NEF CONSULTING

A valuation of the Chichester Harbour Provisioning Ecosystem Services provided by shellfish

Report for Sussex IFCA and the Environment Agency

Sussex IFCA Inshore Fisheries and Conservation Authority

Environment Agency

Title: A valuation of the Chichester Harbour Provisioning Ecosystem Services provided by shellfish

Date: January 25th 2018

Authors: Chris Williams, William Davies and Jake Kuyer

Client: Sussex Inshore Fisheries and Conservation Authority (SxIFCA)

NEF Consulting is the consultancy arm of the leading UK think tank, New Economics Foundation. We help to put new economic ideas into practice.

New Economics Foundation is the UK's only people-powered think tank. The Foundation works to build a new economy where people really take control.

NEF Consulting Limited

New Economics Foundation
10 Salamanca Place
London SE1 7HB
www.nefconsulting.com
Tel: 020 7820 6361

Contents

1. Background and context

Context

A number of EU and national regulatory drivers are significant for improving the marine environment. These include the EU Marine Strategy Framework Directive (MSFD), the EU Water Framework Directive (WFD)[1], the EU Habitats and Birds Directives and overarching vision statements such as the UK Marine Policy Statement and English legislation including the Inshore Fisheries and Conservation Authority (IFCA) byelaws and the South Marine Plan. The UK Government aims to have clean, healthy, safe, productive and biologically diverse oceans and seas.[i]

It is within this context that this research is situated, aiming to evaluate and value the socio-economic and environmental benefits of improving water quality (e.g. by reducing the amount of faecal contamination) in terms of Chichester Harbour shellfish beds using an ecosystem services framework.

This research aims to contribute to the promotion of the wider value of UK shellfish waters, using Chichester Harbour as a case study. By presenting a narrative of the wider value and ecosystem services provided by shellfish beds, and modelling the benefits of water quality improvements for the provisioning services of shellfish beds, it is possible to demonstrate that it is worth investing in better water quality and shellfish productivity to obtain wide societal benefits.

Due to the growing recognition of the ecosystem services provided by suspension-feeding bivalves (such as oysters, mussels and clams), estuarine restoration projects to support natural remediation (water clarity improvements, reduction of nutrient loading / eutrophication, filtration, buffering against algal blooms) may notably improve water quality and enhance resilience of the estuarine ecosystem. Due to their wide tolerance of turbidity, oysters may represent the most desirable type of bivalve for restoration of estuarine ecosystems.[ii]

Improving the evidence base regarding the value of shellfish is of crucial importance to marine and coastal regulators such as the Environment Agency (EA) and Inshore Fisheries and Conservation Authorities (IFCAs). The evidence and model provided in this report can be integrated as a supporting tool for cost-benefit analysis (CBA) when considering possible regulatory and policy interventions, as well as making the case for investment in natural systems.

[1] The Shellfish Waters Directive was repealed in 2013, and subsumed under the WFD.

Background - Chichester harbour

Chichester Harbour is a large estuary and natural harbour located to the south west of the city of Chichester, comprising around 44km^2 of navigable water, the vast majority of which is intertidal. It is one of four natural harbours in the region, together with Portsmouth Harbour, Langstone Harbour and Pagham Harbour. The harbour and surrounding land has been managed by Chichester Harbour Conservancy since 1971[iii] and the harbour area is one of the busiest in the country for recreational activity. It has a wide variety of marine habitats including extensive areas of estuarine flats, intertidal areas supporting eelgrass (*Zostera spp.*), saltmarshes as well as drift line vegetation[iv].

In recognition of the variety and quality of habitats and species found in the harbour, Chichester Harbour has a number of noteworthy national and international conservation designations, listed below.

Conservation significance and status

- Recognising its distinctive landscape qualities, Chichester Harbour was designated as an Area of Outstanding Natural Beauty (AONB) in 1964 under the National Parks and Access to the Countryside Act (1949).[v]
- EU Natura 2000: Chichester Harbour is part of the Solent Maritime Special Area of Conservation (SAC – for numerous Annex I habitats and Annex II species)[vi], and Chichester and Langstone Harbour Special Protected Area (SPA – designated for a wide range of bird species)[vii] making it a wetland of international importance. *SACs and SPAs, which are designated European Marine Sites, can collectively be called Natura 2000 sites*[viii]
- Chichester Harbour is designated as a Site of Special Scientific Interest (SSSI)[ix].
- The tidal waters of Chichester Harbour are designated as a Bass Nursery Area[x].
- Chichester and Langstone Harbours are also designated wetlands under RAMSAR[xi].

Shellfishery context

Throughout their European range, native oyster populations have experienced an acute decline from their late 19th and early 20th century's high point although some areas still support viable (although dramatically reduced) fisheries. The cause of the decline has been due to over-exploitation, habitat loss, environmental and anthropogenic pressure stemming from both pollution and disease.[xii] Oyster reefs in particular are one of the most degraded estuarine habitats globally (over 85% of natural oyster reef habitat have been lost globally in the past 130 years)[xiii].

Chichester Harbour has supported a population of native oysters (*Ostrea edulis*) since records began. The oyster population is thought to be part of the wider Solent stock and commercial fisheries, in particular oyster dredging, have historically formed the basis of the Harbour's economy. As the Chichester Oyster Partnership Initiative (CHOPI) management plan reveals, early records indicate over 7,000 bushels of oysters (valued at £1,500) were landed at Emsworth as early as 1788[xiv]. Furthermore, between 1890-1900 for example, Emsworth was home to the largest oyster dredging fleet in the UK and over 100,000 oysters a week were sent to the London market [xv] and the fishery employed approximately 400 local people in Emsworth alone[xvi].

The productivity of the Solent stock, including Chichester Harbour oyster fishery has been declining for a number of years. Recruitment failures from 2008 to 2010, increased competition from the slipper limpet (*Crepidula fornicata*)[2], increases in the predatory winkle (*Ocenebra erinacea*), habitat loss, skewed sex ratios as well as the significance of the oyster disease Bonamia ostreae[3] are acting in combination with changes in water quality, climate change and fishing effort have all played their part in the decline[xvii]. It is thought that the recruitment failure for three consecutive years is due to low fertilisation success, as a result of low oyster density on the shellfish beds, which is a key requirement for successful reproduction.[xviii] Fishing industry stakeholders interviewed attribute a significant cause in the decline to the removal of fishing effort, which removes silt, competition and thereby improves conditions for oyster spat settlement, but academic studies have drawn the conclusion that harrowing does not improve spat settlement[xix].

In terms of attribution, it is impossible to blame the decline of the native oyster fishery in Chichester Harbour on a single factor. Continued fishing activity of stocks under pressure, the resulting and associated habitat loss, and disease can have the effect of reducing the density of oysters on the beds, which in turn can affect the reproductive processes of the population resulting in recruitment failure. The effects of poor water quality and disease combined with these other factors including siltation have all compounded that decline[xx]. Whatever the under lying cause(s), lack of recruitment to the population will be the eventual cause of stock collapse.

Alongside the socio-economic impacts of the declining fishery, the reduction of the oyster stock has also meant a reduction in the water filtration capacity and biogenic habitat (which

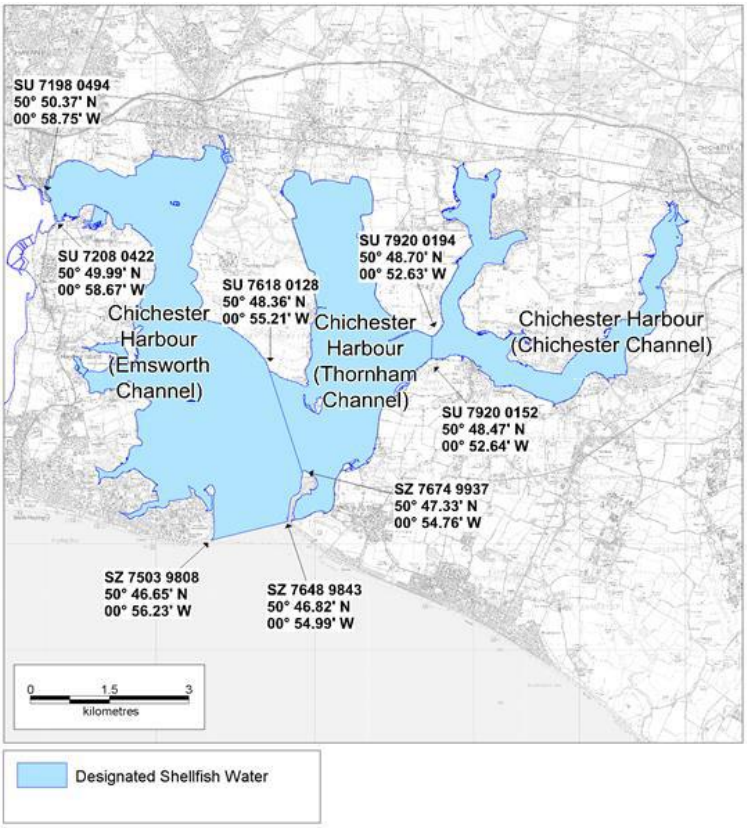
---

[2] Slipper limpets have no natural predators in Europe and have colonised many traditional native oyster grounds in very high densities including the Solent and Chichester Harbour

[3] *Bonamia ostreae* was introduced in re-laid oysters imported from California in the early 1980's and has since been responsible for high levels of mortality in wild and cultivated populations across Europe. It was detected in the UK in 1982 and quickly spread via transfers in the oyster cultivation industry to disease free areas, first being reported in the Solent and Chichester Harbour in 1986. Infection within a population increases with density as the pathogen is transmitted directly between individuals. Tests carried on native oysters in Chichester Harbour indicate that *B. ostreae* is present.

can act as a nursery area) provided, alongside the array of other services which functional shellfish / oyster beds provide (described in section 5).

Figure 1: The five main channels which make up Chichester Harbour [Fishbourne, Chichester, Bosham, Thorney and Emsworth Channels[xxi] and their relationship to the designated shellfish waters (below).



Source: Environment Agency - Shellfish Water Action Plan (2015) Chichester Harbour

Chichester Harbour water quality determinants

The harbour comprises five main channels (shown in figure 1) with three main surface freshwater inputs; the River Ems, Bosham stream and the River Lavant. In combination with these, groundwater and storm water discharges, the water within the harbour is also tidally flushed guaranteeing considerable water exchange.

There are however also pollutant inputs into the harbour system, which include sewage discharges and agricultural / industrial and natural runoff from the surrounding area. There are also three Waste Water Treatment Works (WWTW) located at: Apuldram, Bosham and Thornham, which discharge treated effluent. The considerable level of human activity within the site (e.g. the estimated 12,000 regular boat users) also impacts on pollution and water quality.

