MARINE CONSERVATION SOCIETY

A socio-economic analysis of a bottom-contact fishing ban in the UK

Valuing the impact on ecosystem services within the UK's offshore benthic MPA network

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Executive Summary

The marine environment has huge value to societies and economies around the world, supporting our basic existence and long-term survival. This extends from providing food for local communities to generating oxygen, absorbing carbon dioxide emissions, and mitigating global warming. The benefits that mankind derives from nature are described as *ecosystem services* and these are delivered by assets of *natural capital*. Ecosystem services are broadly categorised into four types:

- *Provisioning services* provide us with natural resources and food.
- *Regulating services* include protection from extreme events, regulation of the climate, carbon burial and waste removal.
- *Supporting services* includes the cycling of nutrients.
- *Cultural and aesthetic services* include the benefits we derive from leisure, tourism and recreation and the less tangible effects on our well-being and existence.

A key paper by Costanza *et al.* (1997) was influential in highlighting the economic value of natural capital and this field has grown in the years since. Today, the valuation of ecosystem services can help to inform decision makers on their importance to society and the impacts we have upon them.

The Office for National Statistics has previously valued the UK's natural capital assets at over £200 billion. Some of the most valuable habitats and species are within Marine Protected Areas that have been designated primarily for the enhancement of marine biodiversity. Properly enforced, these areas enable the marine ecosystems and species within them to recover. This in turn increases their capacity to provide ecosystem services. However, anthropogenic disturbances such as overfishing, pollution and infrastructure development continue to affect the health of ecosystems within MPAs. Possibly the most destructive anthropogenic disturbance is bottom-contact fishing. Dragging heavy gear across the seabed removes species and habitats living on the seabed, affects the structure of the seabed itself and resuspends buried sediments, including long-term stores of carbon. The Marine Conservation Society has previously found that bottom-contact fishing is taking place in 98% of the UK's offshore Marine Protected Areas (MPAs). Allowing destructive activity within MPAs undermines the purpose for which they were created and reduces their benefits to society. More positively, however, it follows that banning this activity within MPAs could allow protected ecosystems to recover and significantly enhance their socioeconomic value. This value should increase over time as ecosystems are allowed to recover. It is therefore important to consider the longer-term socioeconomic impacts of any decisions affecting MPAs.

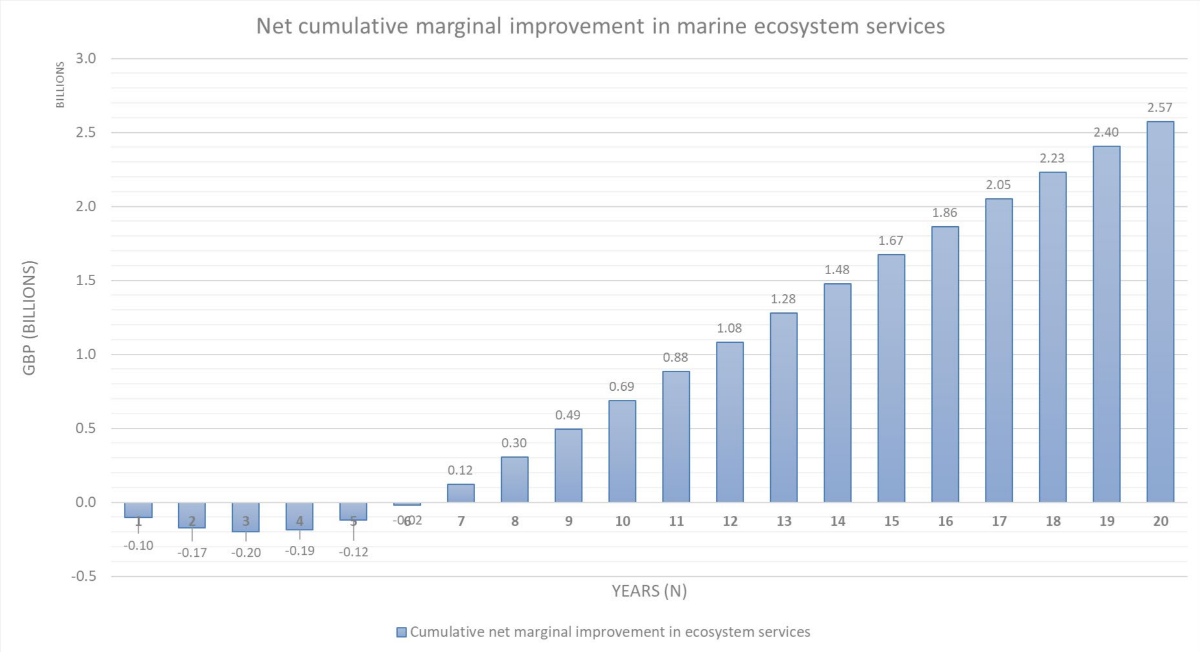
In 2021, Seas At Risk commissioned the New Economics Foundation (Davies *et al.,* 2021) to value the socioeconomic impacts of a potential ban on bottom contact fishing in the EU's network of Nature 2000 protected areas. The analysis conducted here builds on this work to look at the value of ecosystem services within the UK's benthic offshore MPA network and their improvement over a 20-year period following a ban on bottom-contact fishing. This is compared to the administration costs, lost fishing values, and the loss of ecosystem value elsewhere due to displacement, to calculate the net socioeconomic impact.

The first part of the analysis considers the benefits and costs of protecting the UK-wide offshore benthic MPA network from bottom-contact fishing. The analysis is then replicated for the devolved nations, considering the costs to each country of closing offshore benthic MPAs that remain open to bottom-contact fishing.

To calculate the improvement in the value of ecosystem services, impact coding was adapted from the Marine Bill report by Moran *et al.* (2008). For each habitat and ecosystem service, this coding indicates the expected percentage improvement in ecosystem services, how long the improvement takes to occur, and the trajectory of the improvements (i.e. linear, exponential or logarithmic improvement). Financial proxies were then taken from the Ecosystem Services Valuation Database (adjusted to 2020 prices) and used to put a monetary value (in EUR/ha/y) on these ecosystem services. Together, these elements were used to calculate the improvement in the financial value of ecosystem services over 20 years across different habitat types. This was multiplied by the total area of mapped habitats that are currently subject to bottom trawling within offshore benthic MPAs.

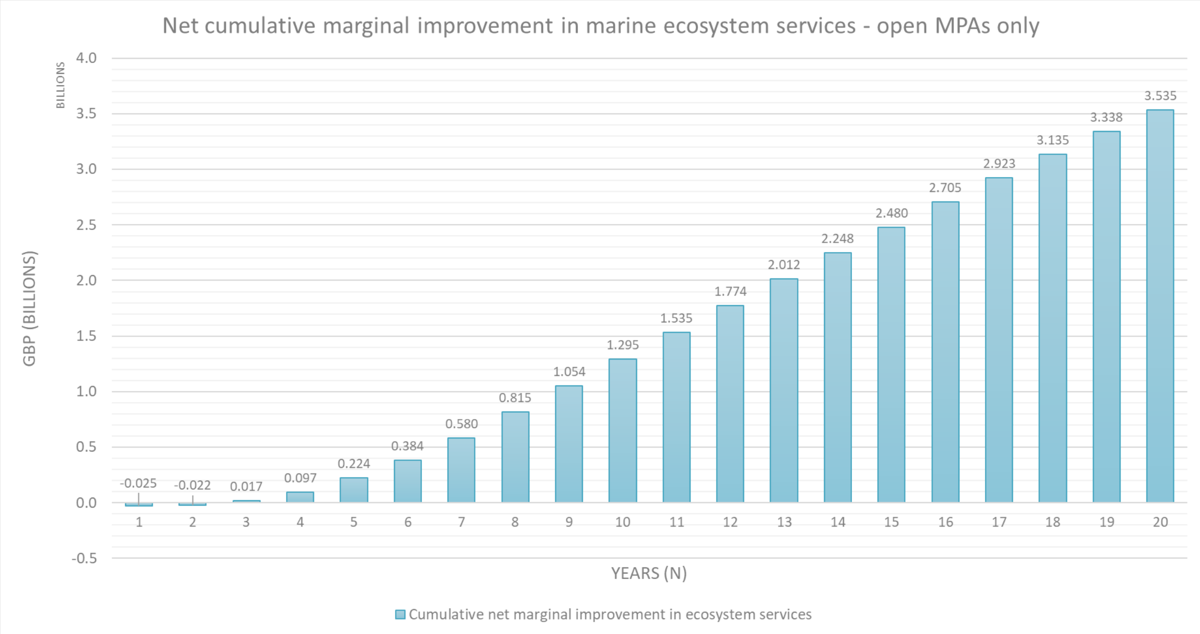
To calculate costs and displacement values, operational costs of implementing a ban were adapted from Davies *et al.* (2021) who in turn took the figures from a UN report. These costs were applied to the total area of the MPA network and lost fishing value was assumed to be 25% of benthic landing values within UK MPAs. Assuming that the remaining 75% of fishing activity would move into unprotected areas outside of the MPAs, displacement values were calculated as the corresponding loss of ecosystem services in those areas.

The results show the cumulative net impact over 20-years amounts to £2.57 billion of additional socioeconomic value for the UK:



The mid-to-long term socioeconomic costs of introducing a ban on bottom-contact fishing substantially outweigh the initial costs incurred. Although ecosystems can require some time to recover from destructive disturbances, the marginal increase in their capacity to deliver ecosystem services can prove highly valuable.

The figures above were calculated considering the operational costs of a ban across the entire offshore benthic MPA network. A more practical approach may be to consider the costs of closing offshore benthic MPAs that currently remain open to bottom-contact fishing. In this case, the economic case in favour of a ban is strengthened, with the overall net impact estimated to be £3.5 billion and a net positive impact beginning in the third year following a ban:



These results highlight key messages for decision makers including:

- The mid-to-long term benefits of a ban on bottom-trawling significantly outweigh the short-term costs that are minimal in comparison to the overall benefits.
- The socioeconomic value of our MPAs needs to be properly accounted for in decisions that affect the health of marine ecosystems.
- Decisions should consider longer time frames and prioritise the longer-term benefits to society over the short-term costs to certain stakeholders.

Finally, it should be noted that these could be considered conservative estimates for various reasons:

- The model compares improvement in ecosystem services versus a baseline scenario of no improvement. In reality, the provision of ecosystem services would possibly decline further with continued disturbance, which would create a greater economic disparity between the improved scenario and the 'business as usual' scenario.
- There was a range of financial valuations for each ecosystem service that could have been adopted from previous research, but lower values were chosen for a more cautionary approach.
- A relatively high level of displacement effect was assumed, while potential spillover effects were not estimated by the model.
- Not all ecosystem services were captured in the analysis and many are difficult to quantify in monetary terms.

- The data is likely to be a significant under-representation of the benefits for all UK seas, as our analysis does not include inshore MPAs (within 6 nm) still subject to bottom trawl fishing. Examples include the Wash, Flamborough Head, Margate and Longsands and Essex Estuaries SACs – these areas only have small sections of their MPAs closed to bottom towed fishing.

1. Introduction

The natural assets within the UK's marine environment, referred to as *natural capital*, provide benefits and economic value to UK society. According to the Office for National Statistics (2021), the total value of marine capital assets is at least £211 billion. This does not capture all the goods and services derived from the marine environment, many of which are difficult to quantity in monetary terms. Nevertheless, the capacity of the marine environment to provide vital services to society is undermined by anthropogenic disturbances, even within areas designated for protection.

The 2021 Marine UnProtected Areas report by the Marine Conservation Society reported that trawling and bottom-dredging activity are taking place in 98% of the UK's offshore Marine Protected Areas (MPAs). Bottom-contacting mobile fishing gear has a destructive impact on valuable marine ecosystems and disturbs sea floor sediments. The indiscriminate method of dragging large nets across the seabed is effective at catching large volumes of commercially valuable species but has severe ecological impacts, including unwanted bycatch, threats to endangered species, damage and destruction of habitats, and resuspension of carbon stores. It is estimated that complete restoration following disturbance can take years or even decades (Paradis *et al.*, 2020).

Bottom-trawling and dredging in MPAs undermines the purpose for which MPAs were established – for the protection of biodiversity, valuable species and habitats. Given that the fishing industry also depends on healthy fish stocks for long term economic security, it is also within their interests to protect biodiversity and the habitats that support fish numbers. Bottom-contact fishing poses a threat to this biodiversity and impacts on the range of important and valuable ecosystem services that the species and habitats provide, including provisioning services and regulating services that carry important economic significance and play a vital role in climate mitigation.

In 2021, Seas At Risk commissioned the New Economics Foundation to carry out a detailed report into valuing the impact of a potential ban on bottom-contact fishing in the EU marine protected areas. The report examined the potential impacts of the ban using a benefit transfer approach to develop an ecosystem services model. This estimated the cumulative value for a suite of ecosystem services in the 20-year period following implementation of a ban.

