruitment. (Rodriguez *et al.,*1993, Turner, *et al.,*1994, Wrange *et al.,*2010). Therefore the availability of coarse sediment in the Blackwater, Colne, Crouch & Roach MCZ may well be a key settlement driver.

Siltation of the Colne and Ray Sand zones where *O.edulis* beds have been found historically, may be a contributing factor to the lack of recruitment in those areas. Subsequent sidescan sonar surveys conducted by the Kent & Essex IFCA have shown that substratum type is beginning to shift towards subtidal sand and subtidal mud. (IFCA, 2016). In a highly sedimentary, low energy, estuarine complex such as the Essex Estuaries maintenance of subtidal coarse sediment is difficult. Areas of high velocity hydrological regime are needed to keep areas free from deposition of fine material. The area of subtidal sediment that supports *O.edulis* populations in the mouth of the Colne, in the Bench Head survey zone is such an area. Located at the confluence of the Blackwater and the Colne, tidal exchange in this area is such that subtidal mixed sediment is maintained naturally. Further up the Blackwater estuary tidal energy is much lower, maintenance of subtidal mixed sediment is achieved predominantly through management. (Table 13)

Standard oyster cultivation practices are employed by the Blackwater Oystermans' Association within the survey zone Blackwater, the presence of a fisheries several order and the continued maintenance of sub tidal mixed sediment through management including relaying of shell and harrowing or 'cleaning the ground' prior to a spawning event (Laing *et al.,*2006) could influence the level of recruitment in this area when compared to the other survey zones which are not supported by these additional management practices . This traditional practice is coming under increased scrutiny as a means to promote settlement (Waugh, 1972, Abbe, 1988, Laing *et al.,*2005, Bromley *et al*.,2015) in a three year study in Lough Foyle, concluded that there was no significant difference in settlement rate between harrowed and unharrowed test plots, and could over long periods contribute to the deterioration of suitable substratum, by breaking shell into particles that are too small to receive veligers. Analysis of the effects of cultivation using bagless dredges on other marine biodiversity is increasingly coming to the fore in the marine conservation sector. Especially, in the Essex Estuaries, when viewed in conjunction with the co-located SAC designated under the Habitats Directive. A recent review looking at the effects of fishing on marine SAC's concluded that the interaction of fishing gear with certain subtidal biotopes can have a significant effect on the species present and community structure (Defra 2014). A three year study by the K&EIFCA into the effects of oyster dredging on subtidal mixed sediment in the Essex Estuaries commenced in 2014 and is due to conclude in 2017, after which the analysis and results will be made publically available. (IFCA, 2016)

Restoration of shellfish beds particularly oysters is becoming increasingly popular globally, however most attempts have focused on restoration either for the purpose of conservation or for their value as a fisheries resource, with the two often at odds with one another. Active management using traditional fisheries methods such as harrowing, dredging and laying of cultch are often considered in conflict with conservation ideals and values (Tully & Clarke 2012, Bromley *et al.* 2015). However, this is not the case for the BCCR MCZ. The long history of oyster cultivation in the area and the different management methods adopted is almost certainly why *O.edulis* continues to be present in the Essex Estuaries. With communication, collaborative working and a conservation led fisheries management plan it is likely that *O.edulis* can fulfil the conservation objectives of the MCZ, whilst also continuing to be a commercially viable fisheries species.

Chapter 4: Distribution and Density of *O.edulis* veligers and suitable settlement substratum availability.

4.1 Introduction

Chapter 3 sought to identify areas of suitable subtidal mixed sediment located within the BCCR and its proximity to adult populations, concluding that while some populations of *O.edulis* exhibited a normal population structure, including the recruitment of new cohorts (Blackwater & Bench Head) other populations did not (Colne & Ray Sand). In order to understand the reasons for this further evidence was required on factors limiting larval supply and recruitment and substratum availability.

4.1.1 Biotic and Abiotic Factors

The environment in which marine populations live offers a wide variety of means to disperse individuals within and between populations (Cowen and Sponaugle, 2009). For benthic sessile species, the dominant means of dispersal is during an early life stage whether as an egg, spore or larvae (Levin, 2006). This dispersal strategy has in the past been over-simplified. Traditional concepts of larval dispersal mechanisms have stated that the process is passive, whereby larvae are released into the water column, mixed in the larval pool and transported by coastal or oceanic currents (Pineda *et al.,*2007). However new research is showing the process to be considerably more complex and there is now a greater understanding of the role that biotic, abiotic and behavioural factors play in larval dispersal and recruitment. A paper by Grantham *et al* 2003a observed that larval dispersal mechanisms are driven by a variety of factors (Table 16) and that dispersal distances ranged over orders of magnitude, from meters to hundreds of kilometres, seconds to months, respectively. Shanks observed that larval dispersal was bimodal, that a short larval phase and small settling distance were positively correlated, and inversely a long larval phase correlated to a larger dispersal distance. Concluding that short-distance dispersal was due to behaviour, that larvae would remain low in the water column prior to settlement where current velocity is minimal and that dispersal and recruitment are ultimately influenced by biotic and behavioural processes as well as abiotic factors.

Daigle (2016) describes this further, introducing larval behavioural mechanisms such as vertical swimming behaviour (Daigle *et al*.,2016) and selective tidal stream transport (DiBacco *et al.,*2001) showing larvae engage in active swimming during different phases of the tidal cycle, for example, swimming down during an ebbing tide into lower velocity tidal currents and up during an incoming tide allows larvae to maximise dispersal trajectory into the upper reaches of an estuary. Turbulence induced sinking behaviour, whereby larvae actively swim down in order to reach lower more stable water along coastal margins (Fujimura *et al.,* 2014). auditory and olfactory cues that may assist homing behaviours whereby larvae are guided to a location by sounds or smells (Wright *et al.,*2005) Gerlach (2007) describes larval dispersal mechanisms as fully open, meaning larvae are dispersed over a large geographical area and are subject to the hydrodynamics of that area, to fully closed, meaning larvae are retained within the immediate area of production with very little geographical dispersal (Gerlach *et. al.* 2007, Cowen and Sponaugle, 2009).

Table 16 Biotic, abiotic and behavioural factors affecting dispersal and recruitment of pre settlement larvae.

	Dispersal	**Recruitment**
Biotic		Presence of parent hormones
	Food availability	
	Larval release site	
Abiotic	Temperature	
	Salinity	
	Hydrodynamics	
	Bathymetry	
	Nutrient availability (phosphates and silicates)	
		Settlement substratum availability
	Tidal phase	
	Seasonal variability	
Behavioural	Swimming speed	
	Depth preference (Diurnally and tidally)	

A greater understanding of the larval dispersal mechanisms of priority species such as *O.edulis* is critical in informing the design of MPA's to ensure that sites that are created function individually and as part of effective networks of marine reserves that can deliver the conservation of priority species and habitats while playing a vital role in the development of truly sustainable fisheries (Buston *et al.,*2012).

Traditionally larval transport and dispersal was thought to be a simplistic mechanism whereby larval dispersal was entirely reliant on hydrodynamics. (Scheltema, 1971). However, recent studies have shown this to be an oversimplification of a much more complex mechanism involving many biotic and abiotic factors.(Table 16) Each of these components acting alone or in combination with one another has the capacity to alter larval transport, dispersal and survival rates. Previous attempts to restore populations of *Ostrea edulis* to an area have focused on relaying cultch and restocking breeding adults. In order to ensure restoration is effective in the long term, a much more detailed site specific understanding of the role played by abiotic and biotic factors in larval dispersal is needed (Smyth *et al.,*2016). Understanding patterns of larval dispersal for benthic sessile species is a major goal of marine ecology; these patterns determine larval exchange, connectivity to Meta populations and have major implications for the survival and longevity of a population (Buston *et al.,*2012). Abiotic factors such as particular marine hydrodynamics, salinity and temperature all have significant impacts on larval transport and dispersal but there are also important ecological traits specific to *O.edulis* that need to be taken into account to begin to understand and quantify larval dispersal and survival for this species (Jones *et al.,*2009). These include gregarious settlement, (Burke, 1986), directional swimming, (North *et al.,*2008), and availability of appropriate settlement substratum at the point in which settlement cues are initiated (see Chapter 1 Habitats and Ecosystems).

In Chapter 3 (Abundance, distribution and size structure), it was found that there are four distinct sub-populations of *O.edulis* within the BCCR MCZ, though it is not known if they function as a meta population or are discrete reproducing units.

The transfer of genes through larval dispersal has historically been neglected, mainly due to a deficit in empirical data. But the question of connectivity is becoming increasingly important, as interest in marine protected areas increases their design and location becomes more focused on connectivity, the ability of a population to sustain itself becomes increasingly pertinent. Population connectivity modelling is becoming gradually more popular as a means to predict dispersal routes for pelagic stages of larval dispersal. Population modelling frameworks typically use predefined parameters such as larval duration, tidal speeds, bathymetry, temperature to predict connectivity and meta population dynamics (Treml, 2015) This is certainly a avenue which warrants further work within the BCCR MCZ, in order to apply the most relevant restoration techniques, protect the most important brood stock areas.

Some of these populations show active recruitment (Blackwater and inner Bench Head) and in others recruitment seems to be limited (Outer Bench Head & Ray Sand). In order to establish why some of the Essex Estuary populations are failing to recruit, we need to determine dispersal kernels (Pineda *et al.,*2007), and the frequency of veligers, then examine this in combination with substratum availability and composition in each of the areas.

4.1.2 Reproductive strategy

After fertilisation and brooding for up to 14 days, veligers are ejected from the brood mantle of the female into the water column (Hedgecock *et al.,*2007).

Planktonic Larval Dispersal (PLD) time ranges from 12 - 15 days depending on water temperature and food availability (Hedgecock *et al.,*2007, Marshall, 2010, Filgueira, 2015). PLD is comprised of three distinct stages; Stage 1 – D shaped veliger (0 – 5 days), Stage 2 –umbo (5-12 days) and Stage 3 – Pediveliger which occurs immediately before settlement (12 days+).(Acarli and Lok, 2009) (Figure 2). PLD mechanisms vary greatly between marine species, ranging from fully closed, the process by which all larvae are retained in the immediate area, producing a consecutive series of cohorts in which to sustain the resident population also known as larval retention (Buston *et al.,*2012) to fully open the process by which all larvae are exported from the adult breeding population in order to colonise new areas (Cowen and Sponaugle, 2009). *O. edulis* larvae are known to exhibit both traits and the ecological preference for gregarious settlement of the species has long been observed. Settlement-inducing compounds are released into the water column by post metamorphosed individuals to stimulate settlement of larvae (Bonar *et al.,*1990, Pawlik, 1992, Doroudi and Southgate, 2002,). The release of these compounds coupled with physical cues such as temperature, salinity and light availability all play a contributing role in the settlement of larvae. It is probable that a combination of several factors are responsible for final settlement including hydrodynamics, suitability of benthic substratum, food availability and proximity to parent stock. It is therefore vital to the success of restoration strategies that site specific knowledge of these parameters are used in combination with a detailed understanding of larval availability and dispersal patterns (Smyth *et al.,*2016).

4.1.3 Transport and dispersal

Larval dispersal is the critical mechanism facilitating population connectivity and exchange of genetic material, particularly in sessile species such as oysters (Munroe *et al.,*2014). However, due to the difficulty in collecting robust empirical data (Pineda *et al.,*2007, Cowen and Sponaugle, 2009) the critical importance of larval connectivity between populations of *O.edulis* is significantly underrepresented in the designation of MPA's in the UK (Munroe *et al.,* 2014). For sessile or sedentary populations, larval dispersal is vital for genetic connectivity and exchange of genetic material including genetically distinct characteristics, such as disease resistance and susceptibility (He. Y, 2012). It is becoming increasingly apparent that the phenomenon of larval retention or the limitation of dispersal due to biotic or abiotic factors plays a much greater role in marine population connectivity than previously thought (Gerlach *et al.,*2007, Cowen and Sponaugle, 2009, Zimmer, 2009, Jones *et al.,*2009, Buston *et al.,*2012). This new understanding of larval retention has pragmatic implications for the conservation and restoration of marine species, in order to successfully restore a population to an area first we need to establish a detailed understanding of the ecology of the species. As stated previously, *O.edulis* are known to exhibit both traits of dispersal (open and closed), they are known gregarious settlers, preferentially seeking to settle on the shell of an adult *O.edulis*, or on subtidal mixed sediment located near to the existing adult populations. We also know that larval production and survival is directly linked to existing oyster biomass (Rimler, 2014). To increase and restore *O.edulis* populations within an MPA it is also critical that sufficient veliger larvae are exported from the established breeding population and surrounding area to colonise new areas or to recruit to lower density sub populations. It is essential that sufficient suitable settlement substratum is available within these veliger transport and dispersal routes to enable the expansion of existing oyster beds, the increasing low population density aggregations, and the establishment of new populations.