Regarding shellfish, the main water quality determinant for shellfish waters is microbial (*E. coli*) and the three designated shellfish waters shown in Figure 1 above have differing source apportionment, indicating the different sources of bacteriological pollution and their respective significance. Where shellfish waters do not meet the necessary bacteriological quality an assessment for the reasons (and respective apportionment) is undertaken. These are presented for the three designated shellfish waters within the harbour in Table 1 below.

Table 1: Comparison of point and diffuse source apportionment for the three designated shellfish waters in Chichester Harbour.

Designated shellfish water:	**Point source**		**Diffuse source**			
	Water Company	Other point source	Urban	Agriculture	Undefined	Animal/Bird
Chichester Channel	M	M	M	L	M	M
Thornham Channel	H	L	L	M	M	M
Emsworth Channel	M	L	M	L	L	M
H - High contribution (>40%); M - Medium contribution (10% to 39%); L - Low contribution (<10%)						

Source: Environment Agency Shellfish Water Action Plan (2015)

Legislative drivers around water quality are described in more detail in section 3.

2. The fishery

Commercial species

Native oyster (*Ostea edulis*)

The European flat oyster (*Ostrea edulis*) is classified as highly endangered throughout the EU and considered extinct in large parts of the German North Sea. Furthermore, *Ostrea edulis* and *O. edulis* beds are in the OSPAR list of threatened and/or declining species and habitats in the North-East Atlantic[xxii]. In addition, *O. edulis* appear in the UK Biodiversity Action Plan (BAP) species and habitat lists with 'Marked decline in the UK' being identified and carry a priority habitat expansion and condition based action status[xxiii], although *Ostrea edulis* is not a protected feature within Chichester Harbour's designated site.

The reproductive biology of the *Ostrea edulis* means that reproductive success is closely related to density. Sexual maturity occurs ≥ 35mm, 1-2 years old, so an individual may potentially spawn in 3 seasons before entering the fishery at 70mm at an age estimated at 4-5 years. Oyster reproductive behaviour means that there will be increased fertilisation success with increased density i.e. proximity of females to males. The low density of oysters in Chichester Harbour and the Solent has raised concerns that fertilisation is being restricted and recruitment failure for two consecutive years supports this theory.

The Food Standards Agency (FSA) closed Thornham Channel for oyster fishing in 2017 due to high levels of *E. coli* detected in the oyster flesh reported in the monitored levels of microbial contamination.

Native oyster (O. edulis) Source: Sussex IFCA

Other bivalve shellfish species: American hard-shell clams (*Mercenaria mercenaria*), Manila clams and native clams or 'palourdes' (*Tapes* spp.) as well as cockles (*C. edule*) are thought to be widespread throughout Chichester Harbour. Although only native oysters (*Ostrea edulis*) are commercially exploited in Chichester Harbour at present, there is also interest in harvesting all the other bivalves found in the harbour. Clams and cockles occur in the intertidal areas mainly. Two discrete zones are recommended for the mixed clam and cockle hand-digging fishery, and the clam fishery has recently been opened under food hygiene regulations by the Food Standards Agency (FSA) and is conducted at small-scale (although landings data is not available).[xxiv] There is no closed season for clams and no minimum landing sizes that apply within the Sussex IFCA district. Clam dredging is not permitted anywhere within the harbour. Uncertainty exists about the clam and cockle stocks as well as the sustainable level of exploitation, although according to a 2011 study the resource is thought to be viable as a fishery.[xxv]

The Pacific oyster (*Crassostrea* /now *Magallana gigas*) was introduced into British waters in 1890 to support an industry suffering from the decline of the native oyster and now has an economic significance, represented by Gross Output and Gross Value Added (GVA) through all stages of the value chain, which using 2011/12 market prices has been estimated at £13 million (annual Gross Output, 5 times the first sale value), and over £10 million Gross Value Added (GVA)[xxvi].

Table 2: bivalve shellfish species found in Chichester Harbour

Species/culture (all from wild stock)	Native oysters (*Ostrea edulis*) Hard clams (*Mercenaria mercenaria*) Manila & native clams (*Tapes spp*.) Cockles (*C. edule*)
Seasonality of harvest	Closed season for native oysters (March-October inclusive).

Source: Cefas (2011)[xxvii]

The native oyster fishery

The Chichester Harbour native oyster fishery operates in daylight hours over the winter from the 1st November to April 30th according to the Sussex IFCA byelaw[xxviii]. Native oysters are commercially dredged from the seabed using a locally standardised dredge design and all stocks of oysters, clams and other bivalves are wild (Table 2). Any clam or cockle harvesting would be via hand digging[xxix]. There are a number of fisheries management regulations which aim to protect the sustainability of this fishery including; a closed season, a diurnal closure, technical fishing gear specifications, a minimum legal landing size (70mm), the settlement substrate for oyster larvae.[xxx] Typically, vessels operating within the fishery are under 10m in length with two dredges, deployed from the stern of the vessel.[xxxi]

Table 3: Number of vessels in the fishery pre byelaw. Source: Sussex IFCA

Numbers of oyster vessels	**2007/2008**	**2008/2009**	**2009/2010**	**2010/2011**	**Grand Total**
Chichester	28	31	8	6	73

The Sussex IFCA oyster emergency byelaw came into effect 2013/2014[xxxii] and a re-laying scheme (CHOPI) has been running for a number of years[4]. Chichester Channel is closed for fishing to act as a conservation area for brook stock for the native oyster repopulation efforts.

From November 2015 onwards, a permit scheme was introduced for all vessels wishing to take part in the fishery: the cost of the permit is £200 for the season.

Table 4: number of permit applications (2013-2017) Source: Sussex IFCA

Year	2013	2014	2015	2016	2017
Number of permits applied for	31	21	14	18	10

[4] **Restocking of native oysters through the CHOPI project:** Three small areas of seabed in Chichester Harbour were collaboratively identified and are under a voluntary agreement amongst local fishing industry stakeholders. Beginning in November 2010, the fishing industry supplied 2.3 tonnes of >70mm oysters from their commercial catch, which were re-laid in these voluntarily closed areas at a density of approximately $40m^2$.

An active oyster dredger in Chichester Harbour. Source: Sussex IFCA

Table 5: Oyster landings by volume and value from Chichester Harbour (2006-2017)

Year	Landings (Tonnes)	Value (£)	Comment
2006	30.06	39,044	Probable values for entire Solent
2007	71.68	80,489	Probable values for entire Solent
2008	48.22	46,131	Probable values for entire Solent
2009	28.28	50,522	Probable values for entire Solent
2010	30.39	61,026	Probable values for entire Solent
2011[5]	5.85	17,550	Probable values for entire Solent
2012	N/A	N/A	Uncertainty around this year's data

[5] Value inputted is an estimate based on £3 per kg price the fishers were being paid at the time. Data is not complete for 2011 due to season running from November until May, landings data was only recorded by SxIFCA when officers were on the ground to physically measure the bag weights.

2013	13.36	46,769	IFCA records deemed accurate for Chichester Harbour
2014	13.06	45,521	IFCA records deemed accurate for Chichester Harbour
2015	26.3[6] (8.8 tonnes Thorney channel; 17.5 tonnes Emsworth channel)	78,900	IFCA records deemed accurate for Chichester Harbour
2016	28.5 (3.9 tonnes Thorney; 24.6 tonnes Emsworth channel)	85,500	IFCA records deemed accurate for Chichester Harbour
2017	5.73 (Thorney Channel not fished)	14,850	IFCA records deemed accurate for Chichester Harbour

*Source: Sussex IFCA; 2006 to 2010 data gathered from the CHOPI management report (Woolmer, 2011); *no data was recorded for 2011/2012; 2013/2014 fishermen did not fish in Thorney Channel as it was deemed a 'class C' bed;*

Post-harvest Destination of the oyster landings:

The majority of the oysters are taken to Viviers UK in Portsmouth and exported, but a percentage is taken to Billingsgate Market in London (the exact breakdown is uncertain, but stakeholder interviews with Viviers indicated when the fishery was running at a higher productivity 80% of native oysters were exported and 20% were for domestic consumption, mainly sold through the London market). CHOPI members and fishermen previously revealed that there majority of native oysters from Chichester Harbour are sold to small number of local shellfish buyers who operate depuration systems, such as Viviers, who have a number of local and national restaurant clients. They also stated that the rise in demand from France and Spain (following local mortality events) meant some fishermen began selling direct to overseas buyers.[xxxiii] A recent Cefas paper states 'catches are generally exported to France for on-growing', which combined two issues: one is the 'growing on' of thinner oysters from the Solent before the Christmas market on the continent, and the other is the majority export destination of ready-to-eat depurated oysters[xxxiv]

Additional employment information provided by Sussex IFCA and local fisheries stakeholders:

[6] £3 per kg is estimate of cost at this time. IFCA officers state that value starts off around £3.50 at the beginning of the season and ends up around £2.50

- The majority of fishermen conduct the repair and maintenance of their dredges and vessels themselves so it has not been possible to directly quantify and value.
- The major depuration plant found locally is Viviers UK in Portsmouth (and estimates of 5p depuration cost per oyster were derived from the Pacific Oyster aquaculture findings)
- Ice plants are not used. The oysters kept bagged and damp before being sent to the markets.
- Engineers – unable to quantify.

3. Water quality issues

The Water Framework Directive (WFD)

The WFD aims for good water quality throughout the EU and covers groundwater, surface water (rivers, canals, lakes, reservoirs, estuaries and other brackish waters, coastal waters) out to one nautical mile from shore as well as wetlands. The groundwater directive was set up within the WFD, and the Urban Wastewater Treatment Directive and Nitrates Directive also fall within it. The Shellfish Waters Directive was repealed in 2013 and protection for shellfish waters is now provided by Art 4.9 of the WFD. The WFD also contains the requirement to assess designated shellfish waters as previously covered by the Shellfish Directive.[xxxv] The WFD establishes a common approach to managing water within the EU. The environmental objectives of the WFD will be delivered by collaborating organisations through River Basin Management Plans (RBMPs)[xxxvi].

Emsworth channel, Thorney channel and Chichester channel are listed as areas designated as shellfish protected areas in England.[xxxvii]

To comply with the WFD Guideline standard for Shellfish Water Protected Areas (guideline E.coli standard), 75% of samples need to achieve ≤ 300fcs/100ml shellfish flesh. If only 3 samples are available then 100% need to meet that standard to comply. If there's less than 3 samples then the SFW is considered unmonitored (U).