The following report estimates the gain in the economic value of ecosystem services within the UK MPA network across the 20-year period following a proposed ban on bottom-contact fishing within the UK's offshore benthic MPA. The report builds on the work of the New Economics Foundation (Davies *et al.,* 2021) by producing a cost-benefit (CBA) analysis that compares the economic gains in improved ecosystem service provision to the administration costs, lost fishing values and displacement effects following a ban on bottom-towed gear.

2. Literature review

Marine ecosystem services

Ecosystem services are defined as benefits that mankind derives from functioning natural ecosystems (Costanza *et al.,* 2017). In the marine sense, this is the benefits provided by coastal and marine ecosystems (Duraiappah *et al.,* 2005). These are categorised into provisioning, regulating, supporting and cultural services. This is summarised in Figure 1.

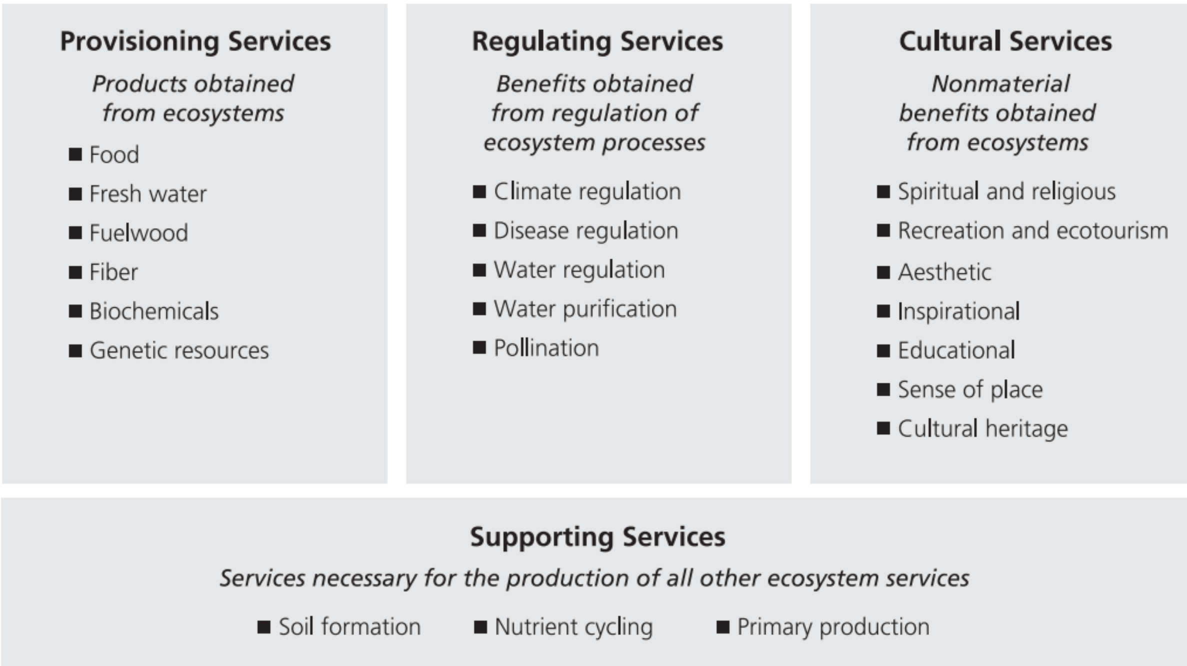


Figure 1: Summary of the four different categories of ecosystem services. Source: MEA (2003).

Many of these ecosystem services can be assigned an economic value through different methods. As explained by Pascual *et al.* (2010), these include:

- Market based approaches, where there is a corresponding market value for a particular good or service provided. If the good or service can be quantified, it can be given a monetary value.
- Cost-based approaches that consider the cost of replicating an ecosystem service artificially if it was not to be provided by nature.
- Revealed preference approaches consider the observable or hypothetical willingness of individuals to pay for a particular good or service provided by nature.

It is not the purpose of this report to critique these methods, but to outline their use in representing the value of marine natural assets. It has been estimated that over 60% of the economic value of the global biosphere is derived from marine ecosystem services (Martinez *et al.,* 2007), so it is essential that this value is recognised in deciding how we interact with the marine environment (Hooper *et al.,* 2019).

For an island nation such as the UK, the value of marine ecosystems is especially significant. The Office for National Statistics (ONS, 2021) has valued the UK's marine natural assets at £211 billion. This underlines the huge value that particular goods and services, including marine recreation and carbon sequestration, have to the UK economy (see Figure 2 below).

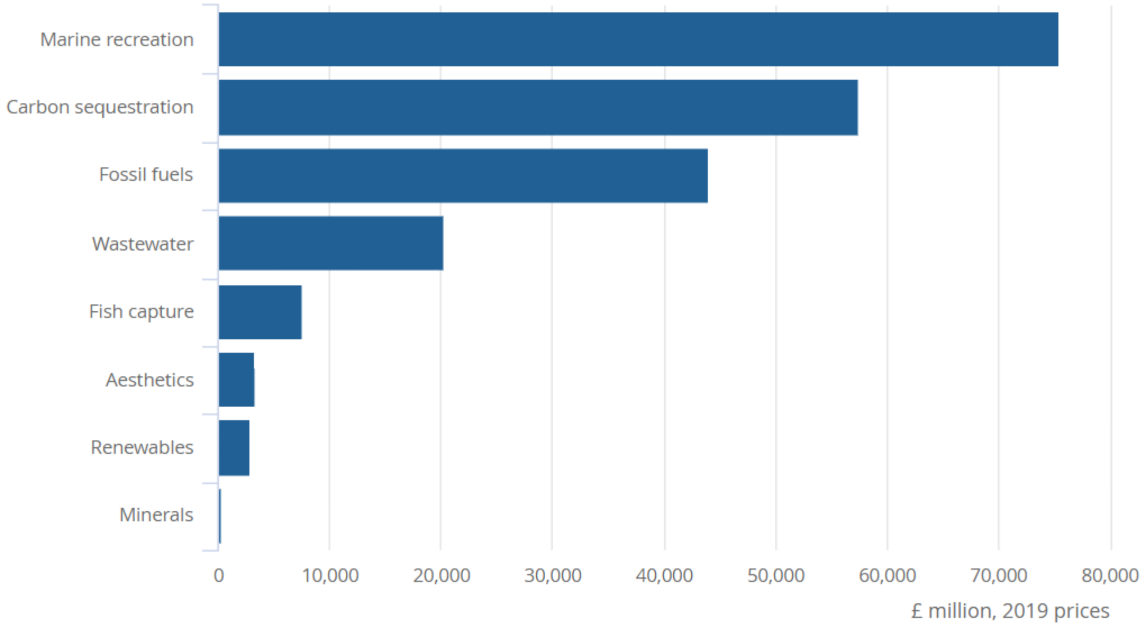


Figure 2: The asset value of marine services in 2018 (in £ millions and 2019 prices), estimated by the Office for National Statistics (ONS, 2021).

Marine ecosystem services have allowed mankind to both survive and thrive. Today, a number of key industries are supported by the marine environment, including marine leisure, recreation and tourism, fishing, extractive industries and shipping. Preserving the benefits of marine ecosystem services will require the protection and recovery of marine ecosystems that are consistently overexploited and degraded by ongoing damaging activities (Plumeridge and Roberts, 2017).

Provisioning services have supported communities and livelihoods for millennia (Roberts, 2007). However, technological advances and intensified fishing efforts have led to overfishing and destructive methods that alter the resilience and functioning of marine ecosystems and their quality of services (Buonocore *et al.,* 2021). Similarly, the oceans have played a key role in mitigating the impacts of anthropogenic global heating. They have absorbed an estimated 25% of manmade CO2 emissions in recent decades (DeVries, 2022) and most of the added energy generated by global warming (Hoegh-Guldberg *et al.,* 2010). The capacity of the oceans to perform this service is decreasing due to the geochemical changes that temperature rises and ocean acidification have on the functioning of marine ecosystems.

Seafloor habitats (particularly soft sediments) play an important role in removing nitrogen from coastal waters and mitigating against eutrophication (Ferguson *et al.,* 2020). Benthic organisms are essential for the removal, storage and recycling of anthropogenic waste pollutants, also known as bioremediation of waste (Rees *et al.,* 2012) which degrades pollutants to an innocuous state below harmful limits (Rani and Dhania, 2014). Sewage is a major source of this waste and other sources include agricultural run-off or outputs from the food and drink industries (Beaumont *et al.,* 2007). Ultimately, the marine environment can only tolerate so much, and ecosystems are starting to reach tipping points where they become overwhelmed and collapse (Bergstrom *et al.,* 2021; Hughes, 1994; Rowland *et al.,* 2018).

In short, the capacity of the marine environment to provide ecosystem services is under threat by climate change, man-made disturbances and overexploitation (Buonocore *et al.,* 2021). As one of the most heavily exploited ecosystems on the planet (Barbier *et al.,* 2017), decision making about the use of marine space can have a key role in the recovery or further degradation of these valuable ecosystems. The natural capital approach can assist in communicating the socioeconomic value that marine ecosystems are providing (Hooper *et al.,* 2019), although it can also be argued that they carry infinite value to mankind given that these ecosystems are fundamentally life-supporting.

Marine Protected Areas

Marine Protected Areas are usually designated to restore or protect biodiversity, but they can also enhance the provision of ecosystem services that carry socioeconomic value (Costanza *et al.*, 1997; Dasgupta, 2021). Figure 3 shows some of the benefits society receives from properly managed MPAs.

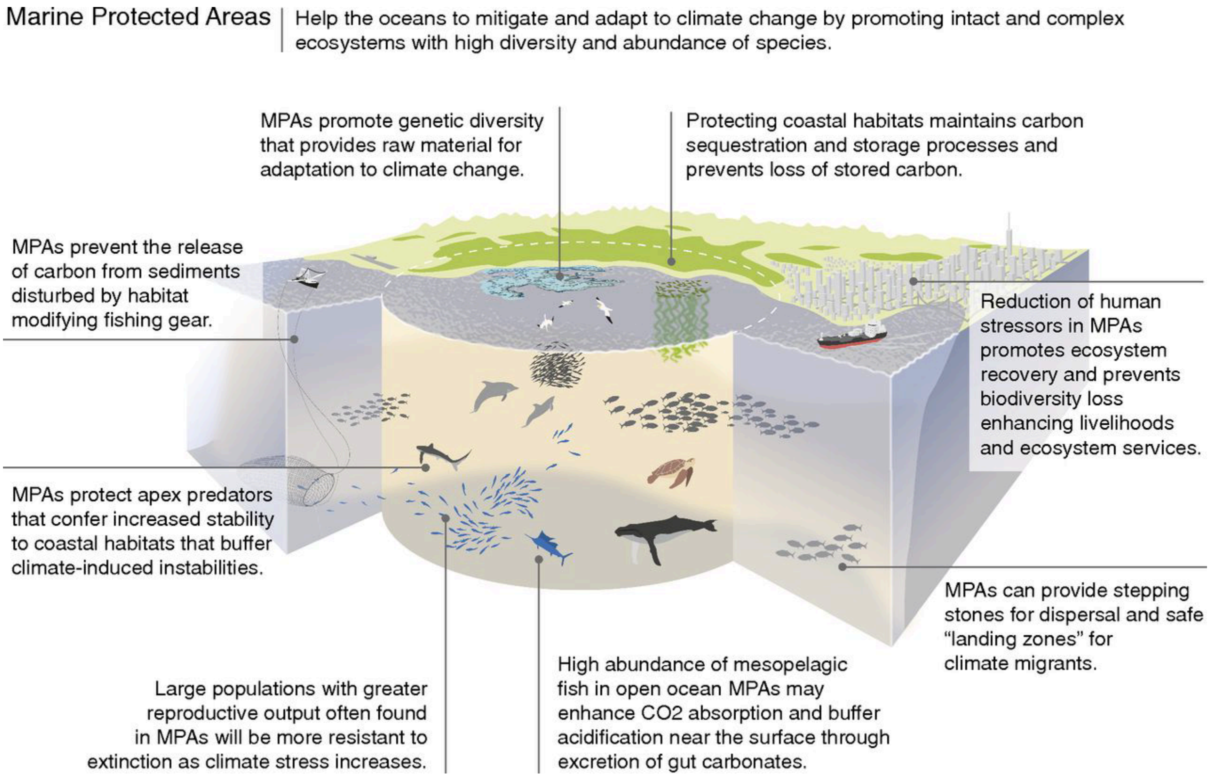


Figure 3: A depiction of some of the benefits to society that MPAs can generate. Source: Roberts et al. (2017).