4.1.4 Substratum availability

Many studies have sought to understand the relationship between larval supply, the availability of suitable substratum and settlement (Crisp, 1976, Burke, 1986, North *et al.,*2013, Rimler, 2014, D'Aloia *et al.,*2015). All conclude that a positive relationship exists between larval supply and suitable substratum in increasing a population, but stipulate the need to assess each site on a case by case basis, taking into account biotic and abiotic factors which are likely to have influence on conclusions made and how a site is managed for conservation or fisheries (Cowen and Sponaugle, 2009, Haase *et al.,*2012, Munroe *et al.,*2014).

Following 12-15 days planktonic dispersal period *O.edulis* larvae must locate a suitable substratum on which to settle or they will not survive. In a low energy highly sedimentary estuarine environment such as the BCCR estuaries, suitable sediment substratum such as subtidal mixed sediment is a relatively infrequent feature, making up only 8.6% area compared to subtidal mud and subtidal sand, which make up 16.8% and 32.7% respectively. As such, suitable substratum availability is limited and therefore successful *O.edulis* settlement potential is reduced.

Stand alone restoration strategies for *O.edulis* and more recently for *O.edulis* as a species of conservation concern within the wider context of MPA interest features have emphasised the importance of the availability of subtidal mixed sediment as a material consideration in the successful restoration of the species (Laing, 2005, Laing et al.,2006, Laing and Spencer, 2006). Ensuring adequate settlement substratum is widely accepted as a first port of call for all restoration projects. Known as shell budget, restoration programmes from around the world such as the Chesapeake bay restoration of *Crassostrea virginica*, have focused on installation of settlement substratum, installing oyster cultch where it is available or reinstating buried fossil shell as a means to increase shell budget. Harris Creek, Maryland restoration efforts have focused on the installation of stone and concrete, 351 acres of hard core supporting 2.13 billion hatchery reared oysters. Matagorda bay, Texas, restored 54 acres of *C. virginica* reef using rocks and boulders. In Europe restoration programmes are in their infancy, projects in Germany, France, Netherlands and the UK are all pursuing feasibility studies which employ the installation of settlement substratum as the initial tool to successful restoration. (NORA, 2018., The Nature Conservancy, 2018)

Quantifiable amounts of shell needed for creation or restoration of an oyster bed still remains unanswered, in 2017 the Nature Conservancy developed an ecosystem services calculator which calculates amount of area of bed needed to be restored for the purpose of filtration or fish production, this ecosystem services approach to oyster restoration is an important tool in the development of robust restoration parameters but stops short of offering advice on how much settlement substratum is needed ensure the habitat function is fulfilled.

This chapter seeks to further our understanding of settlement substratum availability within the BCCR MCZ and if this availability is linked to abundance and distribution of *O.edulis.* This information has been gathered with the intention of informing and implementing targeted *O.edulis* restoration activities in the BCCR MCZ.

4.2 Aims

- Identify suitable settlement substratum for *O.edulis* within the Marine Conservation Zone and how this varies spatially.
- Determine if availability or composition of suitable substrata may limit effective restoration in the future.
- Determine larval abundance and assess if this may limit effective restoration in the future.

4.3 Methodology

4.3.1 Substratum availability

Substratum information obtained from Chapter 3 (Abundance, distribution & size structure) was used to inform stratified sampling approach. Three additional areas were identified for further substratum determination and analysis. A total of 27 grab sample locations were identified. Nine samples were taken in each of the three survey Zones, Blackwater, Ray Sand & Bench Head. (Figure 26). Due to the variability of the benthic substratum throughout the MCZ it was necessary to take additional replicates to ensure adequate representation of each survey zone.

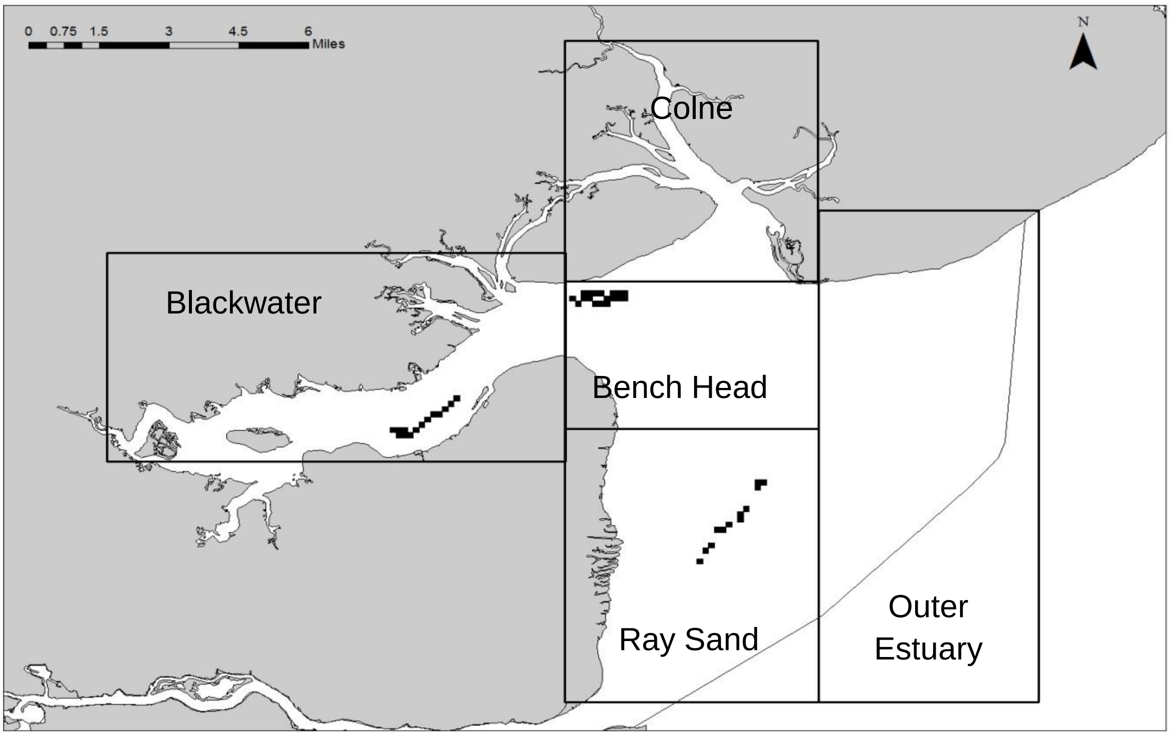


Figure 26 Map of grab sample and additional dredge sample locations used to determine dredge efficiency (n=27) taken from within the BCCR MCZ boundary between November 2012 – February 2013

A $0.1m^2$ day grab was deployed 10 times within each of the survey squares giving a total area of $1m^2$ sample size within each location. Any live *O.edulis* found within the grab were removed, measured, and returned to the sample location. The remaining contents of the 10 grabs were sieved through a 2 mm sieve, photographed and bagged. Samples were dried using a drying oven until a constant weight was achieved with the samples then sieved through a 2 mm, 10 mm and 20 mm sieve. Weight were taken to the nearest 1 g

Finally a further dredge survey was conducted with each of the nine grab sample locations following the methodology in Chapter 3 to determine dredge efficiency.

Equation 1: Dredge efficiency calculated using the following equations;

$$O.edulis\ (m^2) = \frac{\text{No. of } O.edulis \text{ in dredge}}{100}$$

$$DE = \frac{O.edulis\ (m^2)}{O.edulis \text{ in grab}} \times 100$$

In order to estimate the abundance of *O.edulis* within the BCCR MCZ it is necessary to evaluate gear efficiency, this estimation is for two reasons; 1. Survey dredges are fitted with 45mm ring size, it is therefore possible that oysters under 45mm in diameter will pass through without being counted due to the selectivity of the gear 2. When sampling it is possible for the dredge to bounce over areas of seabed, it is therefore likely that individuals will be missed due to sampling area. The process of estimating dredge efficiency accounts for this sampling error and produces a more accurate estimate of numbers.

4.3.2 Veliger collection

Sampling locations were chosen to correspond with substratum type that appeared to be favourable for veliger settlement. The proposed sampling location in the Colne estuary was eliminated as a survey zone, as a comprehensive veliger survey had been conducted May – August 2010 as part of a study by Hardy looking at the viability of establishing an *O.edulis* fishery in the Colne Estuary (Hardy, 2014)   The proposed Ray Sand sampling site was eliminated as a survey zone as it did not comply with the health and safety policy of the University of Essex, which stipulates if sampling from an inflatable RIB then a distance of 3 nm from a safe port cannot be exceeded. Samples were taken in each survey zone in the same locations (n = 3) from June – October inclusively. Temperature and salinity were recorded in each location (Figure 27)

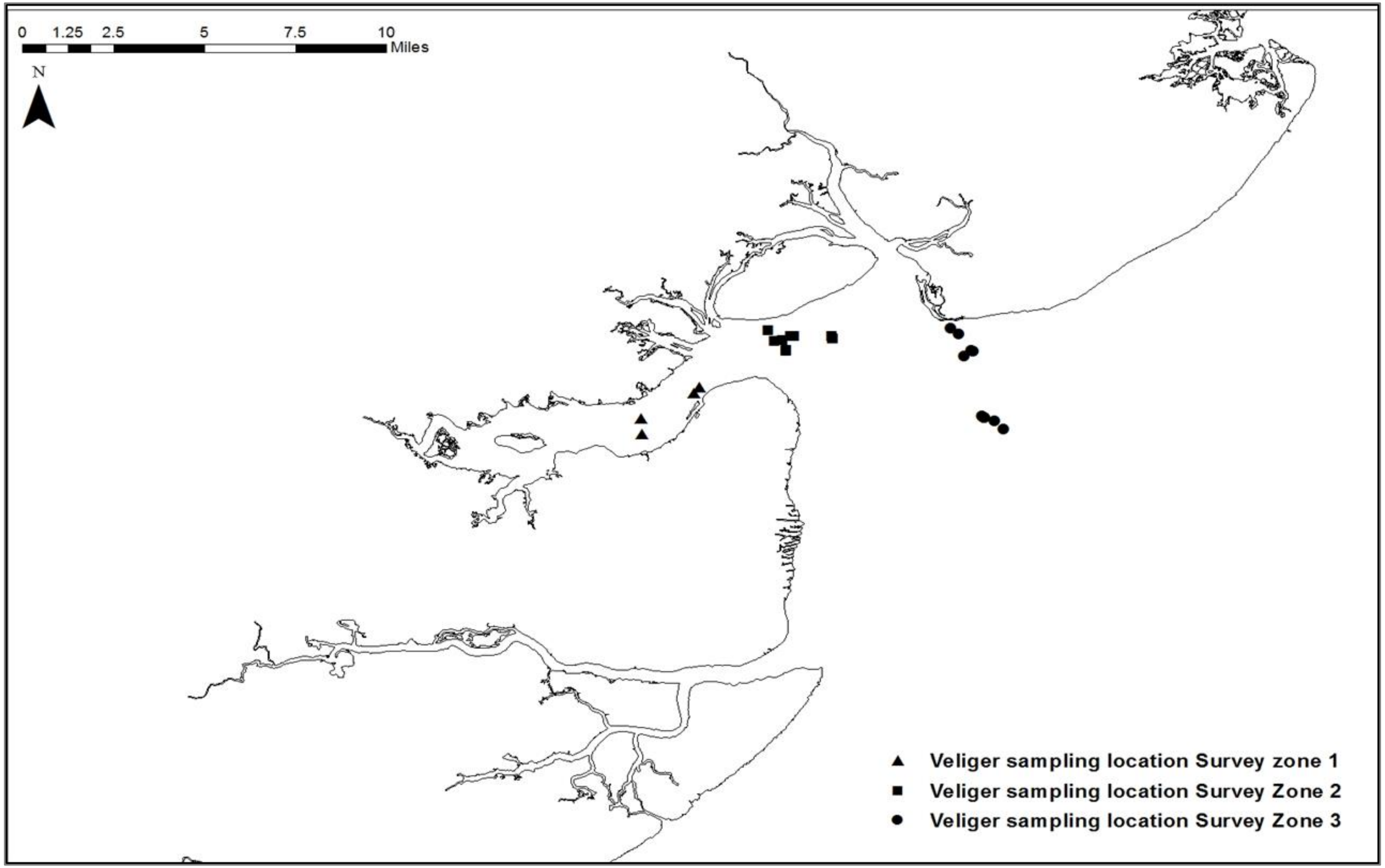


Figure 27 Larval sampling locations of within the BCCR MCZ were conducted May – October 2016 (inclusive) samples were taken using a 50µm plankton sampling net with 50cm wide aperture. The apparatus was towed for approximately two minutes at a constant speed and volume of seawater was calculated using a mechanical flowmeter (General Oceanics model 2030R) suspended in the mouth of the plankton net.