Local Authorities have monitored faecal indicator microorganism levels (*E. coli*) in Chichester Harbour since 2007. In 2009 the Chichester Channel designated Shellfish Water (SW) failed the Guideline (G) faecal coliform shellfish flesh standard (Environment Agency, 2009). Thornham Channel SW only achieved the G standard for faecal coliforms in shellfish flesh in 2005 and 2008, although faecal coliform levels observed in the water column have been consistently low. Emsworth Channel SW achieved the G standard for faecal coliforms in shellfish flesh in 2004 and 2005. The level of treatment at Bosham STW and Chichester STW was upgraded to ultraviolet disinfection in March 2008 as part of a water company investment programme to improve water quality in the catchment and endeavour to ensure compliance with Shellfish Waters guideline standards (Environment Agency, 2009)."[xxxviii]

Shellfish and human consumption

If the harvested shellfish is to be fit for human consumption, this requires water quality that is low in pathogens. Runoff and human sewage therefore pose a threat to human health if faecal coliform bacteria are ingested. Due to their high filtration capacity shellfish concentrate pollutants in their tissue and can be harmful to people by causing diseases such as hepatitis. Furthermore, algal toxins which shellfish also concentrate in their tissue can be a serious, even fatal, risk for human consumers. [xxxix] Therefore, any shellfish restoration, enhancement and management interventions should take into account the potential costs of shellfish consumption-related illnesses, for example. [xl]

Filter feeding promotes the retention and accumulation of microorganisms and therefore the quality of the waters from which they are taken is of fundamental importance to whether or not they are fit for human consumption. If consumed raw or lightly cooked, bivalves including native oysters (*Ostrea edulis*), clams (*Tapes spp, Mercenaria Mercenaria*) and cockles (*C. edule*) that are contaminated with pathogenic microorganisms could cause infectious human diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A and Salmonellosis). Chichester Harbour was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas.[xli] Shellfish harvesting areas are classified according to the extent of *E. coli* contamination and treatment processes are stipulated according to the classification status of the area. There are a very low percentage (<1.5% in 2010) of Class A shellfish beds in England and Wales, which would be the requirement for UK supermarkets to purchase them [xlii].

The Cefas classification categories[xliii] are presented in table 6 below.

Table 6: Cefas shellfish classification classes[xliv]

CLASS	E. coli contamination levels	Requirements for permission for human consumption
Class A	(≤ 230 E. coli/100g)	Molluscs can be harvested for direct human consumption
Class B	(90% of samples must be ≤ 4600 E. coli/100g; all samples must be less than 46000 E. coli/100g.)	Molluscs can be sold for human consumption: ▪ after purification in an approved plant, or ▪ after re-laying in an approved Class A re-laying area, or ▪ after an EC-approved heat treatment process.

Class C	(≤ 46000 E. coli/100g)	Molluscs can be sold for human consumption only after re-laying for at least two months in an approved re-laying area followed, where necessary, by treatment in a purification centre, or after an EC-approved heat treatment process.

Classification of shellfish beds in Chichester Harbour

Table 7: Current status (2017) of designated shellfish waters in Chichester Harbour[7]

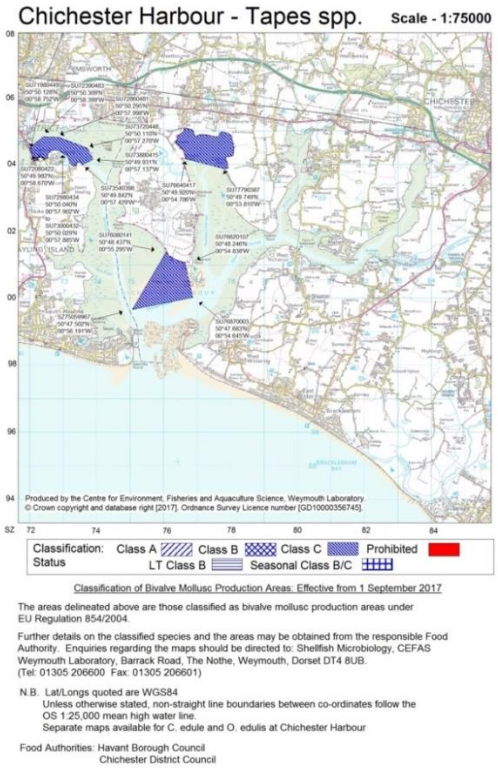
Production Area	**Classification zone**	**Species**	**Class**
	Cobnor	*O. edulis*	B - LT
	Dell Quay	*O. edulis*	B
	Emsworth Channel	*O. edulis*	B - LT
	Prinstead	*C. edule*	C
		Tapes spp.	C
	Northney	*C. edule*	C
		Tapes spp.	C
	Pilsey Sands	*Tapes spp. and C. edule*	Preliminary C

Figures 2 A-C: Cefas classification zone maps for Chichester Harbour shellfish harvesting areas.

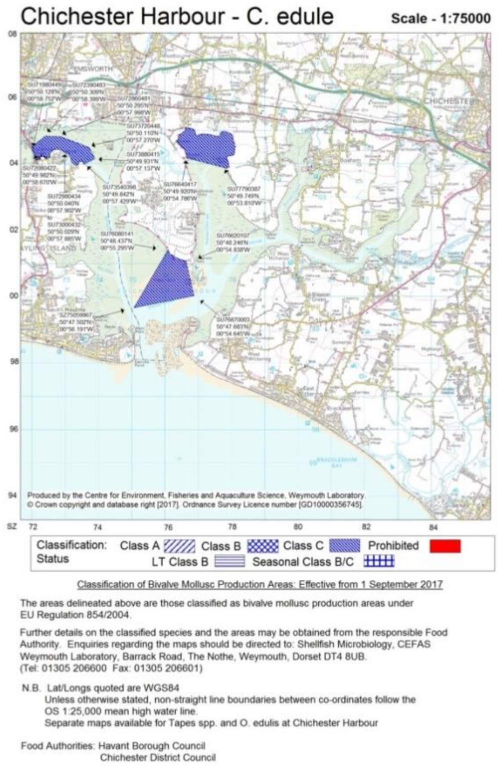
- *Figures 2A (page 17), 2A*[xlv] *(native / manila clam - Tapes spp)*
- *Figure 2B (page 18), 2B*[xlvi] *(Cockles – Cerastoderma edule)*

[7] The performance of each SFW against the FSA classifications (A, B, C) can be found here: https://www.food.gov.uk/enforcement/monitoring/shellfish/shellharvestareas

2A

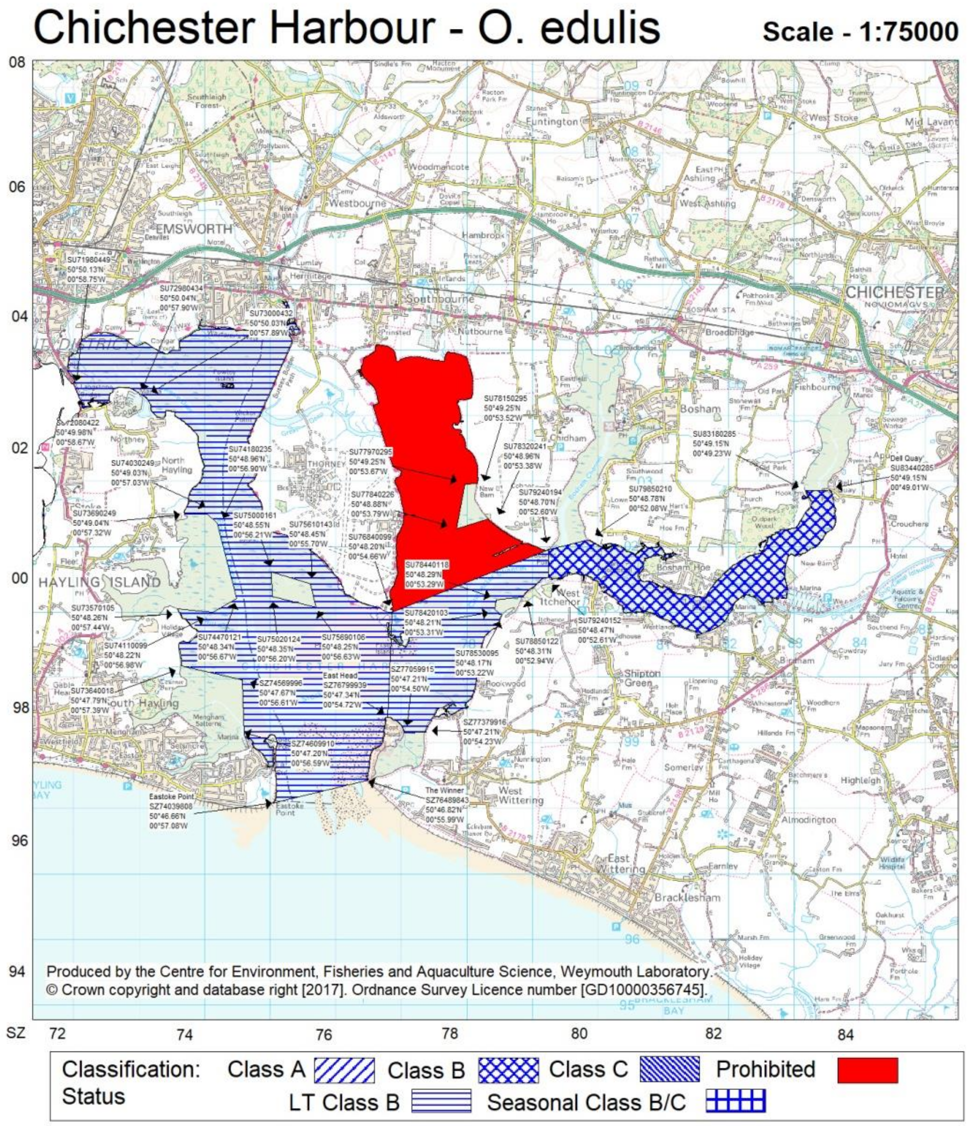


2B



The clam and cockle shellfish bed classification is presented here although there is currently very llittle active commercial fishery for them. This may change in the future and the water quality testing and classification would need to be considered alongside fisheries management measures.