MPAs can be an important tool for climate mitigation (Fox *et al.,* 2012; Russi *et al.,* 2016). Effective protection enables the recovery of ecosystems, thereby increasing their capacity to draw carbon down from the atmosphere. Moreover, effective management of MPAs can reduce the disturbance of carbon stored within the seabed. Indirectly, protection measures can maintain a stable and complex food web. This helps to avoid trophic cascades whereby the proliferation of habitat-structuring species could threaten valuable keystone habitats that provide nursery grounds, store carbon and offer protection against extreme weather (Berkström *et al.,* 2022; Donadi *et al.,* 2017). The benefits of protection also extend to the marine economy. As an example, the health of the marine environment is a fundamental factor supporting the marine recreation, leisure and tourism sector, which is one of the largest sectors of the UK's marine economy (Stebbings *et al.* 2020).

The designation of MPAs has been found to improve the size and sustainability of fishing yields by alleviating pressures and allowing populations to recover (Pitchford *et al.,* 2007), although this is debated in the wider literature (Stafford, 2018, Woodcock *et al.,* 2017). A meta-analysis of scientific studies by Sala and Giakoumi (2017) reported that fish biomass in areas of strong protection was 670% higher on average than in unprotected areas and 343% higher than in partially protected areas. Marshall *et al.* (2019) found that one hectare of MPA equates to between 3 and 255 hectares of unprotected areas for egg production across a range of species, owing to the greater size of fish found within MPAs and their influence on reproduction. The variability in evidence around the efficacy of MPAs for managing and maintaining fish stocks suggests that it is dependent on the MPA in question. Further research highlights factors such as the size, age and management regime of an MPA as key influences on its effect on fishing stocks (Di Lorenzo *et al.,* 2020; Woodcock *et al.,* 2017; Vandeperre *et al.,* 2011). Edgar *et al.* (2014) examined the conservation benefits of 87 MPAs across the world with different levels of fishing restrictions. Conservation benefits were found to increase exponentially for MPAs that were no-take, more than 10 years old, larger than 100 km^2 and surrounded by deep water or sand. The findings showed that implementation of no-take and restricted fishing zones achieved greater biomass and biodiversity than fished areas.

Management regimes are decisive in the level of protection that is afforded by an MPA and the activities that are restricted within them (Motta *et al.,* 2021), with some MPAs offering very little meaningful ecological protection and being termed as merely 'paper parks' (Di Cintio *et al.,* 2023). Edgar *et al.* (2014) highlight that designation of areas for protection alone will not ensure protection of biodiversity without effective design, management and compliance. With bottom-contact fishing occurring in 98% of the UK's offshore MPAs (Dunkley and Solandt, 2021), it can be argued that we are not able to observe the full ecological and socioeconomic potential of our MPA network.

The designation, management, and effective enforcement of an MPA typically require sustained public funding (Bohorquez *et al.,* 2022), which makes it a central component of marine planning discussions. Davis *et al.* (2019) describe three main costs for MPAs: establishment, maintenance and compliance. Establishing an MPA involves research, planning, communication, and coordination with local stakeholders (Leisher *et al.,* 2012; McCrea-Strub *et al.,* 2011). Maintenance covers administration, management and enforcement, each of which requires staff resources and occasionally capital costs such as the deployment of vehicles and technology (Ban *et al.,* 2011). These costs are linked to the effort needed to monitor and research MPAs both during establishment and during the lifetime of the MPA. Additionally, meaningful enforcement may also result in legal fees for dealing with violations (Ban *et al.,* 2011). The total size of these costs depends on the size of the MPA and number of visitors, although the cost per hectare decreases with size (Gravestock *et al.,* 2008). Compliance costs consist of lost benefits from other activities (e.g. fishing) that are no longer permitted, and the administrational costs to affected stakeholders in understanding and ensuring compliance (Davis *et al.,* 2019).

Bottom-contact fishing

Bottom-towed fishing gear has a highly destructive impact on the seabed. The process of dragging heavy gear over the seabed ploughs through the substrate, resuspends sediment and destroys benthic habitats (Jones, 1992). This is depicted in Figure 4 below. It also leads to the removal or mortality of benthic organisms in its path (Kaiser *et al.,* 2002). Cook *et al.* (2013) found that a single pass of a trawl through a study site removed 90% of epifaunal organisms. Similarly, a meta-analysis by Sciberras *et al.* (2018) reported a 26% reduction in benthic invertebrate abundance and 19% fall in species richness after a gear pass. The impact on benthic habitats and communities can have a long-term effect on the functioning of marine ecosystems (Olsgard *et al*., 2008; Pusceddu *et al.,*2014; Van Denderen *et al.,* 2015). For example, the loss of shellfish and bivalve reefs has impaired valuable ecosystem services such as carbon storage and filtering of pollutants and excess nutrients (Dunkley and Solandt, 2021). Previous studies indicate that recovery from bottom-gear disturbance for impacted organisms can take over 10 years due to their slow growth rates (Moran *et al., 2008*; Watling and Norse, 1998). For community assemblages to accrue (rather than individuals of habitat-forming species), this is likely to be longer, particularly in deeper water (Clark *et al*., 2019).

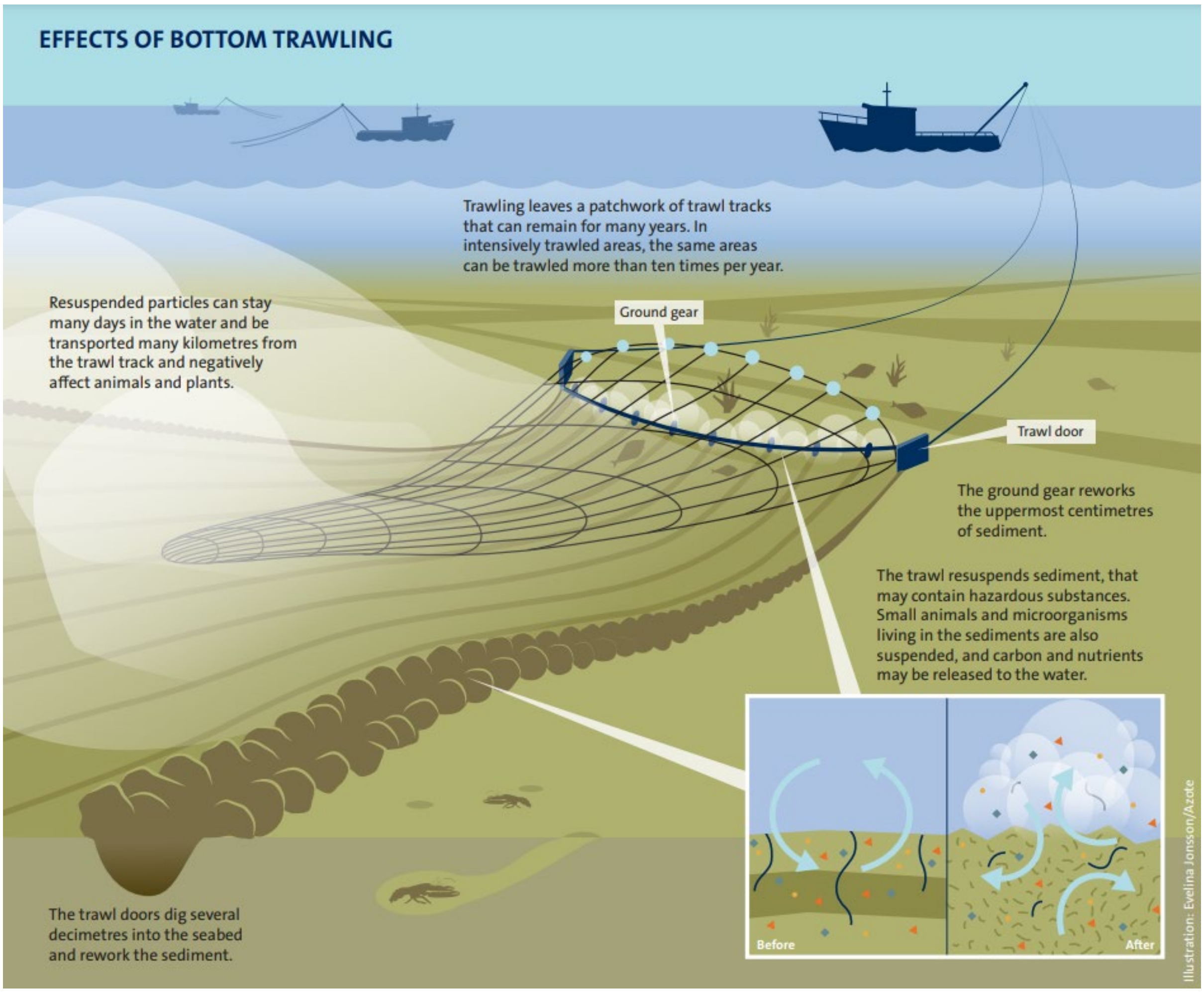


Figure 4: A depiction of the physical impact of a bottom-trawl on the benthic environment. Heavy equipment ploughs up the sediment, resuspending organic matter into the sea column. Source: [Stockholm University Baltic Sea Centre](#) (2022).

The effects of bottom-contact fishing can result in long-term changes in the benthic community, shifting the composition of organisms towards shorter lived species (Rijnsdorp *et al.,* 2018). Low mobility organisms with long life-spans, including bivalves and soft corals, can require a number of years to recover (Sciberras *et al.,* 2018). According to Eigaard *et al*. (2017), 63% of North Sea sediments are subject to trawling between 1 and 10 times each year, suggesting minimal scope for recovery in a number of sites to a pre-industrial baseline (Plumeridge and Roberts, 2017). Together with a reduction in biomass and productivity, this results in weakened benthic ecosystems with lower complexity and resilience (Shephard *et al.*, 2010). The impact on benthic communities affects the structure and resilience of the wider marine food web while decreasing the overall biodiversity of the marine environment.

Physical changes to the benthos include the coarsening (Palanques *et al.,* 2014) and fining (Trimmer *et al.,* 2005) of the sediment, and a reduction in organic matter

(Paradis *et al.,* 2019). Biogeochemical changes may also occur. De Borger *et al.* (2021) found that trawling events across five different sediment types significantly raised oxygen and nitrate concentrations in surface sediments and reduced organic carbon in the top 10 cm of sediments by up to 96%. Overall, rates of mineralisation in the sediment decreased by 28%, owing to the resuspension of organic carbon and the removal of bioturbating organisms (De Borger *et al.* 2021). According to Ferguson *et al.* (2020), disturbance by bottom-contacting fishing gear can affect microbial communities and sediment structures that play a key role in the denitrification process. This reduces the capacity of sediments to remove nitrogen from the water column which subjects the ecosystem further to excess nutrient enrichment (Ferguson *et al.,* 2020).

The disturbance of bottom sediments can potentially release vast amounts of carbon that could otherwise be stored for millennia (Estes *et al.*, 2019; Lovelock *et al.,* 2017). One study by Sala *et al.* (2021) estimates that the global emissions released through bottom trawling is comparable with the annual emissions of the global aviation industry, although a subsequent review by Epstein *et al.* (2022) highlights several uncertainties in those calculations. According to Smeaton *et al.* (2021), the surficial sediments within the UK EEZ are estimated to store 524 ± 68 Mt of organic carbon (OC) and 2,582 ± 168 Mt of inorganic carbon (IC). Research by Black *et al.* (2022) builds on the methods used by Sala *et al.* (2021) and highlights that hotspots of OC-rich sediments within these waters, including the west coast of Scotland, are at particular risk from bottom trawling activity. It is worth noting that carbon is not distributed evenly across marine spaces owing to the variation in biological, geochemical and physical composition across sites (LaRowe *et al.,* 2020). For example, carbon-rich hotspots around the UK are often found in inshore and coastal muddy areas (Smeaton *et al.,* 2021).