The collection and identification of oyster larvae samples was carried out on all occasions between June to October 2016 inclusive during the spring tidal phase. On each occasion three replicate trawls were made using a 50μm mesh plankton sampling net with 50cm wide mouth and removable 50μm mesh screened sample collecting chamber at the cod end. A mechanical flowmeter (General Oceanics model 2030R) was suspended in the mouth of the plankton net. The apparatus was towed from the stern for approximately two minutes at a constant speed. The six digit number displayed by the flow meter counter was recorded before and after each successful sample. At the completion of each sample tow, the net was recovered to the boat and flushed with seawater to dislodge planktonic organisms stuck to the inner surface allowing them to drop into the collecting chamber. The cod end mesh screen was removed and flushed with seawater through a funnel, to dislodge organisms stuck to the sides where they passed into individually labelled 500ml plastic bottles. Each 500 ml sample bottle was packed into a cool box packed with ice blocks. On returning to the laboratory the cool boxes containing samples were stored in the cold room prior to examination, each sample was analysed within 12-24 hours of collection, samples were then fixed with5 ml of Lugols solution in case later analysis was required and stored at 3 ^{o}C in a cold room.

From each sample the number of *O.edulis* larvae (m^{-3}) was calculated using the equations set out below;

The amount of seawater that had passed through the plankton net was obtained from the counter readings from the six digit flow meter rotor using the equation:

Equation 2

$$D = \frac{dn \times rc}{999999}$$

Where D = Distance (m); dn = difference in rotor counts and rc = rotor constant. (26,873)

The volume of seawater passing through the plankton net (m^{-3}) during each sample trawl was calculated using the equation:

Equation 3

$$V = \frac{\pi \times (D \times r^2)}{4}$$

Where V = volume (m^{-3}) of seawater and r^2 = plankton net mouth radius (m) squared.

Following their removal from storage the sample bottles were gently inverted and swirled to re-suspend organisms evenly in their seawater and preservative medium. A 20ml sample was drawn from each sample bottle and transferred to a clear plastic petri dish with a 5mm grid on the bottom. Each sample was examined individually using a compound microscope with a 400x graduated eye piece.

Larvae were identified to species level by examination of morphometric detail and external characteristics, by examining the hinge-line length and umbo character and size (Acarli and Lok, 2009). The numbers of larvae in each sample were counted and this figure was used to calculate the density of individuals per m^{-3} in samples.

4.4 Results

4.4.1 Calculating dredge efficiency

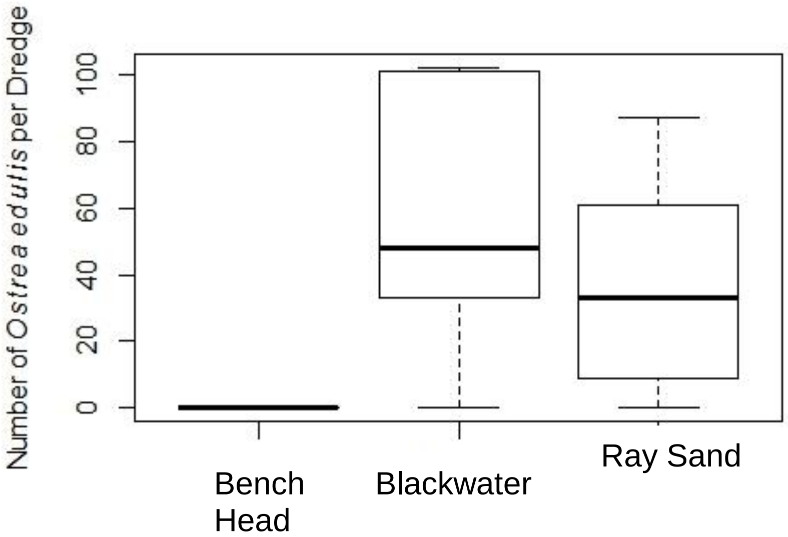
Dredge efficiency measurements were conducted by comparing paired dredge and grab samples. Nine sampling locations within each of the survey zones Blackwater, Bench Head and Ray Sand were sampled using the paired sampling method (n = 27) within each of the sites a $1m^{-3}$ grab area and a 100m dredge area were sampled for the presence of live *O.edulis* (Figure 26) *O.edulis* were recorded in the Blackwater and Ray Sand dredge samples, but only found in the Blackwater within the grab sample. Eight of the nine survey locations within the Blackwater contained live *O.edulis* no other live individuals were found across the remaining two survey zones, Bench Head and Ray Sand. (Table 17) Dredge efficiency was then calculated using Equation 1 (Methodology)

Significant spatial variability was observed in the number of *O.edulis* sampled for both the grab and dredge sampling methods between each of the three survey zones. (Grab; H=24.669, df= 2, $p<0.001$; Dredge; H=15.6254, df=2, $p<0.001$; (Figure 28 . Box plots show number of live *O.edulis* found within each survey zone in (A) 100m dredge and (B) $1m^{-2}$ grab sample (Grab; H=24.669, df= 2, $p<0.001$) (Dredge; H=15.6254, df=2, $p<0.001$)

Table 17 Calculated using: Equation 1 Dredge efficiency calculation based on number of individuals in each 100m dredge sample and number of individuals in each 1m^{-3} grab sample. Dredge efficiency is estimated to be 17.7% based on numbers of *O.edulis* sampled using both dredge and grab survey techniques in survey zone Blackwater.

Site	Blackwater								Average
Number of *O.edulis* in dredge	33	48	45	30	102	101	67	101	**65.875**
Number of *O.edulis* in grab	1	5	6	2	18	2	12	7	**6.625**
Dredge/m^{-2}	0.33	0.48	0.45	0.3	1.02	1.01	0.67	1.01	**0.65875**
Dredge efficiency	33.0	9.6	7.5	15.0	5.7	50.5	5.6	14.4286	**17.7**

A



B

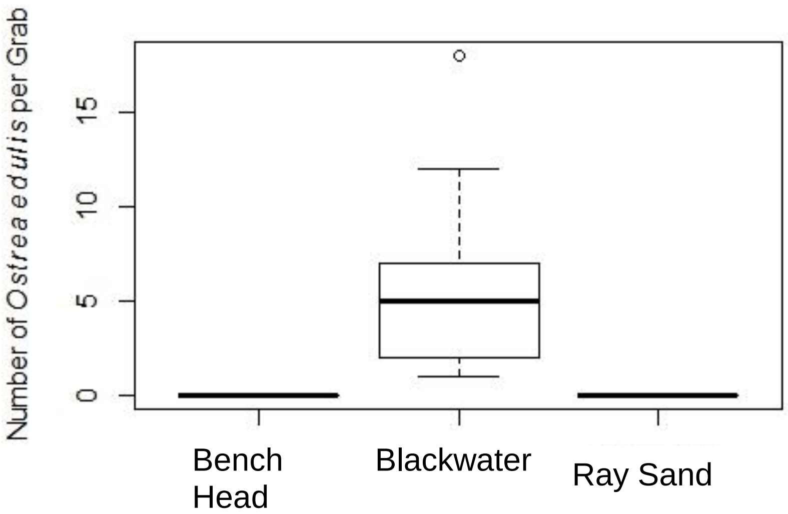


Figure 28 Number of *O.edulis* sampled at 9 survey sites in each of the three survey zones Bench Head, Blackwater and Ray Sand using dredge (A) and grab sampling (B) techniques. Box plots show number of live *O.edulis* found within each survey zone in (A) 100m dredge and (B) $1m^{-2}$ grab sample (Grab; $H=24.669$, $df= 2$, $p<0.001$) (Dredge; $H=15.6254$, $df=2$, $p<0.001$) Live *O.edulis* were recorded in the Blackwater and Ray Sand dredge samples, but only found in the Blackwater within the grab sample.

A significant difference was observed in the number of *O.edulis* found in grab samples within the Blackwater (Grab; H = 24.669, df = 2, ($p < 0.001$) when compared to both the Bench Head and Ray Sand survey zones but no significant difference was observed when comparing the number of *O.edulis* within grab samples taken from the Bench Head and Ray Sand ($p=\geq 0.05$). Significantly more *O.edulis* were found in both the Blackwater and Ray Sands dredges compared to the Bench Head (Dredge; H =15.6254, df = 2, ($p < 0.001$) no significant difference was found between the Blackwater and the Ray Sands ($p = \geq 0.05$).

Using Equation 1, dredge efficiency was calculated to be 17.7% using dredge and grab data from the survey zone in the Blackwater only (Table 17*)*

4.4.2 Substratum availability

The results show a significant difference in the total weight of shell (g/m^{-2}) available when comparing the three survey zones, Blackwater which had 325g/m^{-2} (±126SE), Bench Head which had 979g/m^{-2} (±53 SE) and the Ray Sand which had 127g/m^{-2} (±28 SE). (H=15.075, df=, $p<0.001$) (Figure 29).

No significant difference was observed between Blackwater and Ray Sand when comparing total weight of substratum (g), Bench Head showed a significantly higher total weight (g/m^{-2}) substratum ($p<0.001$) when compared to the Blackwater and Ray Sand.(Figure 29)

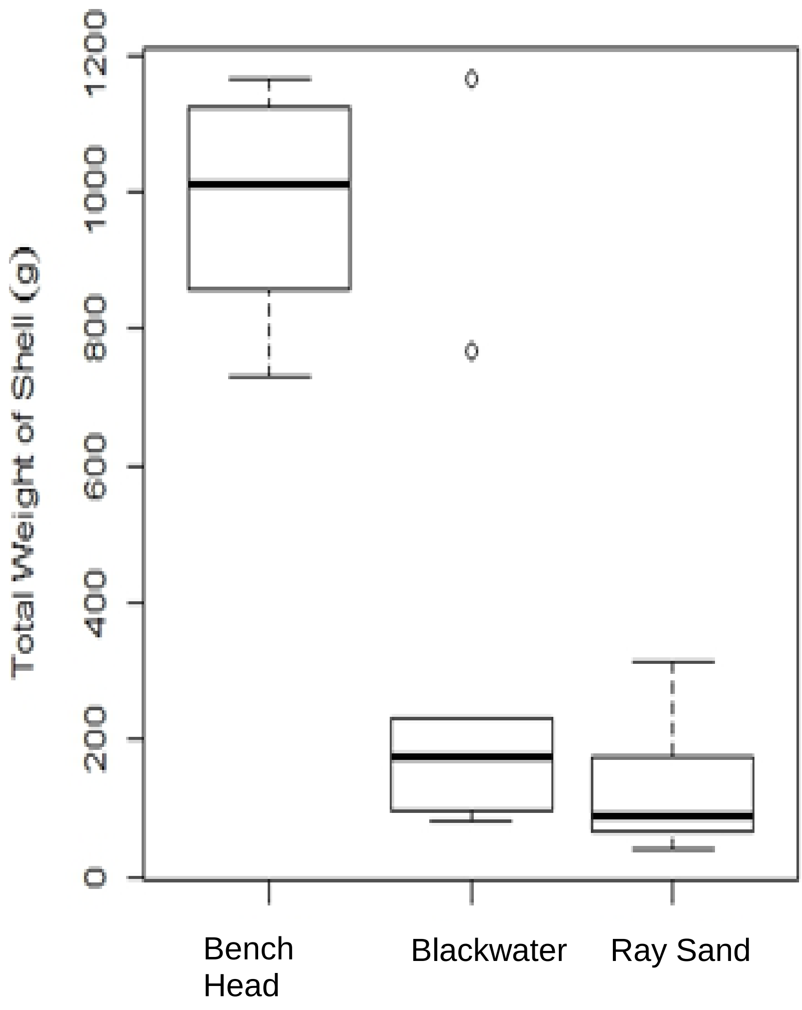


Figure 29. Amount of substratum (1m^{-2}) over 2 mm in each of the three survey zones Bench Head, Blackwater and Ray Sand. Total weight of shell is significantly different across the three sites, Bench Head shows a significantly higher weight (g) of shell compared with the Blackwater and Ray Sand

Table 18 Weight (g) and particle size composition (mm) of three sites Blackwater, Bench Head and Ray Sand.