- *Figure 2C (page 13): 2C*[xlvii] *(Ostrea edulis)*



Classification of Bivalve Mollusc Production Areas: Effective from 3 October 2017

The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

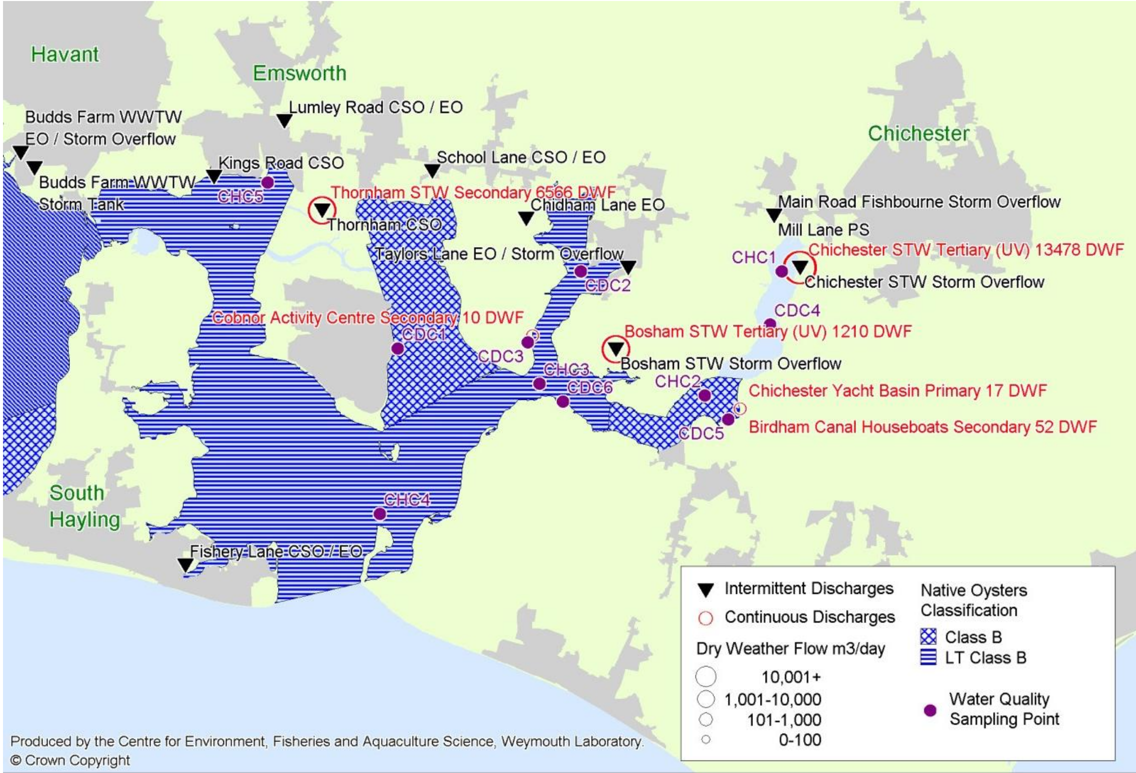
Further details on the classified species and the areas may be obtained from the responsible Food Authority. Enquiries regarding the maps should be directed to: Shellfish Microbiology, CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB. (Tel: 01305 206600 Fax: 01305 206601)

N.B. Lat/Longs quoted are WGS84
Unless otherwise stated, non-straight line boundaries between co-ordinates follow the OS 1:25,000 mean high water line.
Separate maps available for Tapes spp. and C. edule at Chichester Harbour

Food Authorities: Havant Borough Council
Chichester District Council

The native oyster fishery shellfish waters classification is shown above. Emsworth Channel is classed as B; Thorney Channel is currently prohibited for fishing for human consumption, and; Chichester Channel is classed as B (however there are no landings from Chichester Channel at present as it is closed as a fisheries management measure to allow the brood stock to repopulate the harbour).

Figure 3: locations of significant continuous and intermittent sewage treatment works (STWs) discharging directly to Chichester Harbour and Local Authority sampling points[xlviii]



There are three standard regimes interacting, which have different drivers and metrics, but all impact on the shellfish fishery and human consumption. These include the WFD water quality assessments[xlix] (EU), the Food Standards Agency[l] shellfish waters rating (UK), and the Sussex IFCA fisheries management regimes (local).

Table 8: Comparative ratings for December 2017 from WFD, FSA and Sussex IFCA

Water quality Assessment (WFD)
Emsworth – Failing (<300 e.*coli*/100g of flesh in 75 percentile of samples.)
Thorney - Failing (<300 e.*coli*/100g of flesh in 75 percentile of samples.)
Chichester - Failing (<300 e.*coli*/100g of flesh in 75 percentile of samples.)
FSA (food hygiene) Shellfish waters
Emsworth – B
Thorney – Prohibited / closed
Chichester - B
Sussex IFCA fisheries management
Emsworth – open - under oyster permit byelaw – onward sale permitted
Thorney – open – but due to FSA standard cannot be sold into human food chain
Chichester Channel – closed - not open to fishing due to IFCA management (native oyster brood stock for harbour)

Water treatment options

Sewage treatment (a.k.a. wastewater treatment) involves removing contaminants from wastewater. This can be physical, chemical, or biological so as to remove contaminants. By-product of sewage treatment include slurry, which has to undergo further treatment. Sewer systems carry household or industrial effluent to the sewage treatment plant. If the sewer system is a combined sewer, this combines urban runoff or storm-water.

Three stages of sewage treatment:

- Primary treatment - holding the sewage for settlement and separation.
- Secondary treatment - removal of dissolved and suspended biological matter.
- Tertiary treatment - further treatment before the waste water can be released into sensitive or fragile ecosystems. This can include chemical treatment or UV (ultraviolet) treatment.

UV disinfection - UV has a benefit in that there is no chemical residual that is released into the receiving watercourse that could remain if chemical disinfectants are used. UV light can be used instead of chemicals such as chlorine or iodine. UV treatment means the treated water has no adverse effect on other organisms. UV radiation damages bacteria, viruses, and pathogens halting their reproduction. UV light is becoming the most common means of disinfection in the UK.

Combined sewer overflows - A combined sewer (CS) is designed to also collect surface runoff and can cause pollution problems during combined sewer overflows (CSO) when heavy rain overloads the sewer. The resulting pollution discharges can contain human and industrial waste, and tehrefore can cause restrictions on shellfish consumption and contamination of drinking water sources as well as closures to public beaches. Ways of reducing the impact of these discharges, such as building more storage (in the sewers or at the treatment works) or trying to reduce the flows in the sewerage system by stopping clean rainwater from going into the sewers in the first place by diverting it into watercourses.

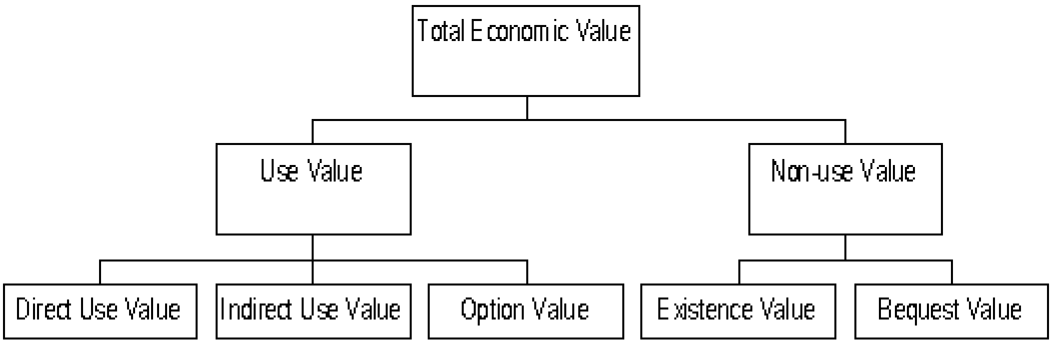
Bosham STW, Chichester STW and Thornham STW all have a high rate type of secondary treatment that is also designed to remove nitrates/ nitrites from the treated flows going into Chichester Harbour. Bosham STW and Chichester STW also have UV disinfection of these flows in addition to the nitrate/ nitrite removal.

Disinfecting CSO discharges is not common practice in the UK, but at Chichester STW Southern Water carry out disinfection by UV treatment of the storm tank flows. This is unusual and is done this for shellfish quality reasons.

4. Valuation

Valuation generally focuses on "Use values". In an economic sense, these refer to ecosystem services, which are instrumental to our economies and societies, e.g. those that provide us with clean water for shellfish and productive soils for agriculture. Nonetheless, nature cannot only be conceived as instrumental to human economies, as nature has equally less tangible attributes such as aesthetic services or intrinsic values, which are not necessarily linked to economic production or consumption and yet influence our well-being. These are often called "non-use values". The sum of "use values" and "non-use values" makes the total economic value (TEV) of an ecosystem, species (flora or fauna) or resource. Figure 4 illustrates the different components of use and non-use values. Further descriptions of the different types of use values described in the figure (direct, indirect and option values), as well as the non-use values (existence and bequest values) are described below.

Figure 4: Total Economic Value (TEV)[li]



Use values

- **Direct use values:** material benefits provided by an ecosystem which are directly linked to the economic system and for which market values may exist - e.g. recreational sites, timber extraction, landscape amenity, lobster stocks on a rocky coastline.

- **Indirect use values:** material benefits provided by an ecosystem which are indirectly linked to the economic system and for which market values are more difficult (yet possible) to derive - e.g. ecosystem services – air quality clarity, carbon sequestration, waste dispersal, insect pollination, biodiversity.

- **Option value:** the value placed on preserving a resource for future material use, which can be either direct or indirect. For example maintaining a river catchment for future irrigation needs (agriculture) or preserving a fish stock for future use.

Non-use values

- **Existence or intrinsic values:** value from knowing an environmental good exists and is preserved, although it might never be used or seen, e.g. Europeans paying to save the giant Panda from extinction even without having seen it or without deriving any direct benefit from the species' survival.