Despite the high impact of bottom-contact fishing on marine ecosystems, it continues to take place in most of the UK’s offshore benthic MPAs. The map in Figure 5 shows the footprint of fishing activity in the UK offshore benthic MPA network:

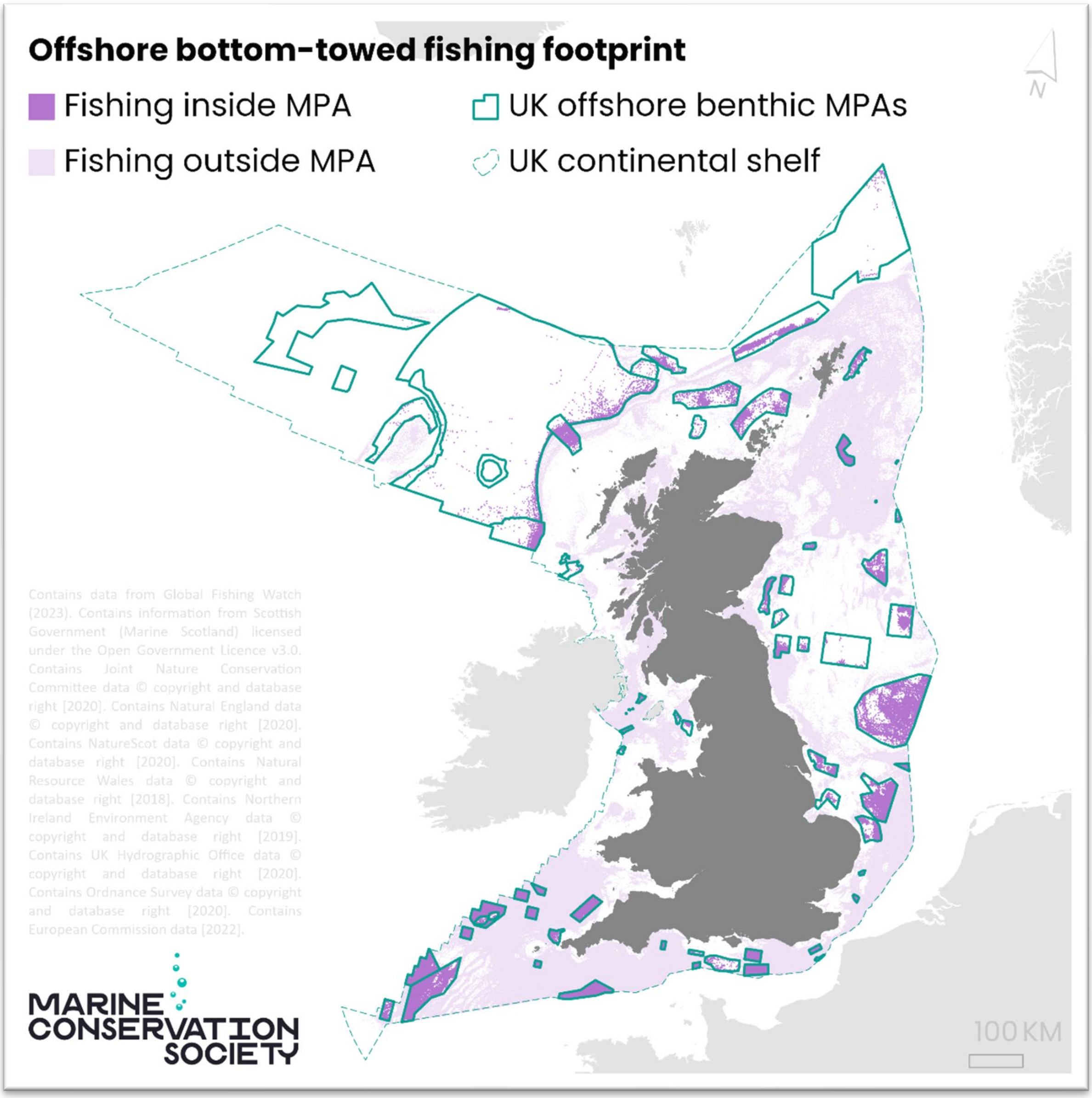


Figure 5: A fishing footprint map showing the presence and absence of vessel activity in the UK's offshore benthic MPA network. Areas of purple within the green marked areas show that bottom-towed fishing is taking place in most of the offshore benthic MPAs.

Trade-offs

Impact on fishing values

The improvement in the value of one ecosystem service may come at the expense of another. In this case, it should be expected that a ban on bottom-contact fishing would have an impact on the fishing industry and livelihoods linked to bottom-contact fishing (Davis *et al.,* 2019). The impact on fishing revenues has been a longheld counterargument against greater measures of protection within MPAs (Dichmont *et al.,* 2013; Hilborn, 2007; Roberts *et al.,* 2005). However, it has also been argued that such a ban could be in the longer-term interests of the fishing industry. A ban on bottom-contacting fishing gears presents the most comprehensive protection of benthic habitats and can lead to improved catch by the non-demersal fleet (McConnaughey *et al.*, 2020). In some cases, local fishing communities have supported the abatement or cessation of demersal fishing in order to enhance or conserve other valuable fishing stocks (Kincaid and Rose, 2017; Gleason *et al.,* 2013). Two years after the closure of the Lyme Bay MPA to bottom-trawling in 2008, Mangi *et al*. (2011b) observed an increase in landings from static gear within the MPA and an increase in landings from both static and mobile gear outside the MPA. Between 8 and 16 years after cessation of fishing with a Mediterranean MPA, Stobart *et al.* (2009) reported a positive response in commercial fish populations that also extended beyond the boundaries of the MPA.

This is known as a *spillover effect*, but the research into this has mixed results. Hermelin-Vivien *et al.* (2008) suggest that the spillover of biomass could be limited mainly to a spatial scale of hundreds of metres. Pantzar *et al.* (2018) also reported a lack of empirical evidence for concluding whether there is a net economic gain for fisheries resulting from greater protection measures. This may be due to a myriad of factors that influence the occurrence and extent of spillover effects. For example, Buxton *et al.* (2014) observed that spillover benefits were only observed in areas of high depletion. Rassweiler *et al.* (2014) estimate that fish stocks need to fall below 65% of maximum sustainable yield before spillover benefits can be realised. In other cases, spillover benefits may be nullified by increased fishing efforts outside the protected area (Buxton *et al.,* 2014; Howart *et al.,* 2017). Other factors that influence the likelihood of spillover benefits include the size and age of MPAs, as well as the species composition within them (Di Lorenzo *et al.,* 2020). However, these studies typically look at specific MPAs rather than whole MPA networks.

Displacement

There may also be spatial trade-offs following a ban, including impacts in surrounding unprotected areas. Introducing greater protection in a marine space may encourage ecological recovery in the protected area but result in ecological degradation by displacement activity in surrounding unprotected areas (Schratzberger *et al.*, 2019). Fishing effort in areas of displacement may also increase to make up for the costs of travelling further, or to compensate for lower fish stocks outside of the MPA (Vaughan, 2017). This would intensify the impact on unprotected areas relative to protected areas.

New opportunities

Although restrictions within MPAs will result in lost jobs and revenues for some sectors, Brander *et al.* (2015) explain that MPAs create new economic opportunities and jobs. There are particular sectors that stand to gain significantly from an improvement in overall marine health. The Office for National Statistics has valued marine recreation as the most valuable natural capital asset in our marine environment (ONS, 2021). According to Stebbings *et al.* (2020), the sector of the marine economy that provides the most jobs is the leisure and recreation sector. Opportunities for growth within this sector are particularly linked to the overall quality of the marine environment (Rees *et al.,* 2015).

Socioeconomic value of protecting the marine environment

When considering the economic value of designating a network of marine conservation zones, Moran *et al.* (2008) found that the greatest economic benefits over 20 years would be achieved in scenarios with the highest levels of protection (including the most limitations placed on destructive and disturbing activities). Protecting a network of 147,200 km^2 was estimated to generate benefits over 20 years with a present value of £22.7 billion and undiscounted mean annual benefits of £1.9 billion. In this scenario, 30% of that area would be closed to all fishing activities and the remaining 70% would have spatial or temporal restrictions on the use of bottom-fishing gears (Moran *et al.,* 2008).

In a report to Scotlink, Gonzalez-Alvarez (2012) estimated that a theoretical network of MPAs up to 102,400 km^2 in size - in which the assessed management regimes would restrict bottom gear fishing in Scottish waters - would yield an overall benefit over 20 years of between £6.3 billion and £10 billion. For these benefits to be fully realised, the report states the need to prevent "those activities currently having detrimental impacts on some areas of the marine environment and their species, such as bottom-towed fishing gear" (Gonzalez-Alvarez, 2012).

Davies *et al.* (2021) valued the expected impact of a ban on bottom-contact fishing in the EU's offshore Nature 2000 sites. The results show a cumulative net benefit of €8.5 billion. Costs, made up of lost fishing value, loss of ecosystem services from displacement activity, and administration costs, did initially outweigh the benefits gained by improved ecosystem service values, but only for the first two years. From year 3, the benefits outweighed the costs and the cumulative net benefit rose for the remainder of the 20-year period analysed. The main drivers of the improvement value came from *bioremediation of waste* and *nutrient cycling*. These supporting services were assigned high economic values which amounted to a large economic gain upon improvement. *Gas and climate regulation* was also valued highly and contributed to 11% of the total overall gain in value.

These socioeconomic analyses are limited to what is quantifiable. There are many benefits that people derive from marine protected areas that are intangible and difficult to measure. This includes the value that people attribute to nature even though there is no direct benefit from it, known as the *non-use value* of an area (Russi *et al.,* 2016). For some, there is value gained from knowing that the site is protected both for future generations and for the benefit of species living within it (Kumar, 2012). Others may see value in the aesthetic experience of a site, or its value in maintaining livelihoods and job opportunities (Angulo-Valdes and Hatcher, 2010). Other examples of non-use benefits from marine and coastal protected areas include those related to maintaining future fishing opportunities, educational opportunities or aesthetic experiences (Angulo-Valdes and Hatcher, 2010).

On a national and international level, MPAs are also important tools for achieving climate and biodiversity related targets. Jankowska *et al.* (2022) estimate that effective MPA management can achieve 2% of the carbon mitigation needed to limit global warming to 2 degrees as set out in the Paris Agreement. Seafloor protection plays a leading role in this, primarily on account of avoided emissions (Jankowska *et al.,* 2022). National and international targets such as the UK's '30by30' pledge (Cunningham *et al.,* 2021) and Convention for Biological Diversity targets will require that MPAs are effectively managed to achieve what they were designated for and enhance marine ecosystems.

3. Study objectives

The primary objective of this study is to model ecosystem service valuations for the UK's offshore benthic MPAs and calculate the annual net impact value over a 20-year period of a bottom-contact fishing ban (in £). This is calculated by subtracting the costs (annual fishing value lost, administrational costs and displacement costs of the sector outside MPAs) from the monetary gain in ecosystem service values.

With a particular focus on bottom-trawling fishing, the gear to be covered by the analysis includes:

- Bottom otter trawls (single and twin)
- Bottom pair trawls
- Beam trawls
- Nephrops trawl
- Dredges (towed and mechanised)
- Danish and Scottish seining

However, in principle this methodology should also be able to be applied to other activities that threaten marine habitats and species. Examples of these include:

- The anchoring of oil and gas rigs
- Drilling and disposal of cuttings from oil/gas wells
- The anchoring of floating turbines
- Laying of cables and pipelines
- Piling of wind turbine foundations

4. Method

The method was constructed based on three previous reports into ecosystem services in the marine environment:

- Moran *et al.* (2008) The Marine Bill – Marine Nature Conservation Proposals – Valuing the benefits. Final Report, CRO380: Natural Environment Group Science Division. SAC Ltd and University of Liverpool, commissioned by Defra.
- Gonzalez-Alvarez, J. (2012) Valuing the Benefits of Designating a Network of Scottish MPAs in Territorial and Offshore Waters: A Report to Scottish Environment LINK. *Scottish Environment Link 2012.*
- Davies *et al.* (2021) Valuing the impact of a potential ban on bottom-contact fishing in EU Marine Protected Areas. *New Economics Foundation and Seas At Risk.*

The extent, timing and rate of ecosystem improvements was adapted from Moran *et al.* (2008) and Gonzalez-Alvarez (2012). The costs and displacement calculations were adapted from Davies *et al.* (2021).

Calculations were made in euros and then converted to pound sterling using the latest available average GBP/EUR exchange rate of 1.1732 for 2022 found on the ONS National Accounts website. In line with the Green Book recommendations, a 2% rate of inflation and a 3.5% discount factor were applied to the calculated values and costs to show their present value across the 20-year period.

3.1. Ecosystem services

The ecosystem services used in this analysis mirrored the goods and services analysed by Beaumont *et al.* (2008) and are defined in Table 1 below.

Table 1: Goods and services identified and defined by Beaumont et al. (2008) as being provided by UK marine biodiversity.