	Weight (g)								
Particle size	**Blackwater**								
2- 10mm	11	100	61	37	21	575	396	13	37
10- 20mm	14	86	24	23	10	250	82	24	112
Over 20mm	56	45	89	162	59	340	288	59	64
Total weight (over 2mm)	81	231	174	222	81	1165	766	96	113
	Bench Head								
2- 10mm	126	424	101	155	396	575	227	452	157
10- 20mm	107	255	263	260	82	250	173	170	51
Over 20mm	498	332	787	708	288	340	457	375	807
Total weight (over 2mm)	731	1011	1151	1123	766	1165	857	997	1015
	Ray Sand								
2- 10mm	191	3	6	7	21	70	61	10	11
10- 20mm	24	11	9	6	10	60	24	86	14
Over 20mm	97	45	26	51	59	51	89	45	56
Total weight (over 2mm)	312	59	41	64	90	181	174	141	81

Samples were analysed for particle size composition (percentage of the total weight (g) across the three survey zones (Table 18). No significant difference was observed when comparing particle composition across the Bench Head, Blackwater & Ray Sand survey zones ($p=\geq 0.05$) (Figure 30)

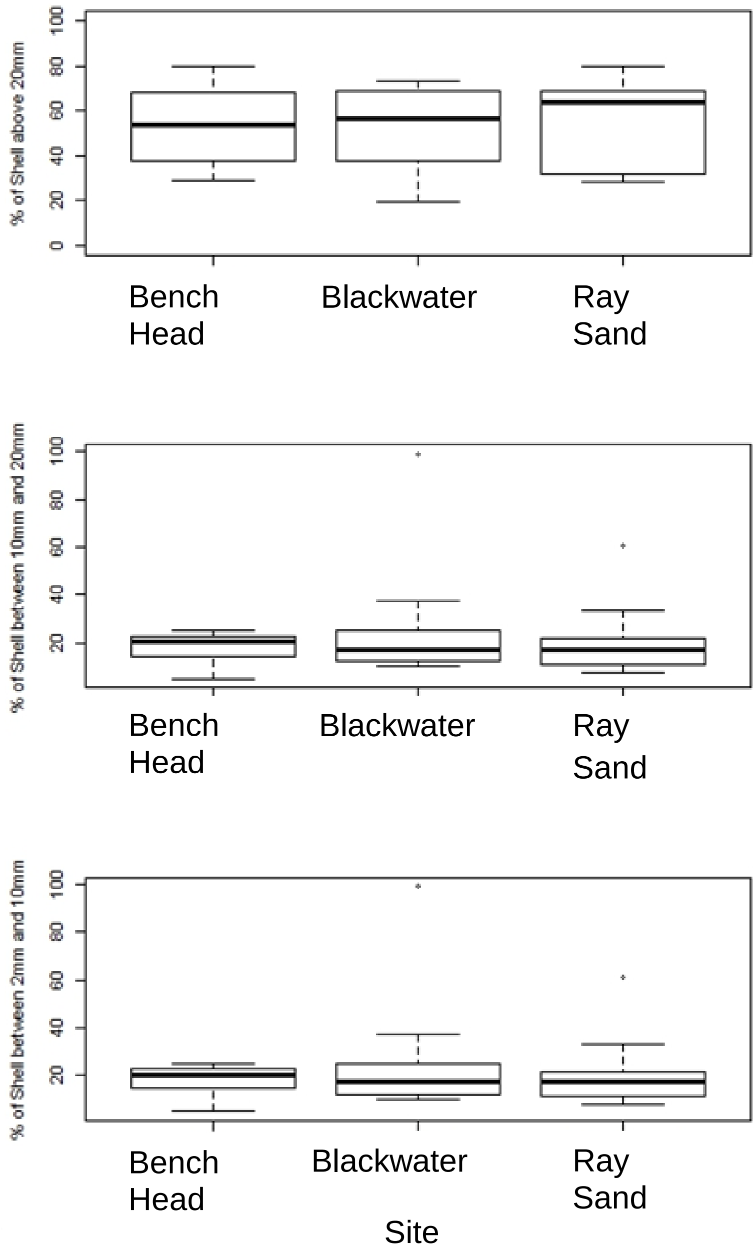


Figure 30 Percentage composition of total weight (g) of substratum across three survey zones Bench Head, Blackwater and Ray Sand. Particle size parameters 2 mm-10mm, 10 mm-20mm, >20mm. No significant difference was observed between the three sites when comparing substratum particle size.

A significant positive correlation was found between total number of *O.edulis* larvae in each sample and the total weight of shell present ($r = 0.66$, $N=16$, $p < 0.05$) (Figure 31). Analysis undertaken did not include the Bench Head site as no oysters were found to be present within the survey zone.

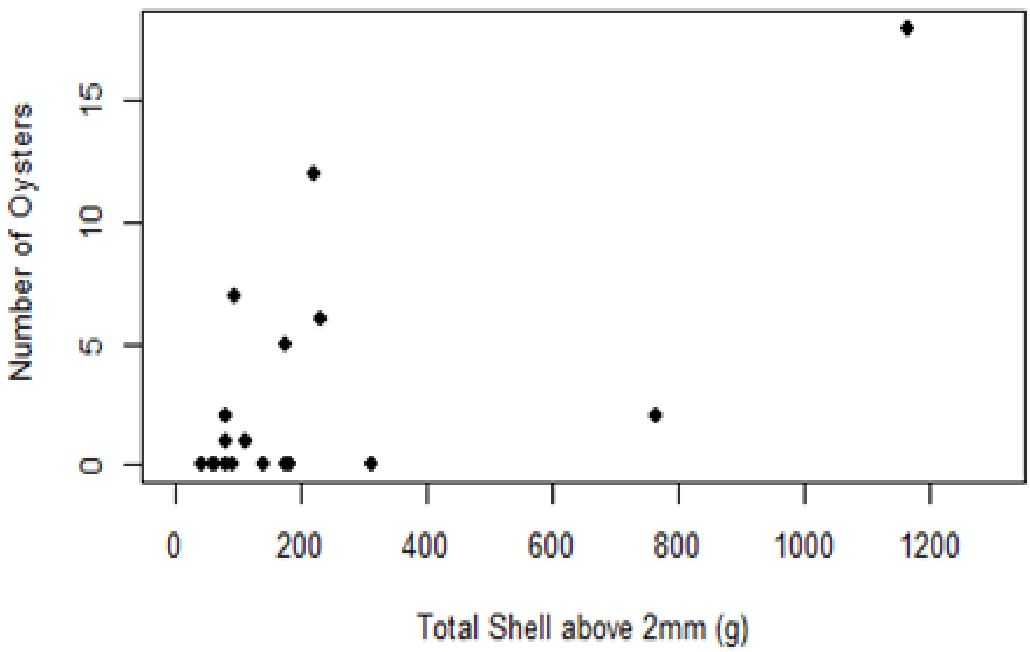


Figure 31 Total weight of shell (g) and total number of oysters within the two survey zones Blackwater and Ray Sand, analysis shows a positive correlation between the amount of shell >2 mm (g) and number of *O.edulis* present.

4.4.3 Veliger counts and dispersal

Number of *O.edulis* veligers across three survey zones Blackwater, Bench Head and Outer Estuary were calculated for June, July, August & October (

Table 19). Spatially there was no significant difference observed between the number of veligers across the three zones throughout the breeding season. The Blackwater showed an average of 78m^{-3}(± 12SE), the Bench Head showed an average of 47m^{-3} (±16 SE), The Outer Estuary showed an average of 95m^{-3} (± 22SE), (F=0.872, p=0.358, df=1).

A significant temporal difference was observed between the number of veligers recorded throughout the BCCR MCZ across the months of June 48m^{-3} (±10SE), July 126m^{-3} (±18SE), August 70m^{-3} (±7SE) and October 0m^{-3}. (F=22.888, p=1.08E-07, df=3), but no significant difference was observed between the survey zones (spatial) and the month (temporal) sampled (F=1.168, p=0.339, df=3).

Table 19 Average number of *O.edulis* veligers (m^{-3}) and sea water temperatures across three sites, Blackwater, Bench Head & Outer Estuary from July – October 2017.

	June				**July**				**August**				**October**			
Veliger	Rep 1	Rep 2	Rep 3	**Average**	Rep 1	Rep 2	Rep 3	**Average**	Rep 1	Rep 2	Rep 3	**Average**	Rep 1	Rep 2	Rep 3	**Average**
Blackwater	51	88	34	**58**	105	133	64	**101**	76	116	33	**75**	0	0	0	**0**
Bench Head	27	35	23	**29**	87	175	103	**122**	75	71	61	**69**	0	0	0	**0**
Outer Estuary	14	110	51	**59**	69	212	189	**157**	54	79	73	**69**	0	0	0	**0**
Temperature	17	18	17	**17**	18	18	18	**18**	19	19	20	**19**	13	14	14	**14**

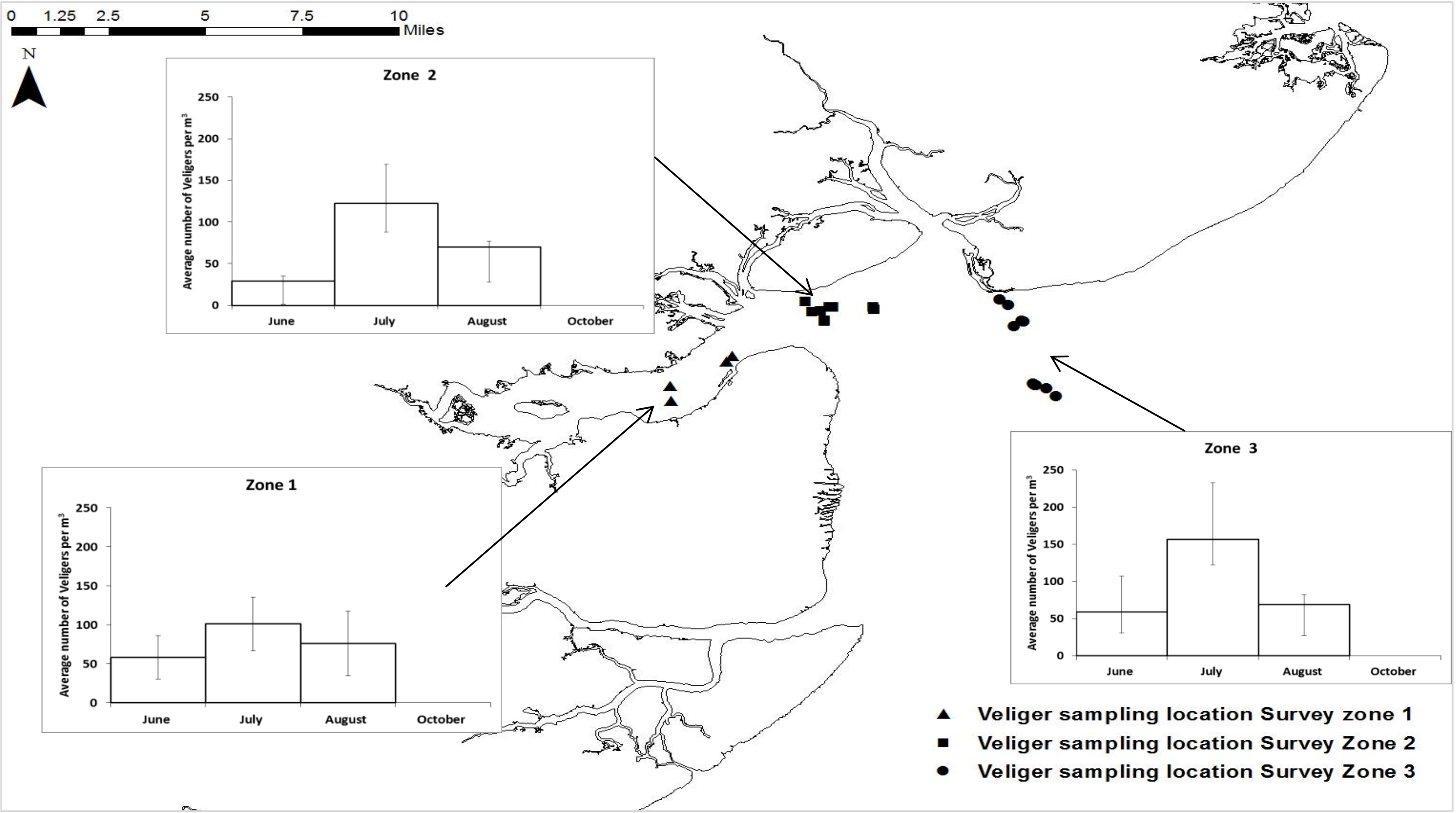


Figure 32 Map shows sampling locations across three survey zones Blackwater, Bench Head, Outer Estuary. Inset bar charts show average number of veligers (m^{-3}) across the three survey zones throughout the breeding season (June – October)

Table 20 Estimates average number of veligers produced per adult individual. Counts (adult oysters) are estimated based on dredge efficiency (17.7%) totalling an average of 3.72 individuals (m^2) across the three survey zones. Counts veligers (61.79 m^3) are estimated based on average number of veligers across three survey zones throughout the breeding season (June – October)

Dredge Efficiency %	No. *O.edulis* in dredge	Area of dredge m^2	No. *O.edulis* at 100% Dredge efficiency	*O.edulis* per m^2	Average Veliger per m^3
17.7	33	100	186	1.86	61.79
17.7	48	100	271	2.71	61.79
17.7	45	100	254	2.54	61.79
17.7	30	100	169	1.69	61.79
17.7	102	100	576	5.76	61.79
17.7	101	100	570	5.70	61.79
17.7	67	100	378	3.78	61.79
17.7	101	100	570	5.70	61.79
Average Oyster (m^2)		3.72	**Average Veliger per Oyster**		16.60

4.5 Discussion

The availability of coarse subtidal mixed sediment is a fundamental consideration when assessing the likelihood of a successful long term restoration and conservation programme for *O.edulis.* This species requires the presence and availability of a clean hard substrate (including dead oyster shells or cultch) on which pediveligers can settle to enable the successful recruitment of new cohorts to an existing population and to increase the likelihood of new populations establishing. However, documented evidence on the critical weight (g) and size (mm) of substratum (m^{-2}) needed to ensure successful settlement and recruitment is lacking in the literature.