- **Bequest value:** value derived from knowing that a resource is maintained for future generations[lii]

5. Ecosystem Services (ES)

The Millennium Ecosystem Assessment (MEA, 2001-2005)[liii]

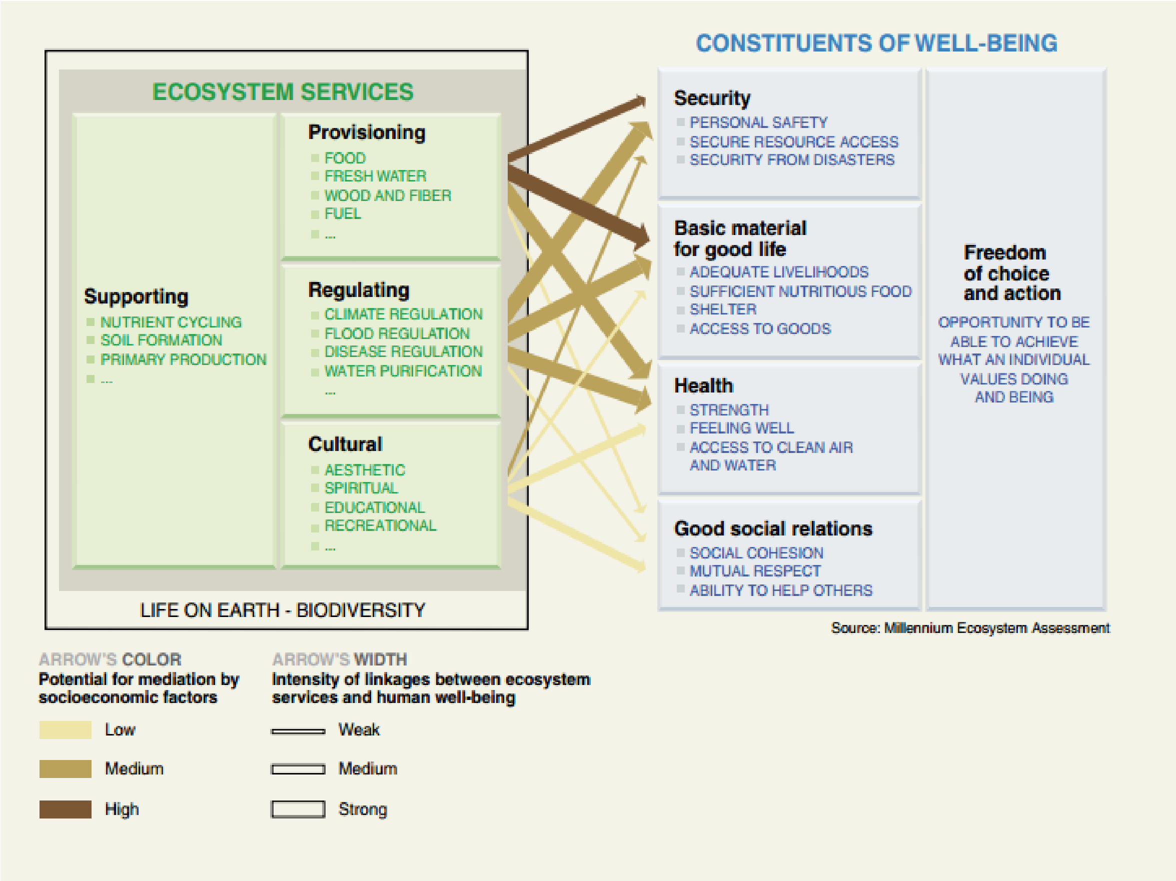
Despite major advances in the ecological sciences in the 1980s and 1990s, the knowledge and evidence produced were not effectively incorporated into policy discussions concerning global ecosystems. As a result, a panel of leading international scientists prepared a draft assessment; "Protecting our Planet, Securing our Future"[liv] (1998), which sought to address these shortcomings. This lead to the Millennium Ecosystem Assessment (MEA), called for by the United Nations Secretary-General Kofi Annan in 2000. The MEA (2001-2005) examined the consequences of changing ecosystems for human well-being and involved more than 1,300 experts worldwide. This provided the scientific basis for action to improve the conservation and the sustainable use of ecosystems, including the provision of clean water, food, timber, fuel, forest products, flood control, and other natural resources.[lv]

The main findings of the MEA were:

- Between 1950 and the new millennium, ecosystems were impacted and changed faster than ever before in human history, largely as a result of human activity. Further, 60% of a group of 24 ecosystem services examined were being degraded. Irreversible biodiversity loss has been one major consequence.
- Any benefits derived from exploiting nature came at the cost of significant degradation of ecosystem services, resulting in higher risks of irreversible change and increased poverty for those most starkly affected.
- The long term impacts for future generations were shown to be a severely depleted resource / natural capital base.
- 'Non-linear' changes including new diseases, water quality decline, fish stock collapse and coastal 'dead zones' were identified, alongside regional shifts in climate.
- Significant policy changes were desperately needed.
- Scientists linked ecosystem services to human well-being and development needs.

The MEA raised the question as to how changes in ecosystems impact on human well-being and how that information can be communicated to decision-makers. The need for it to be accounted for, alongside socio-economic information was also clear. Figure 5 illustrates the linkages between ES provision and human wellbeing, according to the MEA.

Figure 5: From Ecosystem Services to human wellbeing (MEA, 2005)[lvi]



Although the report produced no noticeable political shift in support for environmental protection, it sparked an interest in incorporating economic incentives into environmental policy. The report made it clear that both locally and nationally, only sparse information exists about the state of many ecosystem services. The economic value of non-marketed services was almost non-existent and the costs of the depletion of these services was not tracked in national economic accounts[lvii] (and still do not feature in Gross Domestic Product (GDP) although the Natural Capital Committee advice to Government on the 25 Year Environment Plan[lviii], which came out earlier this year, makes recommendations of using a natural capital accounting approach to the environment).

Following from the MEA, the ecosystem services concept was firmly on the policy agenda. Global environmental issues were framed in economic terms, to be assessed by Cost-Benefit Analysis (CBA). [lix]

The economic valuation of ecosystem services is the process of expressing a value for these services in monetary terms, to bring hidden costs and benefits to view – and more importantly bring these to the attention of decision makers and incorporated into decision-making frameworks such as CBA[lx]. All investment decisions and interventions involve trade-offs and valuation of ecosystem services is a step towards more inclusive decision making by making these trade-offs explicit and comparable in monetary terms. A full valuation of the wide array of services provided by shellfish would enable decision makers to better understand and compare trade-offs [lxi]

Ecosystem services provision by shellfish

Scientific publications demonstrate a growing recognition of the crucial role of shellfish in the maintenance as well as the stability of coastal ecosystems, with oysters in particular being described as "keystone species" and/ or "ecosystem engineers" for certain marine and estuarine environments.[lxii] Oyster reef ecosystem services (excluding harvest, i.e. the non-market ecosystem services) were valued between $5,500 and $99,000 per Hectare per annum and shown to cover their median restoration costs in 2-14 years[lxiii].

The ecological functions and processes, which shellfish provide, contribute to human well-being, and these ecosystem services are recognised by the MEA.[lxiv] Despite this recognition, the management of shellfish and shellfish habitats for objectives beyond commercial and recreational fisheries is not yet widespread.[lxv] A major concern in this regard is the common / public good nature of fisheries resources, including shellfish, which risk a *tragedy of the commons* as many of the non-market benefits (un-priced) accrue to society as a positive externality and society-at-large remains unaware of their contribution to wellbeing and healthy ecosystems and therefore cannot value them. [lxvi] The only directly priced ecosystem service provision by shellfish is that once they are harvested and sold for human consumption or other purposes, but this by no means comprises a fair quantification of their total value to society and the ecosystem as a whole. Furthermore, for that value as a food source to be captured, the shellfish must be harvested, which in turn reduces the ongoing ecosystem service provisions beyond food. They no longer form a habitat, filter water, store carbon or reduce shoreline erosion once removed[lxvii].

Bivalve shellfish ecosystem services and natural resource management

Suspension feeding bivalves, such as oysters, fulfil many roles and functions within estuarine and coastal ecosystems and quantifying ecosystem services provided by particular species and habitats have important applications for natural resource management.

Failing to consider the true costs resulting from the degradation of these ecosystems can result in a reduction of those beneficial flows which human derive from nature. Using an ecosystem services framework, to both appreciate and quantify (where possible) the contribution made by natural ecosystems can enable regulation and investment to protect and conserve those flows of benefits, while also allowing these interventions to be targeted.

An example of this targeted approach may focus on those species, which have experienced a stark decline as a result of human activity, but could be restored through particular strategies and interventions. Taking an ecosystem service approach when considering the function of bivalves such as oysters has demonstrated that they globally provide valuable ecosystem services, thus suggesting their degradation be minimised or avoided.

Although oysters have been the main shellfish species studied in this regard, other suspension feeing bivalves (such as clams, mussels, scallops, cockles etc) provide similar benefits, mainly as a result of their filter feeding behaviour, which removes particles such as phytoplankton, organic and inorganic matter from the water column. This filtering has a clarifying effect on the water column, reducing turbidity and the settlement of some other marine invertebrates as well as transfers of matter to the seabed / estuary. The beneficial impacts of these activities are most pronounced when bivalves are in dense aggregations or reefs due to their cumulative impact. In providing these reefs, shellfish also provide a diverse structural habitat for other species and in the case of muddy estuarine environments, they provide a hard substrate for settlement, which would otherwise be absent. [lxviii]

A case study from the USA[lxix] showed the avoided-cost concerning Nitrogen removal to meet the Clean Water Act (1972) from 1 hectare of oyster reef habitat was estimated at $1385–$6716 per year. In addition, the replacement costs in terms of providing the rocky sea defences provided by oyster reefs was substantial, as were the benefits in terms of habitat enhancement and the resulting fish and crustacean productivity enhancement. A conservative estimate was that 10 m^2 of restored oyster reef habitat creates an additional 2.6 Kg of fish and large mobile crustacean production annually. Oyster reef restoration should therefore be a major consideration for estuarine management.[lxx]

Table 8: Ecosystem services provided by shellfish[lxxi]

Type of Ecosystem service	**Types of benefit flows**
Provisioning services: products / goods people obtain from a restored or maintained shellfish population	Commercial, recreational and subsistence fisheries
	Aquaculture / food production
	Fertilizer and building materials (lime)
	Materials (shells) for building aggregate of jewellery
Regulating services: benefits people obtain from the regulation of ecosystem processes.	Water quality maintenance / filtration
	Protection of coastlines from storm surges and waves
	Reduction of shoreline erosion
	Carbon sequestration

	Stabilization of submerged land by trapping sediments
Supporting services: while not providing direct services themselves, supporting services are necessary for the production of all other ecosystem services.	Cycling of nutrients
	Alteration of energy flows
	Nursery habitats for commercial fish species
Cultural services: nonmaterial benefits people obtain from ecosystems	Tourism and recreation (improving recreational fisheries and water quality for tourism..)
	Symbolic of coastal heritage

Description of key bivalve shellfish ecosystem services

Provisioning services

Food, jobs and revenues

Shellfish landed into Chichester harbour provides food and employment as well and downstream economic benefits to the local community. The full economic value of shellfish fisheries is more than simply landed value, as value can be added along the supply chain and the financial benefit accrue to the local fishing industry; fishermen, fish merchants, fish processors, fish exporters and the national/international food industry; food export and food outlets and also carries a tourism value.

Shellfish fisheries also contribute to public income through licensing fees, as in the case of Chichester with the Oyster permit scheme.

Of course if the fishery is overharvesting there are negative impacts due to the depletion of the resource over time, and globally as well as locally in Chichester Harbour, this has reduced the possible flow of benefits to society over the long term. [lxxii]

Shellfish shells also have a market value and in some instances can also be used for jewellery or building aggregate, as well as lime for agricultural purposes.

Regulating services

Water quality maintenance

Oysters and other bivalves help to buffer shallow estuarine and coastal waters against excessive, sometimes harmful, phytoplankton blooms, which are created by excess Nitrogen. By removing inorganic sediments from the water column they counteract the impact of sediment loading. Shellfish maintain water quality via direct removal of suspended material, and also by controlling the rate of nutrient exchange.