Good or service	Definition
Provisioning Services	
Food provision	Plants and animals taken from the marine environment for human consumption
Raw materials	The extraction of marine organisms for all purposes, except human consumption
Regulation services	
Gas and climate regulation	The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms
Disturbance prevention and alleviation	The dampening of environmental disturbances by biogenic structures
Bioremediation of waste	Removal of pollutants through storage, dilution, transformation and burial
Cultural services	
Cultural heritage and identity	The cultural value associated with the marine environment, e.g. for religion, folk lore, painting, cultural and spiritual traditions
Cognitive values	Cognitive development, including education and research, resulting from marine organisms
Leisure and recreation	The refreshment and stimulation of the human body and mind through the perusal and engagement with living marine organisms in their natural environment
Non-use values - bequest and existence	Value which we derive from marine organisms without using them
Option use value	Currently unknown potential future uses of the marine environment
Supporting services	
Nutrient cycling	The storage, cycling and maintenance of availability of nutrients mediated by living marine organisms
Resilience and resistance	The extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping to alternate states
Biologically mediated habitat	Habitat which is provided by living marine organisms

3.2. Ecosystem service value improvements

Calculating improvements in the value of the selected ecosystem services requires five steps:

- Creating *impact coding* that indicates: the extent to which an ecosystem service will improve over a 20-year period within a given habitat type, the time taken for the improvement to occur, and the rate (or trajectory) of improvement.
- Assigning appropriate monetary values per hectare to each ecosystem service.
- Applying the impact coding to these monetary valuations to determine the increase in the value per hectare of a particular ecosystem service over a 20-year period.
- Multiplying these increases in monetary value per hectare by the total area (in hectares) of a particular habitat present within the MPA network that is subject to demersal fishing.
- Summing these values to show the total monetary increase in value for each respective ecosystem service and the total overall economic gain.

3.2.1. *Impact coding*

The extent, timing and rate of ecosystem improvements was adapted from Moran *et al.* (2008) and Gonzalez-Alvarez (2012). This information was captured in the *impact coding* used in these reports, as shown in Table 2 from Moran *et al.* (2008) below.

Table 2: Impact coding used in Moran et al. (2008). This shows the expected improvement in selected ecosystem services across a range of habitat types. Source: Moran et al. (2008).

Goods and Services	Aphotic reef	Oceanic cold water coarse sediment	Oceanic cold water mixed sediment	Oceanic cold water mud	Oceanic cold water sand	Oceanic warm water coarse sediment	Oceanic warm water mixed sediment	Oceanic warm water mud	Oceanic warm water sand	Photic reef	Shallow strong tide stress coarse sediment	Shallow moderately tide stress coarse sediment	Shallow weak tide stress coarse sediment	Shallow strong tide stress mixed sediment	Shallow moderately tide stressed mixed sediment	Shallow weak tide stress mixed sediment	Shallow mud	Shallow sand	Shelf strong tide stress coarse sediment	Shelf moderately tide stress coarse sediment	Shelf weak tide stress coarse sediment	Shelf strong tide stress mixed sediment	Shelf moderately tide stress mixed sediment	Shelf weak tide stress mixed sediment	Shelf mud	Shelf sand
Resilience and resistance	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Biologically mediated habitat	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Nutrient recycling	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Gas and climate regulation	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Bioremediation of waste	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Option use values	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Non-use / bequest values	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E
Leisure and recreation	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E	M 5/20 E	M 5/20 E	H 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	L 5/20 E	M 5/20L	L 5/20 E	L 5/20 E	L 8/20 E	L 5/20 E	L 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S
Food provision	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S
Raw materials	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S
Disturbance prevention and alleviation	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S
Cultural heritage and identity	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S
Cognitive values	H 10/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 5/20 E	M 5/20 E	M 5/20L	M 5/20 E	M 5/20 E	VH 8/20 E	H 5/20 E	H 5/20 E	H 8/20 E	H 5/20 E	H 5/20 E

Each code contains four elements:

1. The extent to which the ecosystem service would improve following protection. This is expressed as a percentage of overall improvement in the provision of that ecosystem service relative to the baseline of no improvement. This was categorised by five possible levels of improvement shown in Table 3:

Table 3: The percentage improvements used in the impact coding. This shows the relative improvement in the provision of a particular ecosystem service compared to the baseline of business as usual.

Level of improvement	Code	% improvement versus BAU
Very high	VH	95%
High	H	70%
Medium	M	30%
Low	L	5%
Very Low	VL	0.50%

2. Time-profile: The time it would take to reach this level of improvement (0, 5, 8, 10, 15 or 20 years) and how long this level of improvement would be retained for (assumed to be 20 years in each case). Where the code was 0, it was assumed that the improvement would occur immediately.

3. Rate of improvement: The last element of the coding reflects that not all ecosystem services would improve in a linear fashion. In some cases, an ecosystem service could respond rapidly and in other cases be slower to improve. These different rates, or trajectories, of improvement were denoted by *S*, *L* and *E*. *S* indicates that most improvement occurs at the start of the time-profile (a logarithmic increase), *L* indicates a linear improvement and *E* indicates that most improvement occurs at the end of the time-profile (an exponential increase). This is illustrated in Figure 6 below.

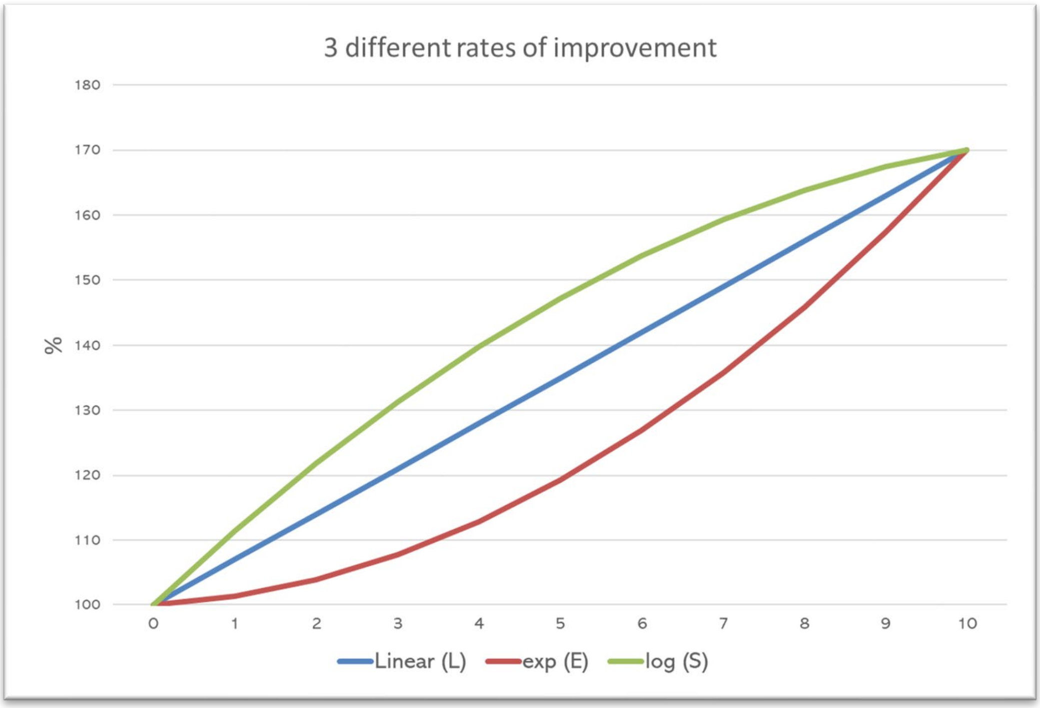


Figure 6: Rates of improvement. Assuming a 70% improvement over 10 years as an example, this graph shows the three potential rates of improvement used in this model. A given ecosystem service may improve rapidly at the start of the time period (green - S), others towards the end of the time period (red – E), and some may improve linearly (blue – L).

3.2.2. Habitat data

The habitat data and fished area data were derived exclusively for the area within benthic offshore MPAs (26,633,353 hectares) - including Special Areas of Conservation, Marine Conservation Zones and Nature Conservation MPAs, using JNCC's 'UK Offshore Marine Protected Areas 2020' GIS data. Area calculations were conducted in Projected Coordinate System European Terrestrial Reference System 1989 Lambert Azimuthal Equal-Area. The data for the UK is shown in Table 4.

Table 4: Habitat data used for the UK offshore benthic MPA network. The data provides total area per JNCC habitat and the corresponding areas that are subject to demersal fishing.

MARINE HABITAT - JNCC classification		**Extent of marine habitat**	**Demersal fishing - offshore benthic MPA**
JNCC habitat code	**JNCC habitat name**	**Area in offshore benthic MPA (km²)**	**Fished area of Marine landscape in MPA (km²)**
M.ArLB.Mx	Arctic lower bathyal Mixed sediment	1,572.95	-
M.ArLB.Sa	Arctic lower bathyal Sand	5.87	-
M.ArMB.Co	Arctic mid bathyal coarse sediment	68.88	1.62
M.ArMB.Mx	Arctic mid bathyal Mixed sediment	2,768.97	60.77
M.ArMB.Sa	Arctic mid bathyal Sand	1,596.61	-
M.AtLB.Co	Atlantic lower bathyal coarse sediment	1,076.14	0.65
M.AtLB.Mx	Atlantic lower bathyal Mixed sediment	1,698.43	2.68
M.AtLB.Mu	Atlantic lower bathyal mud or sandy mud to muddy sand	3,750.73	97.79
M.AtLB.Ro	Atlantic lower bathyal rock or other hard substrata	1,034.90	-
M.AtLB.Sa	Atlantic lower bathyal Sand	2,234.61	4.63
M.AtMA.Mu	Atlantic mid abyssal mud or sandy mud to muddy sand	-	-
M.AtMB.Co	Atlantic mid bathyal coarse sediment	5,635.47	188.59
M.AtMB.Mx	Atlantic mid bathyal Mixed sediment	14,244.91	45.35
M.AtMB.Mu	Atlantic mid bathyal mud or sandy mud to muddy sand	7,016.25	296.16
M.AtMB.Ro	Atlantic mid bathyal rock or other hard substrata	2,169.09	2.76
M.AtMB.Sa	Atlantic mid bathyal Sand	8,756.23	857.36
M.AtUA.Mx	Atlantic upper abyssal Mixed sediment	4.33	-
M.AtUA.Mu	Atlantic upper abyssal mud or sandy mud to muddy sand	0.44	-
M.AtUA.Ro	Atlantic upper abyssal rock or other hard substrata	2.41	-
M.AtUA.Sa	Atlantic upper abyssal Sand	1,328.55	4.08
M.AtUB.Co	Atlantic upper bathyal coarse sediment	1,612.73	367.11
M.AtUB.Mx	Atlantic upper bathyal Mixed sediment	2,914.00	167.62
M.AtUB.Mu	Atlantic upper bathyal mud	2,294.36	20.64
M.AtUB.Ro	Atlantic upper bathyal rock or other hard substrata	785.98	11.65
M.AtUB.Sa	Atlantic upper bathyal sand	2,740.74	841.55
M.AAUB.Co	Atlanto-Arctic upper bathyal coarse sediment	483.79	60.75
M.AAUB.Mx	Atlanto-Arctic upper bathyal Mixed sediment	2,390.78	621.13
M.AAUB.Mu	Atlanto-Arctic upper bathyal mud	89,995.18	1,213.85
M.AAUB.Sa	Atlanto-Arctic upper bathyal sand	144.15	1.03
SS.SCS.CCS	Circalittoral coarse sediment	3,941.33	1,148.09
SS.SMu.CFiMu	Circalittoral fine mud	0.93	0.32
SS.SMx.CMx	Circalittoral mixed sediment	345.23	65.21
SS.SMu.CSaMu	Circalittoral sandy mud	326.66	87.06
SS.SMu.CSaMu Or SS.SMu.CFiMu	Circalittoral sandy mud or Circalittoral fine mud	0.63	0.15
CR.HCR.DpSp	Deep sponge communities	26.87	0.41
CR.HCR	High energy circalittoral rock	149.76	18.15
IR.HIR	High energy infralittoral rock	0.39	0.18
SS.SCS.ICS	Infralittoral coarse sediment	716.14	293.53
SS.SMu.IFiMu	Infralittoral fine mud	-	-
SS.SMx.IMx	Infralittoral mixed sediment	36.6	10.68
SS.SMu.ISaMu	Infralittoral sandy mud	0.44	0
SS.SMu.ISaMu or SS.SMu.IFiMu	Infralittoral sandy mud or Infralittoral fine mud	0.27	0
CR.LCR	Low energy circalittoral rock	385.03	94.95
IR.LIR	Low energy infralittoral rock	4.64	1.57
CR.MCR	Moderate energy circalittoral rock	596.44	118.88
IR.MIR	Moderate energy infralittoral rock	7.63	1.31
SS.SCS.OCS	Offshore circalittoral coarse sediment	18,529.39	8,656.38
SS.SSa.IFiSa or SS.SSa.IMuSa	Offshore circalittoral fine sand or Offshore circalittoral muddy sand	2,364.37	899.2
SS.SSa.CFiSa or SS.SSa.CMuSa	Offshore circalittoral fine sand or Offshore circalittoral muddy sand	7,678.12	2,364.80
SS.SMx.OMx	Offshore circalittoral mixed sediment	1,111.31	841.63
SS.SMu.OMu	Offshore circalittoral mud	3,390.26	2,770.52
SS.SSa.OSa	Offshore circalittoral sand	25,223.53	10,335.30
SS	Sublittoral sediment	149.16	52.58
unknown	unknown	13,760.08	193.79

3.2.3. *Converting codes for the latest habitat data*

The codes used by Moran *et al.* (2008) and Gonzalez-Alvarez (2012) corresponded to a range of habitat types within UK MPAs as defined by JNCC. Since these reports were written, these habitat classifications have been superseded and replaced with a new, more extensive list of habitats.