The weight (g) and composition (mm) of subtidal mixed sediment was obtained through targeted grab samples in three sites, Blackwater, Bench Head and Ray Sand. The results concluded that there was a significantly higher weight of shell in the Bench Head survey zone when compared to the Blackwater and the Ray Sand survey zone, but no significant difference was observed between the survey zones when comparing sediment particle size distributions. A significant lack of adult *O.edulis* was observed in the Bench Head survey zone when compared to the Blackwater and the Ray Sand survey zones. This is of interest when considering the ecological requirement of *O.edulis*. Logically the presence of a greater amount of available shell should correspond with a greater amount of larval settlement and so a greater amount of adult oysters. Therefore, there is either an issue with larval supply larval settlement, or post larval mortality.

There was no significant difference observed between the numbers of veligers recorded across the three survey zones suggesting that the estuary is well mixed and there is no spatial stratification.(Kocum *et al.,* 2002) This suggests that recruitment is limited as a result of an additional factor in the Bench Head survey zone, as it has the highest amount of suitable substrate available, and contains equal numbers of veligers (per m^{-3}) as the other two zones. Discussion and speculation from ENORI on why this may be the case has ranged from the age of the shell present to increased predation of newly settled veligers at the Bench Head site. The composition of the material sampled obtained from the Bench Head was observed to be different to that of the Blackwater and Ray Sand sites. Shells were thick, porous and brittle and when handled would often easily break apart, they were either orange or black, or a combination of the two suggesting long periods of time in the anoxic layer of the estuary bed. Discussion with local oyster fishermen suggests that this area was once a productive fishing ground for *O.edulis* but mass oyster mortalities in the years before 1960 meant it no longer remained profitable to fish and the area was no longer cultivated. Shell samples taken from the Blackwater and Ray Sand sites showed much greater size variation, composition, included a higher weight (g) of all size ranges compared to the Bench Head and there was an observed difference in the character of the shell, with shell and shell fragments retaining the colour of the species when alive.

This suggests that shells within the Blackwater and Ray Sand survey zones were younger, and the fact that these shell fragments did not break up as easily when handled and did not have the porous quality seen in those located in the Bench Head survey site also supports this hypothesis. When the weight and size composition of substratum in the Blackwater and Ray Sand survey sites were compared there was an observed statistical difference between the two sites. The Blackwater survey zone showed an increased weight of available substratum when compared to the Ray Sand site, but size composition remained statistically insignificant between the two sites.

A statistically significant result was found when comparing temporal variation in veliger counts across the sites. Although this is statistically significant, ecologically this is unsurprising, as *O.edulis* requires sea temperatures to be 15 ^{o}C or above for breeding to be initiated and the species will breed continuously while water temperature remains in this range. Water temperature readings taken at the time of sampling in each survey zone show that sea temperatures remained above the critical 15 ^{o}C for June, July and August and decreased quickly in October, this corresponds with the lower number of veligers present in the October samples. This number was calculated using only 4 months of data obtained in one year and in order to better understand the complexities of larval abundance and distribution dynamics the study should be repeated over several years. However, this first year of data gathering and analysis provides robust information regarding larval abundance and distribution in the BCCR estuaries in Essex and the results obtained are comparable to those obtained in previous studies of *O.edulis* in the UK and Ireland. Smyth (2009) considered larval abundance of wild populations of *O.edulis* in Strangford lough estimated veliger density to be approximately 60 m^{-3}. Hardy (2014) recorded counts of veligers in the Blackwater and the adjacent Colne estuary between 3 and 137m^{-3} (average number of adult *O.edulis* present 1.7 m^{-3}) with higher numbers of veligers in the mouth of the Colne Estuary, possibly due to tidal mixing with the Blackwater. Preliminary studies looking at veliger counts in Chichester harbour after installation of *O.edulis* breeding baskets (containing 1000 adults per m^{-2}) estimate veliger density to be in the region of 700-800 m^{-3} (unpublished).

There is very little published data on the optimal amount of *O.edulis* veliger required per m^{-3} from existing wild stocks in the UK to maintain or restore a population to an area and it is therefore unclear as to whether or not the BCCR estuaries can be categorised as being larval supply-restricted. Larval production in *O.edulis* is directly related to the biomass of the spawning stock (Korringa, 1940), therefore any reduction in the number of breeding adults will have an associated effect on larval production. Successful settlement is also directly linked to substratum availability

(Korringa, 1951) and proximity of that substratum to a breeding population (Smyth *et al.,*2016, Daigle *et al.,*2016, Rimler, 2014). Results show that the Bench Head survey site has both large quantities of available larval settlement substratum and is close to existing breeding populations located in the Blackwater survey zone and elsewhere in the Bench Head survey zone (Chapter 3), and has equal numbers of veliger per m^{-3} to the other two survey sites, It is still unclear why settlement and recruitment in this area has not been successful. If the available substratum is no longer suitable due to the age and porosity of the shell material, as suggested by the ENORI then this area is an excellent candidate for the installation of new substratum, known as cultch relaying. When coupled with additional restoration techniques such as the translocation of breeding adults the Bench Head site could be a strategically important location for targeting effort to restore populations of *O.edulis* in the BCCR MCZ.

An attempt to estimate the dredge efficiency was made based on numbers of *O.edulis* recorded in the grab samples and the corresponding dredge samples across the three survey zones Blackwater, Bench Head and Ray Sand. Understanding the dredge efficiency allows an estimation of the overall *O.edulis* biomass across the whole MCZ area to be made. This type of analysis is often subject to scrutiny and substantial statistical ‘noise’ but gives a good indication of the number of individuals per m^{-2} and is therefore a useful comparison tool when assessing the BCCR MCZ against other study sites elsewhere in Britain and Ireland when looking at *O.edulis* population density and larval supply. Dredge efficiency could only be calculated using data from the Blackwater survey zone as individual *O.edulis* were only found in both the grab and the dredge survey techniques at this site. Dredge efficiency was calculated at 17.7%, which is comparable to results obtained by Hardy (2014) who estimated dredge efficiency at 14% in work undertaken in the Colne Estuary, and the K&EIFCA who have estimate dredge efficiency at 20% in work they undertook in 2015 (IFCA per comms 2017).

Based on a dredge efficiency of 17.7% the number of *O.edulis* (m^{-2}) in the BCCR MCZ has been estimated to be between 1.69 individuals/m^{-2} and 5.76 individuals/m^{-2} (average 3.72 m^{-2}). When considered alongside the estimated number of veligers in the BCCR MCZ of 61 veligers m^{-3} this means that the average number of veligers produced per adult is 16.6 veligers per individual oyster. Studies in Oregon in the United States looking at *Ostrea lurida,* a comparable species with similar ecological requirements estimated a population density between 0.7 individuals/m^{-2} and 4.7 individuals m^{-2}. This is a figure comparable to the findings of this study in the Blackwater estuary. Rimler (2014) found a significant linear relationship between the number of veligers and the number of settled successful recruits to be in the region of 1 recruit per 5.5 veligers. The number of successfully recruited juvenile *O.edulis* in the BCCR could be estimated at 3 recruited juveniles per m^{-2} , before predation and natural mortality is considered, therefore if the findings of Rimler are comparable in this case, 3 recruited juveniles per m^{-2} is too low to maintain or increase existing populations of *O.edulis*. These numbers are of course estimates based on findings from comparable studies and are likely to be further refined with repeated sampling in the BCCR estuaries, but they do give an indication of ecological forecast, especially with regard to potential restoration applications. Given the findings from the study, recommendations going forward for the restoration of *O.edulis* in the BCCR are a combination of cultch relaying and renewal in the Bench Head survey zone in combination with retention of adult *O.edulis,* in order to maintain breeding stock. These recommendations were presented to and accepted by the ENORI group in June 2017. In August 2017 the ENORI Conservation Management Plan (Annex 1.1) and associated Habitats Regulation Assessment (HRA) (Annex 1.2) were submitted and accepted by Natural England.

Chapter 5: Marine Protected Areas: A Critical analysis of their implementation in the UK.

5.1 Marine Protected Areas: Critical analysis of implementation in the UK.

Recent additions to marine environmental legislation were designed to fill gaps in protection and management, build on existing practices or correct deficiencies in previous instruments. (Boyes *et al.,*2016). The European Union (EU) is one of the leading administrations globally for the development and implementation of Directives for the furtherance of marine protection. Each of the member states are required to ratify European Directives into domestic legislation to ensure obligations are met. There is now a multifaceted suite of both European and national legislation that can be drawn on for the protection and management of the marine environment. However, translation of European Directives into domestic legislation has resulted in a patchwork of European policies, national policies, private initiatives and regulations on different levels that often conflict with each other (Boyes and Elliott, 2014). The case study of the Essex Estuaries highlights conflicts that can arise between European and National nature conservation designations when being implemented on the ground.

MPA's have caused significant debate since their designation. The interpretation of the legislation by different user groups on how these areas can be used remains in dispute. (Chapter 2) This confusion is understandable: MPA's were not designed nor intended to be highly protected marine reserves where all human activities are excluded. Article 2 (3) of the Habitats Directive states that economic, social and cultural requirements can be taken into account when managing a MPA.

However, Article 2 (2) states that the Directive must be used to maintain or restore, favourable conservation status, natural habitats and species of wild fauna and flora of community interest. The Directive may allow social, cultural and economic activities to take place but only if they are deemed not to have a negative impact on the favourable condition of the MPA.

The wording of the Habitats Directive is:

- To ensure the restoration or maintenance of natural habitats and species of community interest at a favourable conservation status.
- The preservation, protection and improvement of the quality of the environment, including the conservation of natural habitats and of wild fauna and flora, are an essential objective.
- A system should be set up for surveillance of the conservation status of the natural habitats and species covered by this Directive.
- The improvement of scientific and technical knowledge is essential for the implementation of this Directive.
- It is consequently appropriate to encourage the necessary research and scientific work.

5.1.1 Feature Based approach

Each designated site under the Habitats Directive has a suite of supporting documents. Natural England's Regulation 33 document is the statutory document which accompanies every site designated under the Habitats Regulations. It is this document that is used to ensure the obligation under Regulation 33(2) of the

Conservation (Natural Habitats &c.) Regulations 1994 are met. (Council Directive, 1994)

The purpose of the Regulation 33 document is to;

(a) Detail the conservation objectives and

(b) Describe any operations which may cause deterioration of natural habitats or species, or disturbance to species for which the Essex Estuaries European Marine Site is designated.

The aim of the document is to detail the features and their condition at the time of designation. The condition of each feature to be established in a fixed baseline, quantified at the time of designation. Thereafter the condition of the site and the achievement of the legislation are assessed against the baseline established in 1996 or when the particular site was designated. Unfortunately Regulation 33 documents, from which the conservation objectives and baseline survey are detailed, are not quantitative. They instead take the form of a descriptive text, where the interest features are located, rather than a quantitative document that can be used to assess the condition of the feature against the baseline. This lack of quantitative data gathering and assessment was acknowledged as an issue and in 2010 the Habitats Regulations (Regulation 35) which were amended to improve and standardise the process across all European designated MPA's. (DEFRA, 2010)

However, the new format conservation advice and in particular the feature conditions are still universally 'Not assessed'. Of the 63 SAC's and SPA's with marine components in the UK only 1 (Poole harbour SPA) has any quantitative data associated with the designated feature. Of the remaining areas, 37 have no further information available on feature condition or condition assessment and 24 are categorised as not assessed. (Natural England, 2016) (Table 21).