When oysters and other bivalves move nutrients and organic carbon and nitrogen to the bottom, this in turn provides nutrients for micro- and macroalgae and other plants, growing on the seabed as well as invertebrates that serve as prey species for other fish and shellfish in the food web. Oysters are thought to have the highest filtration rate of any bivalve (a single oyster filters 15-50 gallons a day) and also have the capacity to discharge pseudofeces (which means they can continue filtration under conditions of high turbidity). Furthermore, the biodeposits created by mussels and oysters induce denitrification, which helps counter-act eutrophication by releasing nitrogen into the atmosphere as inert nitrogen gas. [lxxiii]

Carbon sequestration

The external shells of bivalves are constructed of calcium carbonate, which they absorb naturally from the ocean water and thereby become a physical store of carbon for long periods of time (until harvest or the point they are dissolved through ocean processes or dissolved by sponges – which also acts as an alkaline buffer against ocean acidification), especially if they are buried in the substrate where they can prevent the carbon from entering the atmosphere.[lxxiv]

Protection of Shorelines and Sediment Stabilization

The shellfish function of reducing nearshore erosion, mainly by reducing wave action and dampening their impact. This is particularly important in protecting salt marsh as well as in decreasing the rate of loss of aquatic vegetation including seagrasses is a key benefit of in-tact shellfish reef systems and coastal shellfish beds. Stabilising aquatic vegetation through the effect of shellfish beds and the associated sediment trapping also increases nutrients available to seagrasses through deposition.

Supporting services

Improved habitat for fish nursery areas

A key ecosystem service delivered by shellfish, particularly when in high densities and regardless of whether its living organisms or dead shells, is the creation of habitats for commercially or recreationally important fish and shellfish species.[lxxv]

Improving water clarity and quality also improves the submerged vegetation or seagrass growth as sunlight can penetrate deeper, providing 'nursery habitat', where juvenile fish and invertebrates are protected from predators. Chlorophyll concentration and water turbidity are key indicators of water quality and clearer water allows deeper light penetration, resulting in better growth of submerged aquatic vegetation (itself a key nursery habitat for many commercially important fish, crustaceans, and molluscs).[lxxvi] The knock-on benefit of more seagrasses for example in increased sediment trapping and thus further adding to water quality.

Biodiversity and available surface area in sediment dominated habitats are improved by some shellfish which provide hard substrate and "biogenic"[lxxvii] reefs, which provide high quality nursery habitat for a wide diversity of species —worms, snails, sea squirts, sponges, crabs, and fish – enabling them to overcome survival bottlenecks in the early life history this boosting recruitment. Overall the ecology is greatly enhanced in shellfish habitat compared to surrounding areas of the seabed.[lxxviii]

Nutrient cycling

Shellfish have a major impact on nutrient cycling in estuarine systems, through their filter feeding, which contributes to maintaining the stability of the ecosystem. Nutrient cycling includes moving carbon, nitrogen and other essential materials which keeps the system in balance and functioning well.

Flow alternation and sediment trapping

Having hard substrate in soft sediment environments disrupts the hydrodynamic flow and creates channels as well as depositional zones, which influence recruitment, growth, and other processes of shellfish as well as other organisms, through both flow rate impacts and habitat creation and stabilisation.[lxxix]

Cultural services

Tourism, heritage and community benefits

Oyster reefs provide storm protection and have been described as a living breakwater which is more natural and also aesthetically appealing than man-made structures fulfilling the equivalent role.

Chichester Harbour is internationally renowned for producing oysters and historically the activity of oyster fishing has played an important role in shaping the natural landscape and commercial development of the harbour. This fishery is of high heritage value and is prominently featured in the local museums and provides a sense of identity amongst the local population[lxxx].

Community-based shellfish restoration efforts[lxxxi] have also been noted in literature to provide benefits around community cohesion and helping connecting people with local foods and traditions. The Chichester Harbour Oyster Partnership Initiative[8] (CHOPI) was started in 2010 through a partnership consisting of local oystermen, Sussex Inshore Fisheries & Conservation Authority, Chichester Harbour Conservancy and Natural England. The project looked to establish 2-3 small areas of seabed within the harbour where oysters can be moved and left to establish as "brood-stock" to replenish native oysters within the harbour.

---

8 Chichester Harbour Oyster Partnership Initiative (CHOPI)
The CHOPI group was formed in 2010 by a diverse group of stakeholders with the intention of addressing the issues affecting the Chichester Harbour native oyster (*Ostrea edulis*) fishery. The group, based on 'Community of Practice' principles, brings together statutory bodies, biologists and fishermen to develop innovative management approaches and work to a common goal.

It is hoped this will facilitate the re-colonisation of the area. Under a voluntary agreement, these areas are closed to fishing[lxxxii].

Shellfish fisheries and aquaculture can also indirectly bring local environmental problems to the attention of nearby communities and serve as a starting point for wider engagement into environmental issues.

6. Methodology

A model was developed to assess the potential Gross Value Added (GVA) from oyster harvesting under different water quality scenarios in the Chichester Harbour area, both in economic and employment terms. This model calculates the direct and indirect GVA generated for each given scenario. Typically, a cost-benefit analysis (CBA) model will subtract the costs of implementation (which in this case involves the cost of water treatment) from total benefits accrued, which provides the net GVA of the policy intervention. However, this project's scope does not factor in the cost of water treatment. As such, the GVAs calculated for each scenario represents total GVAs and not Net GVAs.

Direct GVA is defined as the direct economic turnover generated from oyster harvesting. Here, Direct GVA relates to the turnover received by oyster fishers when selling their harvest upon landing. Indirect GVA represents the measure of economic impact of oyster harvesting on supply chain expenditure. For oyster harvesting, these include the economic benefits from oyster depuration processes, boat and machinery maintenance, oyster transportation, oyster wholesalers and local oyster retailers. Total GVA equals the sum of both direct and indirect GVA. How each GVA was calculated, the data used and the assumptions behind them are now discussed.

Calculating Direct GVA

Table 9 presents the data used to calculate Direct GVA and their sources.

Table 9: Direct GVA data variables and sources

Data variable	Value	Unit	Source and assumptions
Harvest size for each oyster bed:			Data taken from IFCA estimates (See Table 5). An annual average for 2015-2017 harvests is taken
Thorney	3967	kg	
Emsworth	15683	kg	
Chichester	0	kg	
Landing price (local)	3.5	£/kg	Expert opinion (IFCA)

Landing price (export)	3.5	£/kg	Expert opinion (IFCA)

Annual harvest sizes for each oyster bed were estimated by calculating the average harvest size for the time period 2015-17. This data was taken from IFCA estimates (see Table 5). The landing price per kilogram of native Oyster was obtained through email correspondence and phone interviews with IFCA experts. A landing price for exported oysters was assumed as similar to the landing price achieved locally. Using this data, Direct GVA is calculated by multiplying the total harvest size across the three oyster beds by the proportion of the harvest size sold either locally or exported.[9]

Direct GVA = (Total Harvest Size x Proportion of Harvest Size sold locally x Local Landing Price) + (Total Harvest Size x Proportion of Harvest Size exported x Exported Landing Price)

Calculating Indirect GVA

Five indirect beneficiaries from oyster harvesting are identified in the model: oyster depuration processers, boat and machinery maintenance workers, oyster wholesalers, local oyster retailers and oyster transporters. Using a combination of values and proxies, the economic benefits for each were calculated depending on each scenario. Aggregated together, they represent the Indirect GVA generated by the oyster sector. Table 10 presents the values/proxies and the calculations used to determine Indirect GVA.

Table 10: Indirect Economic GVA values and proxies

Indirect beneficiaries	Calculation	Relevant proxies / values			
		Description	Value	Unit	Source
Oyster depuration processers	Cost of processing per oyster x Number of oysters	Cost of depuration (purification) per oyster	0.05	£	Local fisherman estimate
		Average mass of oyster	0.088	kg	Expert opinion (IFCA)

[9] Note: in this instance local and exported landing price are the same, so there is no need to separate the two in the equation. This equation is required if they are different.

Boat and machinery maintenance workers	Annual maintenance costs for boats, machinery and tools per oyster dredger x Number of oyster dredgers	Annual maintenance costs for boats, machinery and tools per oyster dredger	920	£	(Chen et al., 2017) Annual maintenance costs. Converted from US$ into £ ($1=$0.75, Dec 2017)
		Number of oyster dredgers	6	#	Expert opinion
Oyster wholesalers	% of oysters to local market x total harvest size x price paid by wholesalers - % of oysters to local market x total harvest x price paid to fishermen	Wholesale price per oyster	1	£	Estimated value for UK wholesalers price, see Viviers (UK) Ltd: http://www.fishmarketportsmouth.co.uk/shellfish-fresh-lobster
Local oyster retailers	% of oysters to local market x total harvest size x price paid by end users - % of oysters to local market x total harvest x price paid to fishermen	Retail price per oyster	4	£	Estimated value for retailers price:, see https://simplyoysters.com/maldon-native-oysters
Oyster transporters	% of harvest exported x Harvest size x Transportation costs by lorry freight (to France) X % of oysters to export market	Transportation costs by lorry freight (to France)	0.19	£/kg	Expert opinion Converted into £ (£1= Euro0.88, Dec 2017)

Scenario development

During December 2017, five different scenarios were developed in consultation with Sussex IFCA and the Environment Agency. For each scenario, four key inputs were impacted: size of harvest (i.e. that harvest which is fit for human consumption); water quality (e.g. grade A, B, C,); depuration and relaying processes; and the proportion of harvest sold locally or exported. The five scenarios are as follows:

- **Scenario 1:** Do nothing
- **Scenario 2:** Improvement of all beds to class C
- **Scenario 3:** Improvement of all beds to class B
- **Scenario 4:** Improvement of all beds to class A

- **Scenario 5:** Graded improvements with each bed increasing by one classification

The following section presents the results for each scenario.

7. Results

Scenario 1: Do nothing: (deterioration of beds, total prohibition of all beds within the harbour)

In this scenario, no water treatment occurs, there is a deterioration of beds and subsequently oyster fishing is totally prohibited. As such, no economic benefit is generated from its use.

SCENARIO 1 GVA RESULTS

Direct GVA: £0

Indirect GVA: £0

Total GVA: £0

Scenario 2: Improvement of all beds to class C

In this scenario, all three beds are classified as Class C water level. This has a notable impact on harvest size, as Thorney is now able to be harvested. The Chichester bed harvest size remains at zero as oyster harvesting is still prohibited as it remains a site for oyster brood stock to re-populate the harbour. Harvest sizes are expected to be similar to the averages found in recent years (2015-17). Depuration is required for all oyster beds. In addition, both beds require relaying, as oysters in Grade C water require relaying, unlike those in Grade B or A. The cost of relaying is estimated as the cost of Sussex IFCA chartering a fishing vessel per day (approx. £300), with relaying taking approximately two days for each bed (Thorney and Emsworth). The proportion of harvest sold locally is given as 20%, with the remaining 80% being exported.