In order for the latest available data and classifications to be used, the coding shown in Table 2 was converted to be applied to the new habitat classifications.

This required identifying which of the new classifications matched closest with the old classifications based on where they are found (e.g. infra-/circalittoral/bathyal/abyssal) and what sort of sediment they describe (e.g. mud, sand, coarse). JNCC's guidance on how UKSeaMap landscapes were derived in 2006 was consulted to identify where 'shallow', 'shelf' and 'oceanic' waters were deemed to be. The reef classification was based on how much light the reef will get, meaning shallow or infralittoral and shelf or circalittoral reefs will get some light (i.e. photic) while bathyal/oceanic and abyssal/oceanic will be receive next to no light due to their depth (i.e. aphotic).

Where a particular new habitat type corresponded to more than one of the old landscape classifications, a new code was created based on a precautionary approach that adopted the lowest impact and longest time profile.

For example, a new habitat classification corresponded to two of the old habitat classifications that had coding of H 10/20 E and M 15/20 L respectively. In this case, the new habitat classification was given the impact coding of M 15/20 E (applying the lower impact, longer time profile and slower initial rate of improvement).

The resulting codes applied to the JNCC's latest landscape classifications are shown in Table 9 in the Appendix.

3.2.4. *Financial valuations*

To value the change in ecosystem services over time in monetary terms required that financial proxies were selected to represent a monetary value per hectare for each ecosystem service. These were obtained from the Ecosystem Services Valuation Database (ESVD) which provides the following explanation of the database:

"The Ecosystem Services Valuation Database (ESVD) has been developed with the long-term goal of providing robust and easily accessible information on the economic benefits of ecosystems and biodiversity, and the costs of their loss, to support decision making regarding nature conservation, ecosystem restoration and sustainable land management.

The focus of the ESVD is to gather information on economic welfare values related to ecosystem services measured in monetary units. By communicating such values in monetary units, we provide recognisable information that can be used to internalise the importance of Nature in decision making.

The ESVD currently contains over 8,600 value records from over 1100 studies distributed across all biomes, ecosystem services and geographic regions. Our repository of valuation studies contains over 2000 studies and the number is growing continuously so the number of value records in the ESVD will increase over time."

The valuations were filtered first based on the marine biome and the United Kingdom, then by each respective ecosystem service.

All values were provided in $/ha/year and adjusted from their original values to reflect 2020 prices. These were then converted to €/ha/year at a rate of 1 EUR = 1.207 USD in line with Davies *et al.* (2021).

Table 5 shows the final financial proxies used to represent the value of goods and services listed by Moran *et al.* (2008):

Table 5: An overview of the financial proxies chosen from the Ecosystem Services Valuation Database (ESVD) for each ecosystem service and the source paper this was derived from. All figures are

adjusted in the ESVD to 2020 prices and have been converted to euro values based on an exchange rate of 1 EUR = 1.207 USD. In some cases, the values were adopted directly from Davies et al. (2021).

Goods/Services	ESVD Service	€/ha/y	Source
Resilience and resistance	Moderation of extreme events	1.85	Hussain *et al.* (2010)
Biologically mediated habitat	Biodiversity protection	7.24	Beaumont *et al.* (2008)
Nutrient recycling	Nutrient cycling	157.44	Davies *et al.* (2021)
Gas and climate regulation	Climate regulation / C-sequestration	91.77	Beaumont *et al.* (2008) & Hussain *et al.* (2010)
Bioremediation of waste	Waste treatment	180.41	Mangi *et al.* (2011)
Option use values	Existence / bequest values	46.23	Jobstvogt *et al.* (2014)
Non-use / bequest values	Existence / bequest values	46.23	Jobstvogt *et al.* (2014)
Leisure and recreation	Opportunities for recreation and tourism	359.30	Davies *et al.* (2021)
Food provision	Food	46.26	Beaumont *et al.* (2008)
Raw materials	Raw materials	7.31	Beaumont *et al.* (2008)
Disturbance prevention and alleviation	Moderation of extreme events	1.85	Hussain *et al.* (2010)
Cultural heritage and identity	Aesthetic information; Inspiration for culture, art and design; Spiritual experience	1.91	Hussain *et al.* (2010)
Cognitive values	Information for cognitive development	1.91	Hussain *et al.* (2010)

Some of the figures used for particular goods and services are aggregates of more than one service. Gas and climate regulation combines values for climate regulation (34.65 €/ha/y) and carbon sequestration (57.12 €/ha/y).

Marine leisure and recreation has a much higher value than all other ecosystem services, however values on the ESVD range to greater than 30,000 $/ha/year. The value of 359.30 €/ha/y is therefore not considered unreasonable and was adopted here for consistency across the reports.[1]

The value for bioremediation is adopted from Mangi *et al.* (2011a) which was a local-scale study. This value (180.41 €/ha/y) was a conservative choice, as the comparative national study by Beaumont *et al.* (2008) provided a value of 56,163.55 $/ha/y.

Although they were included in the model, some ecosystem services (non-use/bequest, option use and cognitive value) were given monetary value of zero in this study. This was a cautionary approach taken to reflect that these values may be considered intangible and therefore difficult to account for in economic

[1] Davies *et al.* (2021) identified four monetary values (per hectare per year) for leisure and recreation from the ESVD: €683.23, €377.66, €17,501.04 and €17.02. The value of 359.30 €/ha/y adopted for this model is calculated as an average of the three lower values.

decision making. It should be noted, however, that these ecosystems services would increase in value and could be accounted for in this model if required.

3.2.5. *Fishing data*

Global Fishing Watch fishing effort data was used to define the average footprint of vessels using bottom-towed gear in UK waters (henceforth referred to as 'demersal fishing'). Fishing effort data for all vessels defined as using 'trawlers', 'dredge_fishing' or 'other_seine' gear-types was downloaded from the Global Fishing Watch Marine Manager Portal for between 1st January 2015- 31st December 2022.

Global Fishing Watch use vessel tracking data collected from Automatic Identification Systems (AIS) equipment to track fishing activity and vessel types (Kroodsma et al., 2018). AIS must be installed as a legal requirement on all vessels over 15 m in length that fish in EU and UK waters. This means vessels smaller than 15 m in length are underrepresented in the data. As this analysis focuses on the UK's offshore waters, the impact of this on the fishing footprint is minimal.

Prior to mapping, the fishing effort data was cross-referenced with the EU fleet register (European Commission, 2022) to identify the 'main gear' each vessel in the data was registered with for each of the years studied. As UK vessels are not included in the EU fleet register after 2020 due to Brexit, the post-2020 UK vessel activity was cross referenced with a separate UK vessel list. Any vessels registered as using a gear type that was not considered to be a form of demersal towed gear (i.e. bottom trawl, dredge or demersal seine) was removed from the dataset. Vessels that were listed as Guard Vessels involved in offshore wind construction were also removed from the dataset for all years.

The activity from the remaining vessels recorded between 2015 and 2022, was then mapped as point data (0.01 x 0.01 decimal degree resolution) using ArcGIS Pro 2.9.5 (see Figure 5 above). After converting the data to raster layers, an 'average activity (2015-22)' layer was created using the Raster Calculator tool to find the mean fishing hours for each 0.01 dd cells using data from between 2015-2022. This layer was then used as the average fishing footprint to which the habitat data was clipped thereby extracting the habitat categories affected by bottom towed gear use. The fishing effort data used for this model only includes vessels using demersal towed gear and is not weighted according to vessel size or specific gear type. The landings values used to calculate lost fishing values are for landings using demersal towed gears registered in ICES Member Countries and are derived from ICES (2018) data. This includes EU landings as well as UK landings. The values for fishing value lost are therefore likely to be overestimated, as not all of this will fall within the UK fleet.

3.2.6. *Calculating the marginal improvement in ecosystem service value*

The marginal improvement in ecosystem services value was calculated in two steps:

1. Using the impact coding describe above, predict how the €/ha/year financial values for each ecosystem service and habitat type will improve over a 20-year period.
2. Multiply this marginal increase by the area of each habitat found within MPAs that is subject to demersal fishing. This provided a figure in euros for the value of improvement in a particular ecosystem service for a particular habitat type.

> ***Example: A calculation for a hypothetical ecosystem service and habitat type.***
>
> - Impact code: H 10/20 L
> - Financial proxy: 100 EUR/ha/year
> - Habitat area subject to demersal fishing: 50 ha
>
> The value of the ecosystem service would increase linearly (L) by 70% (H) over 10 years to 170 €/ha/year and remain there until year 20. This is a marginal increase of 70 €/ha/year after 10 years that equates to 70 x 50 = 3500 euros of additional value in ecosystem services (not accounting for inflation and present value).

Taking the sum of gains in ecosystem service values showed the overall gain across the offshore benthic MPA area for each year.

3.3. Costs and displacement values

The method for calculating costs and displacement values is based closely on the method used by Davies *et al.* (2021). This constitutes three elements:

- The operational public costs of implementing and enforcing a ban of bottom-contact fishing.
- The loss in fishing value incurred by the ban.
- The loss of ecosystem service value in adjacent areas following displacement of fishing activity to areas outside of the MPA network.

Operational costs

A yearly cost per hectare of €4.86 was adopted from Davies *et al.* (2021) who deduced the figure from the UN's Catalysing Ocean Finance report (Hudson and Glemarec, 2012) using their reported annual operational costs of $21,191,857,538 for protecting 10% of the world's oceans. If 10% of the world's oceans equates to 3,611 million hectares, this breaks down to an operation cost of $5.87 per hectare (€4.86 per hectare) per annum.

This value of 4.86 €/ha/y was applied to the area of MPA being analysed to estimate operational cost of enforcing a ban. On a site-by-site basis, the cost of managing an MPA to enforce the ban would vary significantly depending on the size of the MPA and the management method, so it is recommended that further analysis conducted at a smaller scale would require a case-by-case assessment of the costs involved.

Lost fishing values

The report adopted the assumption by Davies *et al.* (2021) that 25% of demersal fishing activity would be lost, with the remaining 75% being displaced.

Based on ICES (2018) landings data for vessels using demersal towed gear, the average annual landing values for offshore benthic MPAs in the UK was €96,030,287.07, resulting in a predicted loss of €24,007,571.77 per year.

Displacement impact ecosystem services

The 75% of displaced fishing activity was then assumed to have a negative impact on ecosystem services in areas outside of the MPA network. Considering that the quality of ecosystem services would be lower in unprotected sites, Davies *et al.* (2021) conservatively estimated that the quality of ecosystem services in areas outside the MPA network would equate to 90% of the value of ecosystem services calculated within the MPAs. This high estimate reflects the likelihood that targeted fishing effort may occur within protected sites due to healthier fish stocks. The impact of the displaced activity was therefore applied to 90% of the estimated value of ecosystem service improvement each year.

3.4. Adapting the methodology for a country-by-country approach

The analysis can be approached in two ways:

- Considering costs of implementing a ban across the entire offshore benthic MPA network.
- Considering the costs of implementing a ban across areas of the network that are still open to bottom contact fishing.

In line with the methods used by Davies *et al.* (2021), who considered the whole network of Natura 2000 sites when conducting a similar analysis for the European MPA network, the initial analysis here was conducted using the total UK offshore MPA area. This is likely to be an overrepresentation of the true cost in the sense that large areas of the MPA network, particularly within Scottish waters, are already closed to bottom-contact fishing as they cover waters deeper than 800m. This means that they are covered by default by the EU's Deep Sea Regulation that bans the use of bottom-towed gears below 800m depth – this is shown as the white areas in Figures 7 to 10. An argument could therefore be made that a more accurate way to work out the operation costs would be to only consider the area of MPAs that are *still open* to bottom contact fishing, rather than considering the entire offshore benthic area:

- The total UK MPA network area is **261,543 km^2**
- The area that remains open in Scotland is **33,733 km^2**.
- The area that remains open in England is **32,654.12 km^2**
- The area that remains open in Wales is **115.98 km^2**
- The area that remains open in Northern Ireland is **295.73 km^2**

It was therefore decided to provide one conservative UK wide analysis that calculates costs based on the entire UK offshore benthic MPA network, and a second set of results one that considers the costs of closing areas of the network that are still open to bottom-towed gear.

The latter approach also allowed the model to recreate the results for Scottish, English, Welsh and Northern Irish waters. This was not possible when considering the total MPA areas because in the case of Scotland, the area subject to bottom trawling represented a very low proportion of the total MPA area, whereas the opposite was true for England. This would compromise the accuracy of the results, as Scotland would face a disproportionate level of costs compared to England. This problem is avoided by aggregating for the whole of the UK but required a modified approach at an individual country level.