Table 21 Current condition assessment: Special Areas of Conservation with Marine Components in the UK (Modified from JNCC document)

Name	Designation	Location	Condition Assessment
Alde, Ore and Butley Estuaries	SAC	England inshore	Not Assessed
Berwickshire and North Northumberland Coast	SAC	England inshore & Scotland	No Information
Chesil and the Fleet	SAC	England inshore	Not Assessed
Dee Estuary/ Aber Dyfrdwy	SAC	England inshore & Wales inshore	No Information
Drigg Coast	SAC	England inshore	Not Assessed
Essex Estuaries	SAC	England inshore	Not Assessed
Fal and Helford	SAC	England inshore	Not Assessed
Flamborough Head	SAC	England inshore	No Information
Haig Fras	SAC	England offshore	No Information
Humber Estuary	SAC	England inshore	No Information
Isles of Scilly Complex	SAC	England inshore	No Information
Lundy	SAC	England inshore	Not Assessed
Morecambe Bay	SAC	England inshore	No Information
North Norfolk Coast	SAC	England inshore	No Information
Orfordness - Shingle Street	SAC	England inshore	Not Assessed
Plymouth Sound and Estuaries	SAC	England inshore	Not Assessed
Severn Estuary/ Môr Hafren	SAC	England inshore & Wales inshore	No Information
Solent and Isle of Wight Lagoons	SAC	England inshore	No Information
Solent Maritime	SAC	England inshore	Not Assessed
Solway Firth	SAC	England inshore & Scotland	No Information
South Wight Maritime	SAC	England inshore	No Information
Thanet Coast	SAC	England inshore	No Information
The Wash and North Norfolk Coast	SAC	England inshore	No Information
Tweed Estuary	SAC	England inshore	Not Assessed

The Habitats Directive wording is clear, the scientific and technical knowledge needed to ensure effective implementation of the Directive at the centre of the designation. If the information is lacking to ensure effective implementation of the Directive it stipulates that Member States are required to implement research and scientific work in which to quantify this baseline. It goes on to stipulate that this scientific research should be made available to inform the annexes and where necessary amend them to ensure the legislation is effective.

Article 1 states the purpose of the Directive to be;

'A series of measures required to maintain or restore natural habitats and the population of species of wild fauna and flora at a favourable status'.

It goes on to describe favourable status to be where;

'The feature is maintaining itself on a long term basis as a viable component of the natural habitat, that the feature is neither being reduced or is likely to be reduced for the foreseeable future and that the feature has a geographically defined area whose extent is clearly delineated'.

In short, a scientifically robust baseline should be established for each feature within any designation including the Essex Estuaries SAC. The baseline should detail the location, extent and condition of the feature including biotopes and community structure for which the designation was put in place.

It is only within these parameters that the application of the legislation can be assessed to ensure that the UK is legally compliant in its approach to implementation of the Directive. The legislation requires, in order to ensure favourable condition status is maintained, that the features should have been surveyed periodically over the 20 year period in which the designation has been in place. It is in the monitoring of features that the comparison between the baseline and current condition can be assessed and therefore an accurate understanding of the ecological condition of the site can be estimated. Currently it is not possible to ensure that the features have remained in favourable condition and subsequently it is not possible to conclude that the UK has upheld its obligation under the Habitats Regulations. This leaves the UK in a precarious situation in which infraction proceedings brought against the UK government may be upheld in the European courts.

In 2012 the UK government was challenged on their approach to the Directive. The challenge led by Environmental NGO's and Client Earth concerned the allowance of fishing activities within European Marine Sites.

The challenge came from the wording in the legislation;

Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public.

So, fishing activities potentially have the capacity to have a damaging effect on the conservation status of the site. In allowing the activity to continue, Member States (in this case the UK government) are taking appropriate action to 'prevent deterioration' if the activity, in this case fishing, is likely to have a significant effect then under the Habitats Regulations an appropriate assessment is required.

'Following an appropriate assessment it must be proven beyond reasonable doubt that the proposed activity will not adversely affect the integrity of the site. Unless a finding of no adverse effect can be made following the appropriate assessment then the activity cannot be permitted by a competent authority'.

The outcome of this process is critical, and in light of this the European Courts requested a revised approach to fishing activities within SAC's and SPA's be undertaken. In August 2012 Defra announced, in light of the success of the environmental NGO's and Client Earth's challenge, a revised approach to fishing activity within a European Marine Site would be undertaken.

Defra stated;

'In order to ensure that EMSs receive the requisite level of protection, and ensure compliance with the EU Birds and Habitats Directives, Government has decided to revise the approach to the management of commercial fisheries affecting EMS. Building on existing management measures, this will ensure that all existing and potential commercial fishing activities are subject to an assessment of their impact on EMSs'.

The Revised approach upholds a legal obligation to ensure all existing, planned and potential fishing activities within every marine based SAC and SPA nationally which could have an impact on the integrity of the site are assessed for their potential impact and if deemed to be having an likely significant effect then management stipulations must be placed on the fishery to ensure the UK are compliant with their obligation under Article 6 of the Habitats Regulations. In order to ensure this compliance, all fishing activities within an SAC and/or SPA must undergo an

Assessment of Likely Significant Effect. If the activity is deemed to have a likely significant effect then a full appropriate assessment must be completed. (DEFRA, 2013)

The implementation of the Revised Approach is on a risk-prioritised basis, where the most damaging activities on the most fragile habitats were to be assessed first. In order to assess impacts versus features, a matrix has been developed in which all fishing activities are allocated a ranking, red, amber, green and blue, depending on the impact of the fishing gear to the feature. Each of these status levels provides regulators with an indicator of which activities need priority management. (DEFRA, 2014). The initial stage relates to red risk interactions; those that are deemed to be most damaging. In 2012 the UK took the unprecedented steps to impose a deadline of 2013 in which to ban all red risk interactions in any of the EMS in which the activity took place. Assessment of Amber interactions and any subsequent management must be complete by 2016. Fishing activities contained with amber interactions need further analysis and assessment. This is undertaken in a site specific approach conducted by the competent Authority.

In order to assess impact of a fishery on a designated feature a *Test of Likely Significant Effect* is required to be undertaken. This is the easiest way to assess impact but it is arguably not in the ethos of the Directive especially when applied to an estuarine complex such as the Essex Estuaries. The Directive speaks of site integrity, the ability for the site to function as a coherent whole. Integrity goes beyond the health and condition of each of the features but how they interact with one another. It could certainly be the case that by simplifying the Directive or separating the site into component parts and assessing impact on individual features that the complexities and their interactions with one another are overlooked. Instead of progressing the conservation advice based on site integrity, Defra have opted for a feature-based approach and have chosen to assess the conservation status and damage to each of the features against the conservation objectives that were developed for each of the sites and each of the features.

In the case of the Essex Estuaries this feature based approach protects those features listed in Table 7 Essex Estuaries Special Area Conservation (SAC) qualifying features Table 7. Given the lack of baseline data during the initial designation and the assessment of the condition of the Essex Estuaries coupled with the lack of condition monitoring, it is certainly possible to argue that it is not possible to state beyond any reasonable doubt that these activities are not adversely affecting site integrity and therefore under the precautionary approach activities should discontinue.

5.1.2 Marine Conservation Zones

In 2012 at the same time as the process involved in the revised approach to fishing activities within an MPA began to gain traction, the Marine Act began the process of designating MCZ's throughout UK territorial waters.

The Marine and Coastal Access Act implementation guidance also gives provision for the establishment of reference areas within each designated MCZ;

'Each broad-scale habitat type and FOCI should have at least one viable reference area within each of the four regional MCZ project areas where all extraction, deposition or human-derived disturbance is removed or prevented.'(JNCC, 2010a)

The addition of reference areas to each of the recommended MCZ was intended to progress understanding of the value of the marine environment and the impacts of activities (JNCC, 2010b) and through the prohibition of any extractive or depositional activities the un-impacted state of a broad range of marine features could be established in the context of prevailing environmental conditions. However, during consultation of the first tranche of MCZ's it was noted that reference areas were one of the "most controversial" aspects of the recommendations (Defra, 2013). Given the opposition from certain sectors and stakeholders the Government's decision in 2013 was not to designate any reference areas at that stage, it would instead undertake a review to "take a fresh look at requirements for reference areas, including size, number, location and management measures" (Defra, 2013). Unfortunately 2 years later during the designation of tranche 2 MCZ's, reference areas were still not included. Given that the combined total of all recommended reference areas in 2011 was under 2% of the total recommended MCZ area (Natural England, 2011) and their scientific importance as stated by the Ecological Network Guidance (ENG) (OSPAR, 2003), the decision by government to 'park' this option seems retrograde.

5.1.3 Colne, Blackwater, Crouch & Roach Marine Conservation Zone

In 2010 Natural England provided formal advice to the Balanced Seas committee citing the need for quantitative evidence to support the inclusion of *O.edulis* in the designation of the MCZ (chapter 3). Further evidence was also needed to assess the health of the beds and ascertain exactly what constitutes favourable condition and if this can be achieved in the context of current fishing practices and biological constraints.

5.1.4 Feature Frameworks

The newly created MCZ's have a suite of supporting documents designed to aid understanding of the features of conservation importance (FOCI) identified within each MCZ and how best to manage their recovery. These documents include:

1. *Conservation Advice (CA) – an overarching document, produced by Natural England, lists each feature within the MCZ, and allocates a conservation objective to each. BCCR, the conservation advice is to recover O.edulis and O.edulis beds.*
2. *Feature Frameworks –inform the Conservation Advice (CA). Written at a national level, they are a tool designed to determine favourable condition for each feature, based on desk studies and data trawls the feature frameworks are a road map or how to guide. Crucially this advice also encompass all the attributes that make up the integrity of a feature (e.g. extent of feature, distribution of feature, structure and function. (Natural England, 2017)*

The *Feature Frameworks* are a key document, they will, for the first time set out quantitative targets for each of the features, as opposed to the qualitative approach that was taken when designating and assessing the existing SAC and SPA network. Feature Frameworks will be instrumental in the design of the management plan and any subsequent monitoring, they will allow for the first time a robust baseline in which to work and monitor from and in the case of BCCR, should be a significant step forward in our understanding of what an oyster bed is and what a recovered bed should exemplify. (Natural England, 2014)

5.2 Aims

- Identify a range of restoration project options that will achieve the conservation aims of the Marine Conservation Zone.
- Identify and implement an effective restoration project for *O.edulis* in the Marine Conservation Zone as a means to critically analyse current legislative frameworks in the UK.
- Ensure delivery of a robust management and restoration plan for the Marine Conservation Zone based biotic and abiotic parameters within the designation area.

5.2.1 Implementation in Essex

In order to progress the recovery of *O.edulis* ENORI was established, the remit of this group is:

- To forge a path for the implementation of restoration guided by the Feature Frameworks required under the Marine Act.
- To develop Conservation Advice and feature frameworks for the recovery of native oysters and native oyster beds.
- To establish what favourable condition is for both features within the Essex Estuaries MCZ
- To trial and develop innovative restoration techniques to achieve restoration.

Early advice provided to the statutory regulators from the ENORI group was that active intervention was needed to increase numbers of native oysters, this active intervention included closed areas, to protect breeding stocks where numbers of oysters were declining and evidence of recruitment failure was observed (Essex Wildlife Trust, 2012). Additional proposals for active intervention include laying cultch, translocation of breeding stock and cultivation using harrows and dredges, a technique used by the oyster industry to promote recruitment of oysters from the planktonic stage by cleaning cultch (benthic based shell fragments and the subsequent settlement of veligers. (Waugh, 1957., Laing *et al.,*2006, Blackwater Oystermans' Association per comms, 2016) (Section 4.1.4)

This technique was suggested to the statutory regulators by the ENORI group in 2012 and was considered and accepted by Natural England as a method which encourages settlement (ENORI, 2012). The decision of "active intervention" as a technique to maximise potential settlement opportunities and therefore work towards increasing numbers of oysters. This technique has been used successfully in oyster cultivation for many years, but is now coming under increased scrutiny i.e. (Bromley *et al.,* 2015) concluded that harrowing does not increase settlement, can cause substratum deterioration and is not suitable for all oyster production areas and should only be employed with caution.

This increased scrutiny becomes more influential when viewed in combination with the co-located SAC. This is because under the Habitats Directive legislation and its “feature-based” approach, (Section 5.2.1 & Table 7) any gear interaction with the sea bed may be deemed to have a significant detrimental impact to the feature and the communities that it supports (Client Earth, 2014). Because of this approach, oyster dredging, harrowing or ‘cleaning’ is classed as having a significant effect to the SAC features unless it is proven otherwise. Thus, when two designations which share the same geographical location but are empowered under different legislation, the proposed measure towards restoration of oyster beds complements one, but conflicts with another. Given that they both have a legal requirement to progress, is it possible both can proceed given the constraints of the framework?