Table 11: Description of impact for Scenario 2

Variables	Description of impact
Size of harvest	Harvest increased as Thorney channel re-opened due to improvement in water quality to Class C. Increase in harvest, extra bed would provide more ground to fish.
Water quality	100% Class C (≤ 46000 E. coli/100g)
Depuration and relaying	Depuration required Relaying required for two oyster beds
Proportion of harvest sold local or exported	20% local 80% export

Table 12: Direct and Indirect GVA for Scenario 2

Impact scope	Impact	Economic value
Direct GVA	Oyster fishers' earnings	£68,775
	Direct GVA	**£68,775**
Indirect GVA	Depuration processors	£12,365
	Boat, equipment, processing maintenance	£5,520
	Wholesalers profit (local, domestic and foreign export)	£30,904
	Local retailers profit	£133,977
	Transport of shellfish to end user	£3,043
	Indirect GVA	**£185,810**
	Total GVA	**£254,585**

Scenario 3: Improvement of all beds to class B

In this scenario, all three beds are classified as Class B water level. Like Scenario 2, this has a notable impact on harvest size, as Thorney is now able to be harvested. Chichester Harbour still remains closed to oyster fishing. With an improvement of water quality, a possible uplift of 10% to the fishery harvest size is estimated. Depuration costs are required but there is no need to relay oyster bed given improved water quality. As water quality improves, there is reputational uplift for local oysters leading to a greater proportion of harvest sold locally, 30%, with the remaining 70% being exported.

Table 13: Description of impact for Scenario 3

Variables	Description of impact
Size of harvest	Harvest increased as Thorney channel re-opened. Possible uplift to fishery overall through better water quality e.g. all beds 10% more productive. Extra bed open would provide more ground to fish. Shellfish would have increased survivability, and a potentially higher recruitment rate.
Water quality	100% Class B (90% of samples must be ≤ 4600 E. coli/100g; all samples must be less than 46000 E. coli/100g.)
Depuration and relaying	Depuration required
Proportion of harvest sold local or exported	30% local 70% export

Table 14: Direct and Indirect GVA for Scenario 3

Impact scope	Impact	Economic value
Direct GVA	Oyster fishers' earnings	£75,653
	Direct GVA	**£75,653**
Indirect GVA	Depuration processors	£14,169
	Boat, equipment, processing maintenance	£5,520
	Wholesalers profit (local, domestic and foreign export)	£50,992
	Local retailers profit	£221,063
	Transport of shellfish to end user	£2,929
	Indirect GVA	**£294,673**
	Total GVA	**£370,325**

Scenario 4: Improvement of all beds to class A

In this scenario, all three beds are classified as Class A water quality. Like Scenarios 2 and 3, this has a notable impact on harvest size, as Thorney is now able to be harvested. Chichester bed still remains closed to oyster fishing. Water quality improvement to Class A is estimated to increase harvest size by 20%. Depuration costs are required but there is no need to relay oyster bed given improved water quality. As water quality improves to Class A, there is an even greater reputational uplift for local oysters than Class B, leading to a greater proportion of harvest sold locally, 40%, with the remaining 60% being exported. With an increase in landings and quality, expert view was that the result could be the initiation of a local supply chain and depuration system with added value through direct oyster sales to the end consumer.

Table 15: Description of impact for Scenario 4

Variables	Description of impact
Size of harvest	Harvest increased as Thorney channel re-opened. Possible uplift to fishery overall through better water quality e.g. all beds 20% more productive. Extra bed open would provide more ground to fish. Shellfish would have increased survivability, and a potentially higher recruitment rate.
Water quality	100% Class A (≤ 230 E. coli/100g)
Depuration and relaying	Depuration required
Proportion of harvest sold local or exported	40% local 60% export

Table 16: Direct and Indirect GVA for Scenario 4

Impact scope	Impact	Economic value
Direct GVA	Oyster fishers' earnings	£82,530
	Direct GVA	**£82,530**
Indirect GVA	Depuration processors	£16,797
	Boat, equipment, processing maintenance	£5,520
	Wholesalers profit (local, domestic and foreign export)	£185,425
	Local retailers profit	£321,545
	Transport of shellfish to end user	£2,191
	Indirect GVA	**£531,479**
	Total GVA	**£614,009**

Scenario 5: Graded improvements with each bed increasing by one classification

In this scenario, each bed sees a graded improvement, moving up one grade in water quality. Thorney bed moves up to Class C, which in turn opens it up for harvesting. This has a notable impact on harvest size. Chichester bed moves from Class B to Class A. However, this has no significant effect, as it still remains closed to oyster fishing. Similarly, the Emsworth bed moves up from Class B to Class A, leading to an increase of its harvest size by 20%. Depuration costs is required for all beds, but there is only need to relay the Thorney oyster bed. In this graded improvement scenario, the proportion of harvest sold locally is estimated as 50%, with the remaining 50% being exported. With an increase in landings and quality, expert view was that the result could be the initiation of a local supply chain and depuration system with added value through direct oyster sales to the end consumer.

Table 17: Description of impact for Scenario 5

Variables	Description of impact
Size of harvest	Harvest increased as Thorney channel re-opened. Possible uplift to fishery in Emsworth bed through better water quality leading to 20% greater productivity. Extra bed open would provide more ground to fish. Shellfish would have increased survivability, and a potentially higher recruitment rate.
Water quality	33.3% Class C, 66.6% Class A
Depuration and relaying	Depuration required for all beds and Relaying required for Thorney bed
Proportion of harvest sold local or exported	50% local 50% export

Table 18: Direct and Indirect GVA for Scenario 5

Impact scope	Impact	Economic value
Direct GVA	Oyster fishers' earnings	£79,753
	Direct GVA	**£79,753**
Indirect GVA	Depuration processors	£11,765
	Boat, equipment, processing maintenance	£5,520
	Wholesalers profit (local, domestic and foreign export)	£89,593
	Local retailers profit	£388,409

	Transport of shellfish to end user	£1,902
	Indirect GVA	**£497,189**
	Total GVA	**£576,942**

Table 19 presents the direct, indirect and total GVA for each scenario for comparative purposes.

Table 19: Direct, Indirect and Total GVAs for each scenario

	Scenario 1 - Do nothing	Scenario 2 - Improvement of all beds to class C	Scenario 3 - Improvement of all beds to class B	Scenario 4: Improvement of all beds to class A	Scenario 5 - Graded improvements
Direct GVA	£0	£68,775	£75,653	£82,530	£79,753
Indirect GVA	£0	£185,810	£294,673	£532,026	£497,189
Total GVA	**£0**	**£254,585**	**£370,325**	**£614,556**	**£576,942**

8. Conclusions

Benefits of water quality improvement for shellfish ecosystem services

The results obtained demonstrate that better water quality leads to a higher direct and indirect GVA as a result of the increases in oyster harvest. As there is a higher harvest and more oysters are sold locally (and local retails make a profit at a greater price) instead of them being exported.

Improvements in shellfish waters would also mean Thorny Channel could be re-opened and harvested.

It is clear that of all the scenarios modelled, scenario 4 (improving all shellfish beds to grade A) presents the greatest increases in GVA and associated benefits.

Significant ecosystem services are offered by low impact nature of bivalve mollusc production acting as a carbon and nitrogen sink as well as a water 'cleanser'. These benefits have been described in the narrative but have not been valued in terms of their ecosystem service flows.

According to SEAFOOD 2040[lxxxiii] "[o]pportunities [of shellfish restoration] include: The production of filter feeding bivalves (mussels, scallops and oysters) which would generate sustainable protein for domestic consumption or high value exports, support the driver for 'slow clean' water onshore and the coastal leisure industry, and provide employment in fragile coastal communities''.[lxxxiv]

As no costs for the respective necessary interventions were provided, it has been impossible to present the findings as a cost-benefit ratio.

SEAFOOD 2040 further stated it was crucial to ensure "that shellfish harvesting waters are afforded the protection given under the Water Framework Directive and that this protection is maintained and delivered by the Environment Agency (EA) and others."[lxxxv]

The net benefits to society as a whole accruing from better water quality and increased shellfish harvests and the associated GVA also needs to consider the way in which the respective costs and benefits of any restoration or water treatment projects are distributed within society.[lxxxvi]

---

[i] SeaView Report -Chichester Harbour (2017) Environment Agency and Sussex Inshore Fisheries and Conservation Authority http://arunwesternstreams.org.uk/sites/default/files/uploads/Sussex%20SeaView%20report%20Final.pdf

[ii] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9

[iii] Chichester Harbour Conservancy http://www.conservancy.co.uk/

[iv] SeaView Report -Chichester Harbour (2017) Environment Agency and Sussex Inshore Fisheries and Conservation Authority http://arunwesternstreams.org.uk/sites/default/files/uploads/Sussex%20SeaView%20report%20Final.pdf

[v] Chichester Harbour Conservancy and UE associates (2009) VALUING CHICHESTER HARBOUR http://www.chichester.gov.uk/CHttpHandler.ashx?id=7890&p=0

[vi] JNCC http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0030059

[vii] JNCC http://jncc.defra.gov.uk/default.aspx?page=2034

[viii] SeaView Report -Chichester Harbour (2017) Environment Agency and Sussex Inshore Fisheries and Conservation Authority http://arunwesternstreams.org.uk/sites/default/files/uploads/Sussex%20SeaView%20report%20Final.pdf

[ix] Natural England: designated sites view https://designatedsites.naturalengland.org.uk/SiteDetail.aspx?SiteCode=S1003245

[x] Cefas – Bass Nursery Areas https://www.cefas.co.uk/publications/techrep/Bass.pdf

[xi] JNCC http://jncc.defra.gov.uk/pdf/RIS/UK11013.pdf

[xii] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013) Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf

[xiii] Grabowski, J.H. et al (2012) Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience. Vol. 62 No. 10. https://academic.oup.com/bioscience/article/62/10/900/238172

[xiv] 1 bushel is equivalent to 36.4 litres. 7000 bushels = 254,800 litres. ~ 250 tonnes valued at £1500 which is the equivalent of £84,000 (https://www.nationalarchives.gov.uk/currency/results.asp#mid).

Calculated from: Woolmer, A. P (2011) Fisheries and Conservation Management plan for Native Oysters in Chichester Harbour - Report to Chichester Harbour Oyster Partnership Initiative (CHOPI). Salacia Marine: Marine Ecological Consultancy.