For the devolved nations, habitat data, areas subject to demersal fishing and landing values were broken down for Scottish, Welsh, Northern Irish and English waters respectively. The methodology remained the same as outlined previously, and the operational costs were based on the area of offshore MPAs that currently remain open to bottom-contacting gear. For reference, maps outlining the areas of Scottish, Welsh, English and Northern Irish waters already closed to bottom-towed gear are shown in Figures 7 to 10.[2]

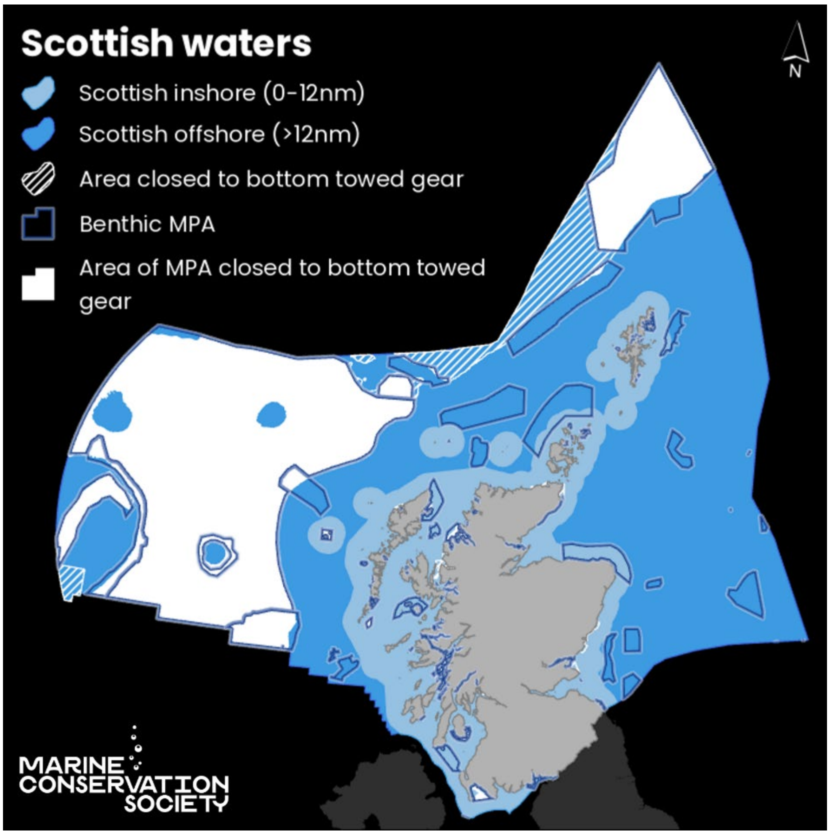


Figure 7: A map of Scottish waters showing areas that are already closed to bottom towed gear and covered by the EU's Deep Sea Regulation.

[2] Maps produced contain information from Scottish Government (Marine Scotland) licensed under the Open Government Licence v3.0. Contains Joint Nature Conservation Committee data © copyright and database right [2020]. Contains Natural England data © copyright and database right [2020]. Contains NatureScot data © copyright and database right [2020]. Contains Natural Resource Wales data © copyright and database right [2018]. Contains Northern Ireland Environment Agency data © copyright and database right [2019]. Contains UK Hydrographic Office data © copyright and database right [2020]. Contains Ordnance Survey data © copyright and database right [2020].

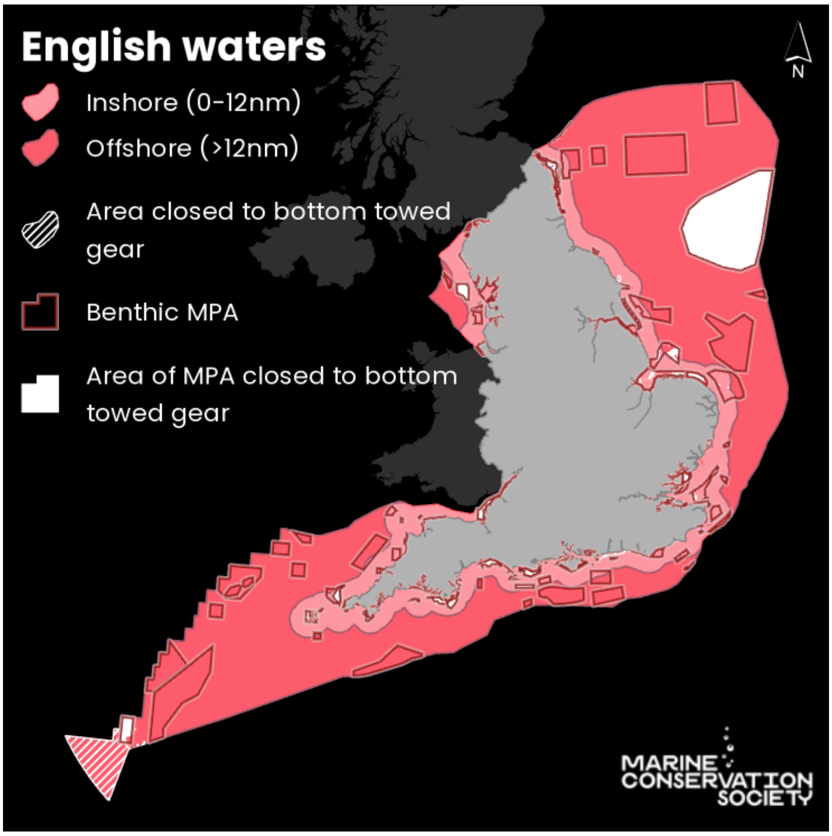


Figure 8: A map of English waters showing areas that are already closed to bottom towed gear and covered by the EU's Deep Sea Regulation.

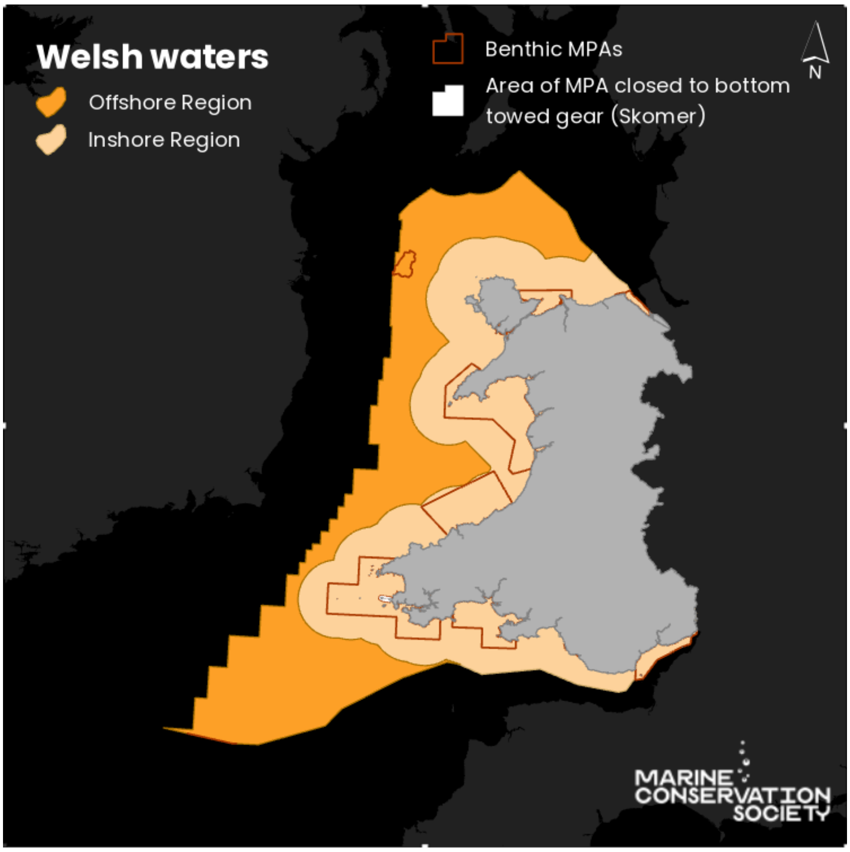


Figure 9: A map of Welsh waters showing one benthic MPA (Croker Carbonate Slabs SAC) in offshore waters, that remains open to bottom towed gear.

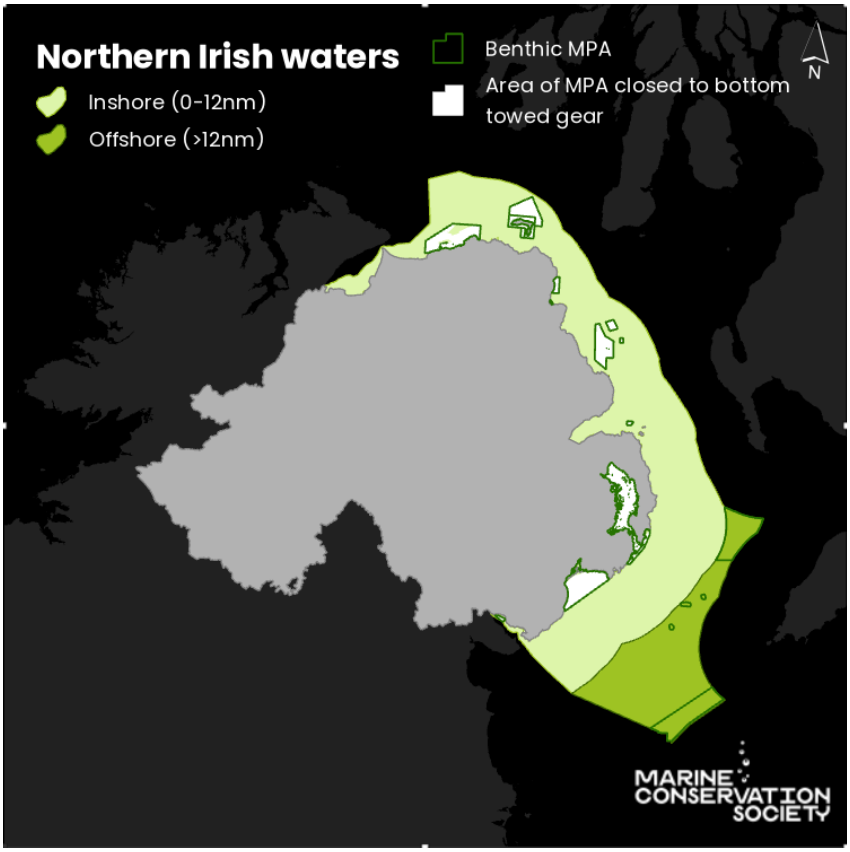


Figure 10: A map of Northern Irish waters, including offshore benthic MPAs open to bottom towed gear.

4. Results

4.1. Part 1: Results based on costs of protecting the entire offshore benthic MPA network

4.1.1. UK entire offshore benthic MPA network

The results show an overall socioeconomic net benefit to society of £2.57 billion over the whole 20-year period. As shown in Figure 11, the cumulative costs outweigh the improvement in value for the first five years before they effectively become even in year 6. From year 7, the cumulative net improvements outweigh the costs for the remainder of the 20-year period. The total monetary value of ecosystem services increases by £6.64 billion over the full period. Costs and displacement values rise to £4.07 billion in total, leaving an overall net gain of £2.57 billion.

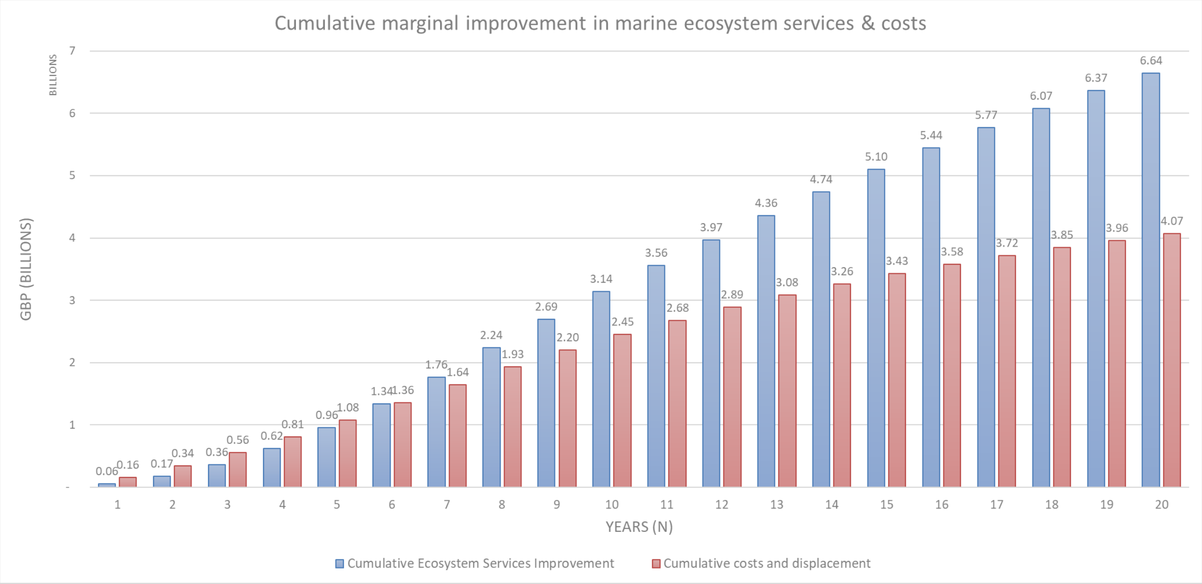


Figure 11: A comparison of the cumulative marginal improvement in ecosystem service value (in blue) versus the cumulative costs and displacement values (in red) across a 20-year period following a ban on bottom-contact fishing within the UK's offshore benthic MPAs. Values are shown in £ billions.