By May 2015, the advice given by the Natural England was;

‘At this point in time, there is too much uncertainty over future native oyster dredging activity within the SAC and little information around the impacts of oyster dredging on the features of the SAC; therefore priority should be given to investigating these issues before committing to further activities’ (Natural England, 2015)

A three year trial running from 2015 – 2018 conducted by the Kent & Essex IFCA into the effects of oyster dredges and harrows is currently underway, but preliminary observations suggest that oyster dredges are likely to have a significant impact on the SAC features subtidal mud, due to its stability and the utilisation of subtidal mud by other estuaries species such as Plaice (*Pleuronectes platessa*) (Seitz *et al.,*2014, IFCA, 2016).

Advice on the likely significant effect of dredges on sub tidal mixed sediment is still unclear. If trials show that bottom towed gear interactions with this feature have a likely significant effect then the Habitats Regulations stipulates that this activity must be stopped. This is in line with the current bylaw put in place in September 2016 prohibiting trawling in the Essex Estuaries SAC due to sensitivity of Subtidal mud to bottom towed gear.

The challenge is how to determine a legal and pragmatic progression within the confines of the legislation. Subtidal mixed sediment is one of the features protected by both the SAC & the MCZ due to its ability to support a wide range of benthic and epibenthic fauna.(Alexander, 2016) including *Ostrea edulis*.

'As a broad-scale habitat subtidal mixed sediments may contain native oyster beds (Marine Habitat Classification for Britain and Ireland). SS.SMX.IMx.Ost (Ostrea edulis beds on shallow sublittoral muddy mixed sediment) is the biotope made up of dense oyster beds and clumps of dead shells'.

If the act of harrowing is deemed to have a likely significant effect on subtidal mixed sediment then the opportunity for restoration of native oyster is under the current guidance of 'active intervention' is compromised, and alternative restoration techniques such as translocation and cultch laying will become a more likely option,

Laying cultch in Essex Estuaries SAC, to recover native oysters, should be targeted to areas where this biotope is known to occur.(Natural England, 2015)

This is a proportionate and pragmatic way forward and is not, in the ethos or the wording of the legislation. But given the complexities of the overlapping designations it may be seen as reasonable way forward that remains legally compliant.

Table 22 Stakeholders and their associated groups and organisations responsible for implementation of BCCR MCZ management and restoration plan

Group/ organisation	Area of responsibility	Responsibilities	Statutory regulator	Legislative Drivers
Natural England	Nature Conservation	Statutory body responsible for implementation of nature conservation legislation in the UK	Y	Habitats Directive Birds Directive Wildlife and Countryside Act
Environment Agency	Water quality	Non-governmental department responsible for protection and enhancement of the Environment	Y	Water Framework Directive
Cefas	Fisheries	Sustainable fisheries management	Y	Marine Strategy Framework Directive
IFCA		Sustainable use of the Marine Environment	Y	Marine & Coastal Access Act
MMO	Marine Licencing	Addressing alone and cumulative impacts of various marine based activities	Y	Marine & Coastal Access Act
Crown Estate	Land owner	Management of Crown land and Assets	Y	Crown Estate Act
Wildlife Trust	NGO	Nature Conservation	-	-
Zoological Society London		Nature Conservation	-	-
Blue Marine Foundation		Marine Nature Conservation	-	-
Blackwater Oystermans Association	Aquaculture/ cultivation	Cultivation of *O.edulis* within the BCCR	-	-

5.3 Case Study – Creation of a new Native Oyster *Ostrea edulis* bed within the Blackwater, Colne, Crouch and Roach Marine Conservation Zone (MCZ).

5.2.1 The Background

During designation of the MCZ, communication with statutory bodies; Natural England and the K&EIFCA began to highlight the potential for conservation conflicts to arise. Redpath (2013) neatly defines conservation conflict as '*situations that occur when two or more parties with strongly held opinions clash over conservation objectives and when one party is perceived to assert its interests at the expense of another*'. Where most case studies on conservation conflicts detail the conflict which arises between a resource and how that resource is used in the case of the Essex Estuaries the conflict is between nature conservation designations.

The area has historically been used in different ways (Table 13) and regulated by different statutory bodies. Within the Essex Estuaries there are several designated shellfish beds. A Several Order, leased from the Crown to the Tollesbury and Mersea Oyster Company Limited. The neighbouring Colne Estuary is tenanted from Colchester Borough Council by the Colchester Oyster Company Limited for the purpose of shellfish cultivation and Rivers Crouch & Roach have a combination of privately owned or tenanted oyster grounds. At present, despite being located within a SAC, SPA and MCZ, these private and tenanted shellfish cultivation grounds are exempt from management stipulations of the conservation designations covering the area, instead when a fisheries or several order byelaws are renewed it is the responsibility of the fishermen or Oystermen to provide the statutory bodies with Environmental Impact Assessments, management and monitoring plans which detail Likely significant effect to the designated site or features and how they can be mitigated.

In addition to the number of designations and number of groups using the area, there is also the added complexity that that each activity is regulated by a different and separate statutory body. Fishing activities are licenced and regulated by the K&EIFCA, Marine infrastructure activities are licenced and regulated by the Marine Management Organisation (MMO). Nature Conservation, monitoring and management of designations is the remit of Natural England. Maritime plans and projects are licenced and regulated by the MMO.

In response to the complexity of the geographic area, the designations and the stakeholders involved ENORI was formed. ENORI's main aim is to develop innovative restoration techniques, aid communication, develop protocols and work through any potential conflicts.

5.3.2 The Project

In 2016 a restoration project was proposed, this was a pilot project from which to develop a larger restoration plan. The project proposal, to translocate 25,000 breeding adult *O.edulis* to a site in the Blackwater Estuary. Translocation is the intentional movement of a species in an area where it is common to where it has become depleted (Bromley et al., 2016), and it has been used successfully in terrestrial conservation for many years as a method to increase the distribution, resilience and breeding potential of the target species (Seddon et al., 2014). Translocation of marine species for the purpose of marine conservation is less common and although generally accepted is not studied in the same depth as its terrestrial equivalents (Bromley et al., 2016). However, in recent years the act of restoration of estuaries and the coastal zones has become increasingly popular. Ecological engineering (Ecoengineering) refers to the restoration of coastal systems from past degradation either through modification of physio-chemical structure (Type A) or the act of relaying or transplanting biota in order to modify the physical system in order to restore natural processes (Type B) (Elliott et al., 2016) This type of restoration has been implemented extensively throughout UK and Europe mainly through saltmarsh restoration and managed realignment. There are very few examples of Type B ecoengineering projects for Oyster bed restoration in the UK and Europe, instead most have occurred in the United States (section 4.1.3)

The BCCR project translocated *O.edulis* from an area of private grounds within the MCZ that support high numbers of *O. edulis* and placed in an area of public ground that has historically supported *O. edulis*. The project aimed to create a meta-population from an indigenous population, reducing the risk of mortality or importation of pests or disease and ensuring that local genetic variability is maintained. The complexity of the overlapping conservation designations and the numerous regulatory bodies present in the area requires significant co-ordination, co-operation and agreement of a wide range of organisations and individuals before any practical work can be undertaken. The range designations, and legislation combined with groups and individuals involved can lead to significant confusion.

In order for restoration to progress, all necessary licences needed to be obtained. Firstly Natural England were approached and advised that a full Habitats Regulation Assessment needed to be undertaken. Natural England also advised that given that the proposed project did not take place within a SSSI, they would not be the relevant authority to licence the activity. Recommendations were made to contact the Centre for Ecology, Fisheries and Aquaculture Science (Cefas) as oysters would be removed from an area of aquaculture production. Cefas were contacted as a potential statutory authority to licence the project, but they advised that as the relaying of *O.edulis* within the same designated site (SAC & MCZ) was for the purpose of nature conservation and not for cultivation, it was not an activity they could licence, as it would no longer be an aquaculture activity.

The K&EIFCA were contacted for advice on an application for a derogation of a shellfish bylaw covering the area, but as the project was a conservation activity and not fishing activity, they confirmed that it could not be licenced within their remit. As the licencing body for all marine activities and protected species, the MMO were contacted. A licence application was submitted. The MMO advised that a licence was not required to carry out the activity, as *O.edulis* is not a listed species under the Wildlife and Countryside Act 1981. Therefore no licence was required.(Table 23)

Table 23 Statutory organisation involved in the licencing of translocation project within the BCCR

Group/ organisation	Area of responsibility	Responsibilities	Response to Case Study
Natural England	Nature Conservation	Statutory consultee for nature conservation within the UK, responsible for providing advice on projects within European designated sites and SSSI's	The project does not take place within a SSSI. The species is not protected under the Wildlife and Countryside Act It is therefore not within the statutory remit of Natural England
Environment Agency	Water quality	Statutory consultee responsible for providing advice on water quality and resource issues throughout the UK. Responsible for implementing European Water Framework Directive within the UK	The project does not effect water resources or water quality, it is therefore not the remit of Environment Agency
Cefas	Fisheries	Responsible for sustainable resource management, including the licencing and assessment of several orders, designation of shellfish waters and shellfish health	*O.edulis* will be removed from an existing several order area licenced for the extraction of the species this does not need a further licence and relayed. The process of relaying the oysters becomes and act of conservation, not aquaculture and is therefore outside the statutory remit of the organisation. This type of activity does not require a Cefas Licence
IFCA		Responsible for the sustainable exploitation of marine fish stocks and implementation of MCZ's through the Marine Act.	Deposition of live shellfish within a European designated site is an act of conservation and not fisheries and is therefore not within the statutory remit of the IFCA and cannot be licenced.
MMO	Marine Licencing	Responsible for marine licencing within UK territorial waters	*O.edulis* is not protected under the Wildlife & Countryside Act and is therefore not within the statutory remit of the MMO and so cannot be licenced by the organisation.
Crown Estate	Land owner	Management of crown estate assets including beaches and foreshore	The activity does not take place on crown estate land and therefore cannot be licenced by the organisation

The project proposal for active intervention through the installation of a brood stock area had previously been accepted by Natural England for the furtherance of the conservation objectives of the MCZ, but could not be licenced by any of the statutory bodies. The team leading the project were left with a situation whereby it is not possible to progress the conservation advice from Natural England of “active restoration” due to the complexities of competing nature conservation designations, the perceived potential impact the relaying may have on the SAC feature, mixed subtidal sediment, the lack of statutory regulation to assess the impact and range of organisations involved, along with the innovative nature of the pilot project proposal has made implementing the project problematic. As the activity cannot be licenced, the progression of the restoration project was precarious, but progressed regardless due to the ENORI group. Additional comments by Natural England suggested that, as there was no option for a licence, then there was no framework in which to assess the activity, therefore NE could give advice as a ‘critical friend’, but if the activity were to proceed and it was deemed to have a negative effect on the SAC, then a legal challenge would be possible.

This inability to resolve the conflicting legal situation means the restoration project team were left in a situation whereby a project designed to restore a key interest feature of the Essex estuaries, could not be licenced under the current licencing regimes of the various organisations responsible for the management and restoration of the Essex estuaries SAC, SPA and

MCZ. This is a highly unusual situation. The restoration project proceeded regardless of the difficulties and complexities as there was no sound legal or conservation reasons not to.

In October 2016 the translocation project and the 6.5 ha of new oyster bed that was created, was formally ‘adopted’ by Natural England and included in a much larger conservation area for the progression of native oyster conservation. This 200 ha ‘no take zone’ mimics that of the originally proposed reference areas that were dropped from the MCZ in 2012. The translocated oysters are to act as a breeding stock for the continued production of veligers into the MCZ area. While also monitored biannually to increase knowledge of the development of oyster beds, their associated communities.

Chapter 6: General Discussion

In many parts of the world oyster populations have become extinct or have undergone catastrophic declines (Beck *et al.,* 2011, Smyth *et al.,* 2016), leaving behind the legacy we see today of fragmented populations vulnerable to loss through disease, pollution, unsustainable harvesting or loss of habitat. The passing of the Marine Act in 2009 sought to redress the balance, protecting, restoring and conserving marine species and habitats in the UK. The Act has arguably been the most progressive step forward for marine conservation in a generation, and has been brought about by the culmination of countless studies and increasing political pressure brought to bear on government to act to protect and restore the UK's marine environment.