[xv] Chichester Harbour Conservancy and UE associates (2009) VALUING CHICHESTER HARBOUR http://www.chichester.gov.uk/CHttpHandler.ashx?id=7890&p=0

[xvi] Woolmer, A. P (2011) Fisheries and Conservation Management plan for Native Oysters in Chichester Harbour - Report to Chichester Harbour Oyster Partnership Initiative (CHOPI). Salacia Marine: Marine Ecological Consultancy

[xvii] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013)
Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority
https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf

[xviii] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013)
Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority
https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf

[xix] Restoring degraded European native oyster, Ostrea edulis habitat: is there a case for harrowing? Bromley, C., McGonigle, C., Ashton EC. Dai Roberts, D. (2015) Hydrobiologia https://link.springer.com/article/10.1007/s10750-015-2544-2

[xx] Woolmer, A. P (2011) Fisheries and Conservation Management plan for Native Oysters in Chichester Harbour - Report to Chichester Harbour Oyster Partnership Initiative (CHOPI). Salacia Marine: Marine Ecological Consultancy

[xxi] SeaView Report -Chichester Harbour (2017) Environment Agency and Sussex Inshore Fisheries and Conservation Authority
http://arunwesternstreams.org.uk/sites/default/files/uploads/Sussex%20SeaView%20report%20Final.pdf

[xxii] University Of Portsmouth (2017) https://www.eurekalert.org/pub_releases/2017-12/uop-nea120117.php

[xxiii] BRIG, 2007, UKBAP 2009, JNCC and Defra, 2012.

[xxiv] Cefas and FSA (2013) EC Regulation 854/2004 CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES SANITARY SURVEY REPORT - Chichester Harbour. https://www.cefas.co.uk/media/41347/final-chichester-harbour-sanitary-survey-report-2013.pdf

[xxv] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xxvi] Humphreys, J. et al (2014) A reappraisal of the history and economics of the Pacific oyster in Britain. Aquaculture 428–429 http://dx.doi.org/10.1016/j.aquaculture.2014.02.034

[xxvii] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xxviii] Sussex Inshore Fisheries and Conservation Authority. MARINE AND COASTAL ACCESS ACT 2009 . Oyster Permit Byelaw https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/Oyster-permit-byelaw.pdf

[xxix] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xxx] Sussex Inshore Fisheries and Conservation Authority. MARINE AND COASTAL ACCESS ACT 2009 . Oyster Permit Byelaw https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/Oyster-permit-byelaw.pdf

[xxxi] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013)
Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority
https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf

[xxxii] Sussex Inshore Fisheries and Conservation Authority. MARINE AND COASTAL ACCESS ACT 2009 . Oyster Permit Byelaw https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/Oyster-permit-byelaw.pdf

[xxxiii] Woolmer, A. P (2011) Fisheries and Conservation Management plan for Native Oysters in Chichester Harbour - Report to Chichester Harbour Oyster Partnership Initiative (CHOPI). Salacia Marine: Marine Ecological Consultancy

[xxxiv] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xxxv] SeaView Report -Chichester Harbour (2017) Environment Agency and Sussex Inshore Fisheries and Conservation Authority
http://arunwesternstreams.org.uk/sites/default/files/uploads/Sussex%20SeaView%20report%20Final.pdf

[xxxvi] UK Government (2015) https://www.gov.uk/government/collections/river-basin-management-plans-2015

[xxxvii] Defra (2016) Water Framework Directive: List of Shellfish Water Protected Areas in England
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/504984/shellfish-waters-list-2016-england.pdf

[xxxviii] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xxxix] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9

[xl] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009).
http://www.pacshell.org/pdf/ShellfishEcoServices.pdf

[xli] Cefas and FSA (2013) EC Regulation 854/2004 CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES SANITARY SURVEY REPORT - Chichester Harbour. https://www.cefas.co.uk/media/41347/final-chichester-harbour-sanitary-survey-report-2013.pdf

[xlii] Seafish (2010) Classification of shellfish harvesting areas - issues. Fact Sheet.
http://www.seafish.org/media/Publications/FS31Shellfishharvestingareasclassification_201001.pdf

[xliii] Cefas (2017) Classification and microbiological monitoring https://www.cefas.co.uk/cefas-data-hub/food-safety/classification-and-microbiological-monitoring/

[xliv] Cefas (2017) Classification and microbiological monitoring https://www.cefas.co.uk/cefas-data-hub/food-safety/classification-and-microbiological-monitoring/

[xlv] Cefas classification zone maps for Chichester Harbour shellfish harvesting areas.
https://www.cefas.co.uk/media/52693/chichester-tapes-spp.jpg

[xlvi] Cefas classification zone maps for Chichester Harbour shellfish harvesting areas.
https://www.cefas.co.uk/media/52694/chichester-c-edule.jpg

[xlvii] Cefas classification zone maps for Chichester Harbour shellfish harvesting areas.
https://www.cefas.co.uk/media/1442/chichester-o-edulis.jpg

[xlviii] Kershaw, S., Campos, C.J.A and Morgan, O. (2011) Microbial pollution of the water in Chichester Harbour. Cefas report to Chichester District Council and Chichester Harbour
http://ow.ly/zbF530h4YHq

[xlix] Chichester District Council (2017) http://www.chichester.gov.uk/article/25658/Oysters-in-Chichester-Harbour
[l] FSA (2017) https://www.food.gov.uk/sites/default/files/classificationlist05dec2017.pdf
[li] NEF. Economics in policy-making series (2013) Briefing 3: Valuing the environment in economic terms http://b.3cdn.net/nefoundation/d2e4b5d5f652b5428b_dxm6bn7nw.pdf
[lii] NEF. Economics in policy-making series (2013) Briefing 3: Valuing the environment in economic terms http://b.3cdn.net/nefoundation/d2e4b5d5f652b5428b_dxm6bn7nw.pdf
[liii] Millennium Ecosystem Assessment (MEA, 2005) http://www.millenniumassessment.org/en/index.html
[liv] "Protecting our Planet, Securing our Future: Linkages Among Global Environmental Issues and Human Needs" (1998) by UNEP, NASA, and the World Bank http://siteresources.worldbank.org/INTRANETENVIRONMENT/Resources/ProtectingOurPlanet.pdf
[lv] Millennium Ecosystem Assessment (MEA, 2005) http://www.unep.org/maweb/en/index.aspx
[lvi] Millennium Ecosystem Assessment (MEA, 2005) http://www.unep.org/maweb/en/index.aspx
[lvii] Speich, D (2011) The Use of Global Abstractions, Journal of Global History http://www.academia.edu/5676897/The_Use_of_Global_Abstractions_Journal_of_Global_History_2011
[lviii] Natural Capital Committee (2017) Advice to Government on the 25 Year Environment Plan https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/650314/ncc-advice-on-25-year-environment-plan171009.pdf
[lix] Kill, J. Economic Valuation of Nature- The Price to Pay for Conservation? A Critical Exploration. (2014) Rosa-Luxemburg-Stiftung Brussels Office. http://rosalux-europa.info/userfiles/file/Economic-Valuation-of-Nature.pdf
[lx] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009). http://www.pacshell.org/pdf/ShellfishEcoServices.pdf
[lxi] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009). http://www.pacshell.org/pdf/ShellfishEcoServices.pdf
[lxii] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009). http://www.pacshell.org/pdf/ShellfishEcoServices.pdf
[lxiii] Grabowski, J.H. et al (2012) Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience. Vol. 62 No. 10. https://academic.oup.com/bioscience/article/62/10/900/238172
[lxiv] The Millennium Ecosystem Assessment (2005) http://millenniumassessment.org/en/Condition.html
[lxv] Brumbaugh, R.D and Toropova, C. (2008). Economic valuation of ecosystem services: A new impetus for shellfish restoration? Basins and Coasts News 2 (2):8-15.
[lxvi] Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260. https://groups.nceas.ucsb.edu/ma-eco-tradeoffs/documents/valuation-reprints-and-resources/Costanza%20et%20al%20-%20The%20value%20of%20the%20world2019s%20ecosystem%20services%20and%20natural%20capital.pdf/view
[lxvii] Sequeira, A., J.G. Ferreira, A.J.S. Hawkins, A. Nobre, P. Lourenço, X.L. Zhang, X. Yan, and T. Nickell. 2008. Trade-offs between shellfish aquaculture and benthic biodiversity: A modelling approach for sustainable management. Aquaculture 274 (2-4):313-328.
[lxviii] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for

Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxix] Grabowski, J.H. et al (2012) Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience. Vol. 62 No. 10. https://academic.oup.com/bioscience/article/62/10/900/238172
[lxx] Grabowski, J.H. et al (2012) Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience. Vol. 62 No. 10. https://academic.oup.com/bioscience/article/62/10/900/238172
[lxxi] Adapted from Brumbaugh and Toropova (2008) and Northern Economics (2009) Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. http://www.pacshell.org/pdf/ShellfishEcoServices.pdf

[lxxii] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxxiii] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009). http://www.pacshell.org/pdf/ShellfishEcoServices.pdf
[lxxiv] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxxv] Atlantic States Marine Fisheries Commission. 2007. The Importance of Habitat Created by Shellfish and Shell Beds Along the Atlantic Coast of the U.S. Washington, D.C.
[lxxvi] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxxvii] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxxviii] Atlantic States Marine Fisheries Commission. 2007. The Importance of Habitat Created by Shellfish and Shell Beds Along the Atlantic Coast of the U.S. Washington, D.C.
[lxxix] Ecosystem Concepts for Sustainable Bivalve Mariculture (2010) Chapter 7 Ecosystem Services of Bivalves: Implications for Restoration. National Research Council. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press. doi: 10.17226/12802. https://www.nap.edu/read/12802/chapter/9
[lxxx] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013)
Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority
https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf
[lxxxi] Chichester Harbour Oyster Partnership Initiative: CHOPI (2013)
Belinda Vause and Robert Clark Sussex Inshore Fisheries and Conservation Authority
https://secure.toolkitfiles.co.uk/clients/34087/sitedata/files/OystersCHOPIposter.pdf
[lxxxii] CHOPI http://sussexlnp.org.uk/chichesterOysters.php
[lxxxiii] Seafish (2017)SEAFOOD 2040 - A strategic framework for England
http://www.seafish.org/media/publications/SEAFOOD_2040_lo_singlep.pdf
[lxxxiv] Seafish (2017) SEAFOOD 2040
http://www.seafish.org/media/publications/SEAFOOD_2040_lo_singlep.pdf

[lxxxv] Seafish (2017) SEAFOOD 2040
http://www.seafish.org/media/publications/SEAFOOD_2040_lo_singlep.pdf
[lxxxvi] Northern Economics, Inc. Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature. Prepared for Pacific Shellfish Institute. (2009). http://www.pacshell.org/pdf/ShellfishEcoServices.pdf