Following the Marine Act and after long discussions with the local oyster industry the decision to seek the designation of the Essex estuaries as an MCZ for *O.edulis* and *O.edulis* beds was made in 2010. The drivers were both the pressing need to protect remaining oyster populations in the Essex estuaries from nomadic fleets and securing a legislative requirement to restore and enhance those populations. Discussions with the UK government on how to secure the MCZ designation highlighted a lack of up-to-date data on the species within the proposed MCZ area. Without a current and scientifically robust data set on abundance and distribution of *O.edulis* within the recommended MCZ area confidence in recommending the area for designation would be low. The initial driver for the study was to obtain the necessary information on abundance and distribution of *O.edulis* within the recommended Blackwater, Colne, Crouch and Roach (BCCR) MCZ area to fill the data gap and increase government confidence in order to obtain the designation.

The study has shown that *O.edulis* is present within the BCCR MCZ, that the spatial extent of the species within the MCZ is patchy and comprises of 4 spatially distinct subpopulations; Blackwater, Bench Head, Colne and Ray Sand. These subpopulations differ in their densities and population profile. Counts of individual *O.edulis* within the Blackwater survey zone are significantly higher than those found in the Bench Head and Colne but are comparable to numbers found in the Ray Sand. However, the structures of the Blackwater and Ray Sand populations are very different.

Size frequency data shows that the Blackwater supports a higher proportion of small individuals or younger age cohorts (under 40mm) compared to the Ray sand which proportionally supports a greater number of older cohorts (over 60mm). This indicates that recruitment in the Ray sand population may be limited.

The Bench Head population displayed a similar age profile to the adjacent Blackwater populations suggesting recruitment and retention of younger individuals is likely. This may be a result of the historical aquaculture practice of restocking *O.edulis*, combined with the current oyster cultivation practice of cultch cleaning working in combination with the species natural propensity for gregarious settlement. The results of the study into abundance, distribution and size structure presented in Chapter 3 were submitted to the UK government in 2012 for consideration during the designation of the first tranche of UK MCZ's. In November 2013 the BCCR was awarded MCZ status, for the presence of *O.edulis* and *O.edulis* beds.

Surveys to establish the characterisation of benthic substratum established that *O.edulis* will preferentially settle on subtidal mixed sediment. The findings from Chapter 3 show subtidal mixed sediment is found within the MCZ area and is composed of coarse mixed sediment (predominantly comprised of shell, or shell fragments) but that distribution of this suitable substrate is patchy throughout the BCCR MCZ area. *O.edulis* populations associated with these patches of shell and shell fragments vary significantly in their composition. The Blackwater supports high densities of *O.edulis* with a range of age class cohorts, the Ray Sand supports equally high densities of *O.edulis* but the range of cohorts is skewed towards older individuals, whereas the Bench Head supports very few individuals, despite its proximity to known breeding populations.

These findings prompted further investigation to consider why some areas of subtidal mixed sediment support populations of *O.edulis* and others do not. The availability of subtidal mixed sediment is a fundamental consideration when assessing the likelihood of a successful long term restoration programme for *O. edulis* (Laing 2005). This species requires the presence and availability of a clean hard substrate (including dead oyster shells or cultch) on which pediveligers can settle to enable the successful recruitment of new cohorts to an existing population and to increase the likelihood of new populations establishing. (Bromey *et al.,* 2015) The study has shown that the composition of settlement substratum throughout the BCCR varies significantly in size (mm), availability (g) and possibly suitability. Substratum availability is highest in the Bench Head (8816g m^{-2}), followed by the Blackwater (2929g m^{-2}) and then Ray sand (1143g m^{-2}).

Given the close proximity to existing breeding populations and good substratum availability the Bench Head should theoretically support greater numbers of *O.edulis* than it does. Communication with oystermen and shellfish restoration experts suggests that this may be due to the suitability of the substratum, that the age and shell porosity of the cultch may be a factor which reduces frequency of settlement of veligers, a theory which certainly warrants further investigation in the future. Substratum availability in the Ray Sand is the lowest of the three sites, with less than half of that present in the Blackwater. This is supported by the K&EIFCA sidescan sonar surveys undertaken over a three year period between 2015 – 2017, whose findings indicate a shift in substratum regime towards subtidal sand and mud. In addition the survey technique of targeted grab samples used in this study only considered the weight and size of shell, and did not assess species composition or whether the sample was alive or dead. However, it was observed that the majority of the shell substrate sampled in the Ray sand was comprised of living Slipper limpet *Crepidula fornicata* and Blue Mussel *Mytilis edulis*, and given that both species are known to be direct competitors with *O. edulis* for space and food resources, may indicate an additional possible reason for the lack of younger size classes within this survey zone.

Surveys of the BCCR MCZ identified not only a potential lack of suitable settlement substratum in some areas, but also a lack of recruitment. Larval supply is a pre-requisite for the maintenance of any sustainable population of *O.edulis* and is the building block of any potential restoration attempts in the future. Further investigation into the potential reasons for the lack of recruitment (Chapter 3) led to the consideration of larval concentrations in the estuaries. In order to ascertain if larval supply is a limiting factor for recruitment and therefore restoration, veliger sampling was undertaken during the summer of 2016. The study found low concentrations of larvae in the water column during the breeding season. It is likely that this lack of larvae is at least in part the result of low adult oyster densities, although alternative theories such as low breeding fecundity have not been pursued as part of this study. As the males broadcast spawn, low densities of adults or a reduced amount of spermatozoa can result in reduced fertilization of eggs within the females, (Walne 1964) as well as a lack of suitable settlement substratum (Waugh 1972). This recruitment limitation can potentially be overcome by placing adult oysters at higher densities in brood stock sanctuaries.

This was in part the rationale behind the translocation project (Chapter 5, Case Study: Creation of a new Native Oyster *Ostrea edulis* bed within the Blackwater, Colne, Crouch and Roach Marine Conservation Zone (MCZ)). This pilot project was designed to develop and lead to larger restoration plan proposals. The project proposed to translocate 25,000 breeding adult *O.edulis* collected from the wider BCCR MCZ site and relay them in densities of 5m^2 within the Blackwater Estuary, creating a brood stock sanctuary as well as an *O.edulis* bed, as defined by OSPAR. The project was successful in its implementation, and a new 6.5ha *O.edulis* bed was created May 2016.

Although successful in its implementation the project highlighted the complexities facing conservationists when attempting to implement shellfish restoration projects in the UK. Co-located nature conservation designations and their associated legislation, coupled with conflicting conservation advice from multiple statutory bodies with various remits created a problematic rather than pragmatic approach to restoration. The translocation project is the first of its kind in the UK and although difficult and complex in its planning stages has proved to be a valuable process in testing the legislation and working closely with the statutory bodies involved.

6.1 Post designation: How the study has contributed to the long term knowledge and conservation of *O.edulis* in the UK

The designation of the BCCR MCZ based on the findings of the study is a huge and progressive step forward for marine conservation. However the designation is only the first step, the true measure of success is how that designation is implemented. Following designation there is a legislative requirement for Conservation Objectives (CO) to be established for each of the designated features, in this case *O.edulis* and *O.edulis* beds. The purpose of conservation objectives is to describe the desired ecological state of the feature within that MCZ and to provide information on whether the feature is meeting the desired ecological state and should be 'maintained', or if the feature is not meeting the desired ecological state and therefore there is a need for action to be undertaken for the population to ‘recover’ (JNCC, 2012). Initial communication with Defra and Natural England regarding the conservation objectives for the BCCR suggested that the statutory authorities favoured a conservation objective allocation of ‘maintain’ for *O. edulis* and *O. edulis* beds. However, following discussions with Natural England and the submission of the findings in Chapter 3 which show a lack of suitable settlement substratum in the Bench Head survey zone, and a lack of veliger recruitment in the Ray Sand survey zone the decision was taken to change the recommended Conservation Objectives from ‘maintain’ to ‘recover’, in order to ensure active restoration is implemented. (Essex Wildlife Trust ,2012) . Findings from Chapter 3 were also submitted to the K&EIFCA in 2012 with the recommendation that all beds outside of private ownership be closed to fishing, in order to retain the breeding stock as a minimum conservation requirement. In January 2013 an emergency byelaw was passed prohibiting the extraction of *O.edulis*. The beds remain closed to date.

The major findings of the study namely the distribution, abundance, age profile, larval supply of *O. edulis* and the availability of suitable settlement substrate have all been instrumental in the designation of the BCCR MCZ. The thesis has provided the key datasets to inform decisions in relation to conservation and management of the MCZ (see Annex 1.1) and has been an invaluable tool to progress discussions between the fishing industry and the statutory bodies on management plans and practices for and within the MCZ. The study has been a major contributor to progressive conservation projects within the MCZ such as the creation of the UKs first *O.edulis* bed, and has developed a series of additional studies considering the breeding capacity of adults within a brood stock sanctuary. This has highlighted the importance of brood stock sanctuaries within the UK, and work is continuing to determine if they are a feasible option for restoration of *O. edulis* populations within a designated *bonamia* area.

Continued studies beyond the time frame of this thesis seek to further develop our understanding of what an oyster bed is, what the associated communities are and how long it will take for oyster beds to be restored and for them to deliver the ecosystem services that the literature shows that they can provide. It has informed the development and designation of a highly protected reference area within the wider MCZ in which fishing activities are not permitted. This has the aim of both retaining brood stock and trialling different restoration techniques to inform shellfish bed restoration within the wider MCZ and more widely around the UK.

The study and the wider project to restore native oysters to the Essex estuaries has shown that the conservation and fishing sectors can work together with shared values to achieve the collective aims of both sectors and ultimately benefit the species both are trying to protect. It has shown that through close and ongoing communication and the integration of a range of stakeholders including scientists, conservationists and regulatory bodies the gains can be great, integrated and progressive. It has brought together different communities, and has sought to open, maintain and develop close communication and partnership working between a wide range of partners.

The study adds to a growing number of examples emerging in the field of practical conservation management where the need for robust scientific evidence is coupled with long term stakeholder engagement and communication in order to establish shared values. It is through this meeting of science and close personal relations and the establishment of shared values and objectives, that long term change can happen that leads to the enhancement and restoration of an environment. (Reed 2008, Redpath *et al.,* 2013., Ranger *et al.,* 2016., De Juan *et al.,* 2017)

This study has been an instrument to challenge the legal framework surrounding our nature conservation designations in the UK and has highlighted flaws in our legislative approach. It has shown that the Marine Act is progressive in its ideals but the statutory bodies which implement it are conservative in their approach and at times can inadvertently hinder its implementation. The study has progressed our understanding of oysters in the Essex estuaries and has helped establish a robust MCZ . It has also highlighted that there is a great desire from both the conservation bodies and the fishing industry to make the partnership work and it has forced us to compromise and learn hugely from each other and to respect experience and professional opinion.

At the beginning of this process the thesis was a tool to help obtain the MCZ designation the BCCR estuaries so desperately needed. It provided data and scientific rigour to the statutory bodies to progress the MCZ designation with confidence. It then became a tool that was used to discuss options and make informed decisions on management practices and restoration projects in the estuaries. More widely the project has shown that by working together real conservation objectives are delivered and accomplishments are shared and a win – win scenario for people and the environment can be achieved.

6.2 Future research

The study has been successful in delivering its original aims, producing a robust data set on which to designate an MCZ and using that data set to inform a progressive restoration and management plan. The study focused on the presence of *O.edulis*, amount and location of suitable settlement substratum, the presence of veligers within the BCCR and made suggestions about how these can be integrated into a management plan for the restoration of using a suite of restoration techniques that include Cultch relaying, establishment of brood stock areas and no take zones. It does however fall short in many ways. In order to ensure restoration is successful it is important to understand the complexities and interactions of predators and competitors. This was not measured at the time but was observed as a potential implication in a successful restoration plan, for example the cultch in the Ray sand was observed to be made up of live slipper limpets *C.fornicata* and Blue Mussel *M.edulis*, this is likely to have an impact on recruitment and longevity of individuals in this survey zone due to competition and warrants further investigation.

The composition and suitability of shell found within different survey zones. Abundance of shell in the Bench Head survey zone was found to be high in comparison to the other zones sampled, but observations suggests that although settlement substratum is present recruitment of younger cohorts is low and therefore the substratum it may not be suitable due to structure, age or porosity.

It is suggested that the BCCR MCZ may be recruitment limited, therefore veliger numbers were measured and found to be low, however this assumption as based on only one year of field data, this needs to be replicated over a period of several years before any conclusions can be drawn. It is also assumed that recruitment is veliger limited, however further studies should consider predation as a major limiting factor to successful recruitment of younger age cohorts to the beds.

This study focused on the top down approach to marine conservation, suggesting restoration can be motivated by legislative drivers. It does not look in any detail at the bottom up approach to restoration of *O.edulis* beds, the environmental parameters in which the restoration effort is taking place, water quality, seasonal variations, predation and competition, all need to be established in order to determine if restoration is possible within biological constraints as well as political ones.

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