Subtracting the cumulative costs and displacement values from the cumulative gain in ecosystem service value, Figure 12 shows that the net impact becomes positive from year seven.

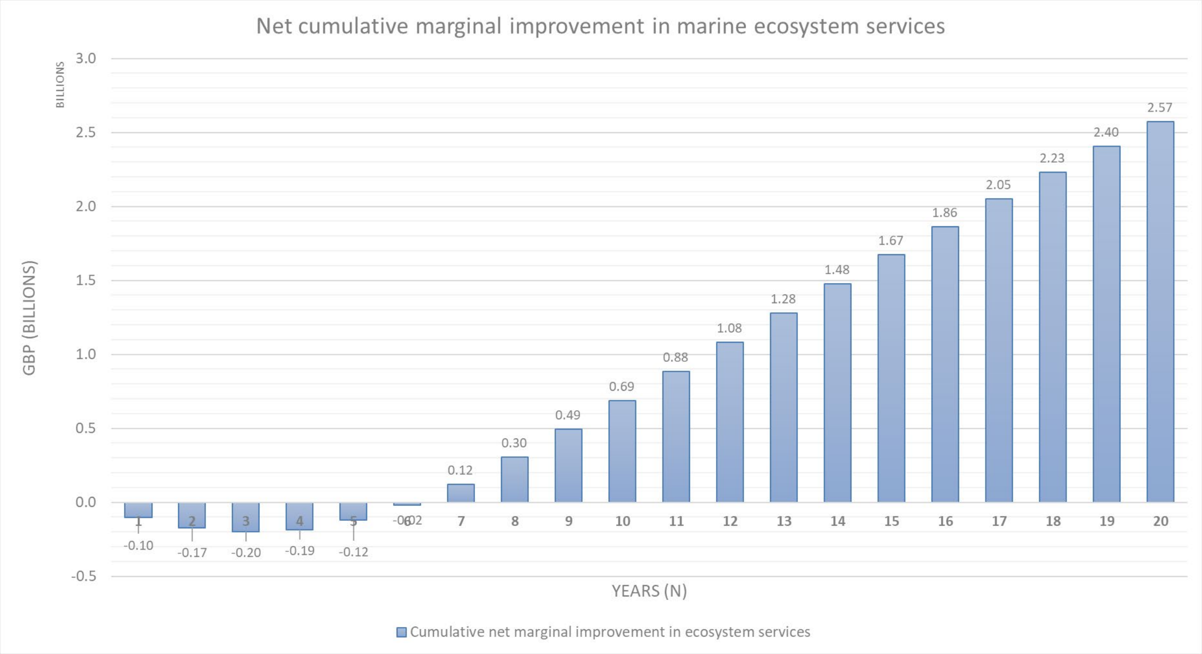


Figure 12: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in the UK offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values. Values are shown in £ billions.

Table 6 outlines the annual marginal improvement in the value of each ecosystem service. The annual total across all ecosystem services peaks at £474 million in year 8. This reflects the impact coding in which most ecosystem services reach their peak value between 5 and 10 years. After this, the effect of the 3.5% discounting reduces their absolute value. In total, there is a present value of £6.6 billion improvement in the monetary value of ecosystem services within the offshore benthic MPA network across 20 years.

Table 6: The annual value of improvement (in £ millions) for each ecosystem service for the UK offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Annual total (£ millions)
Years	1	0.147	0.574	12.486	7.278	14.308	19.826	0.589	0.093	0.024	0.024	**55.3**
	2	0.331	1.295	28.165	16.417	32.274	38.485	0.557	0.088	0.022	0.023	**117.7**
	3	0.546	2.135	46.426	27.061	53.200	56.548	0.528	0.083	0.021	0.022	**186.6**
	4	0.784	3.069	66.729	38.896	76.465	73.949	0.500	0.079	0.020	0.021	**260.5**
	5	1.041	4.074	88.593	51.640	101.519	90.637	0.474	0.075	0.019	0.020	**338.1**
	6	1.219	4.769	103.714	60.454	118.845	89.822	0.449	0.071	0.018	0.019	**379.4**
	7	1.411	5.524	120.115	70.013	137.639	89.469	0.425	0.067	0.017	0.018	**424.7**
	8	1.620	6.339	137.837	80.344	157.947	89.562	0.403	0.064	0.016	0.017	**474.1**
	9	1.564	6.119	133.065	77.562	152.479	86.196	0.381	0.060	0.015	0.016	**457.5**
	10	1.512	5.917	128.660	74.995	147.431	83.077	0.361	0.057	0.014	0.015	**442.0**
	11	1.456	5.699	123.932	72.239	142.013	78.694	0.342	0.054	0.014	0.014	**424.5**
	12	1.404	5.496	119.510	69.661	136.947	74.542	0.324	0.051	0.013	0.013	**408.0**
	13	1.356	5.305	115.368	67.247	132.199	70.609	0.307	0.049	0.012	0.013	**392.5**
	14	1.310	5.126	111.478	64.980	127.743	66.884	0.291	0.046	0.012	0.012	**377.9**
	15	1.257	4.918	106.938	62.333	122.539	63.355	0.276	0.044	0.011	0.011	**361.7**
	16	1.190	4.658	101.295	59.044	116.074	60.012	0.261	0.041	0.010	0.011	**342.6**
	17	1.127	4.412	95.951	55.929	109.950	56.846	0.247	0.039	0.010	0.010	**324.5**
	18	1.068	4.180	90.888	52.978	104.149	53.847	0.234	0.037	0.009	0.010	**307.4**
	19	1.012	3.959	86.093	50.183	98.654	51.006	0.222	0.035	0.009	0.009	**291.2**
	20	0.958	3.750	81.551	47.535	93.449	48.315	0.210	0.033	0.008	0.009	**275.8**
	ES Total (£ millions)	**22.312**	**87.318**	**1898.795**	**1106.786**	**2175.823**	**1341.681**	**7.382**	**1.166**	**0.295**	**0.305**	**6641.9**

Looking at the results strictly on a year-by-year basis, Table 7 and Figure 13 display the annual gains in ecosystem value compared to the annual costs and displacement values following the introduction of the ban. In the first three years, the annual marginal gain in ecosystem services value is outstripped by the yearly costs and displacement values. From year 4, the annual marginal gain begins to exceed the annual costs and displacement value. In year 7, the cumulative gain exceeds the cumulative costs. The annual improvement in ecosystem service valuations peaks in year 8 at £474.1 million. After this point, the annual improvement starts to decline as maximum improvement has been achieved for many ecosystem services and habitat combinations, and the discounting factor begins to erode their absolute value.

Table 7: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the UK offshore benthic MPA network. The cumulative net marginal impact shows the economic value in terms of gains in ecosystem services following the bottom-

contact fishing ban over a 20-year period. Costs are calculated based on the operational cost of enforcing a ban across the entire UK offshore benthic MPA network.

		Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	**Cumulative net marginal impact (£ millions)**
Year	1	55.3	55.3	157.4	157.4	-102.1	**-102.1**
	2	117.7	173.0	186.9	344.3	-69.2	**-171.3**
	3	186.6	359.6	216.6	560.9	-30.0	**-201.3**
	4	260.5	620.1	245.3	806.2	15.2	**-186.1**
	5	338.1	958.2	272.3	1078.5	65.8	**-120.3**
	6	379.4	1337.6	278.1	1356.6	101.3	**-19.0**
	7	424.7	1762.3	284.3	1640.9	140.4	**121.4**
	8	474.1	2236.4	291.0	1931.8	183.2	**304.6**
	9	457.5	2693.9	268.7	2200.5	188.8	**493.3**
	10	442.0	3135.9	248.5	2449.0	193.6	**686.9**
	11	424.5	3560.4	228.8	2677.8	195.6	**882.5**
	12	408.0	3968.3	210.9	2888.7	197.0	**1079.6**
	13	392.5	4360.8	194.6	3083.4	197.8	**1277.4**
	14	377.9	4738.7	179.8	3263.1	198.1	**1475.5**
	15	361.7	5100.3	165.4	3428.6	196.3	**1671.8**
	16	342.6	5442.9	151.3	3579.8	191.3	**1863.1**
	17	324.5	5767.5	138.4	3718.3	186.1	**2049.2**
	18	307.4	6074.9	126.8	3845.1	180.6	**2229.8**
	19	291.2	6366.0	116.2	3961.3	175.0	**2404.8**
	20	275.8	6641.9	106.5	4067.8	169.3	**2574.1**
	Total (£ millions)	6641.9	6641.9	4067.8	4067.8	2574.1	**2574.1**

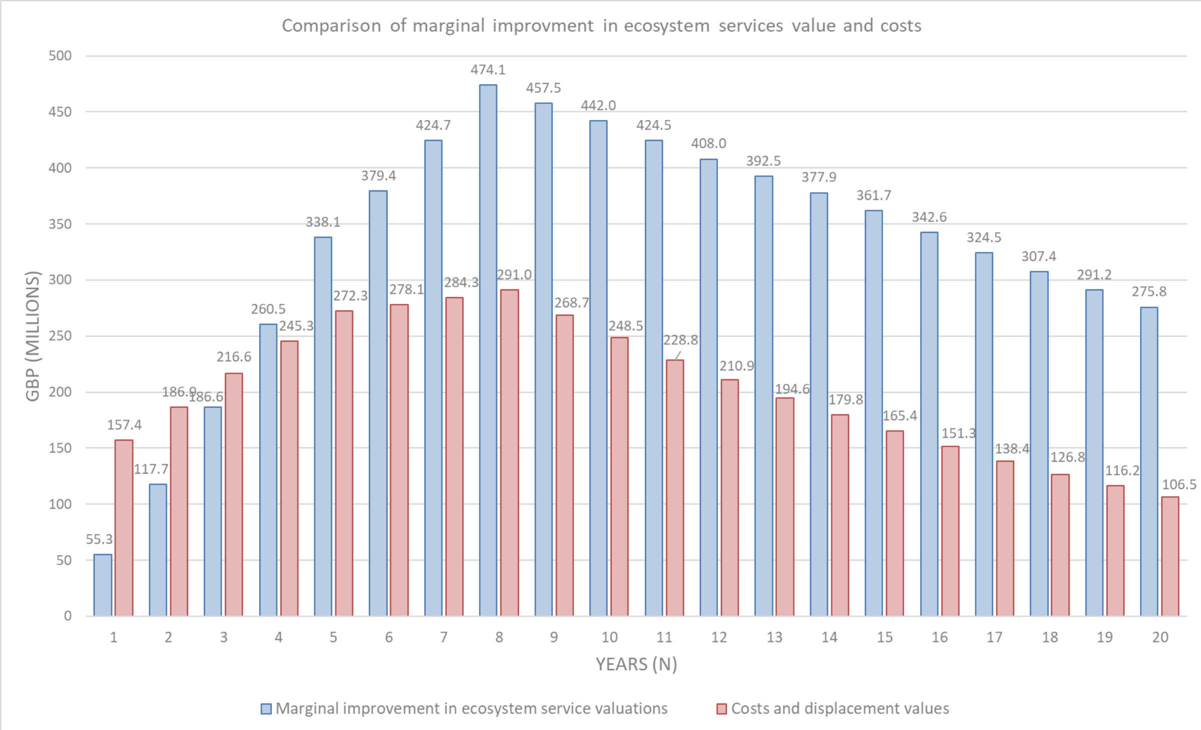


Figure 13: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for the UK offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban across the entire UK offshore benthic MPA network.

Figure 14 shows the annual net marginal impact. The net yearly impact becomes positive in year 4 and increases substantially between years 4 and 8. After this point, the marginal increases are observed until year 14 where they peak at £198.1 million, after which the annual net impact starts to decline. This again reflects that, based on the impact coding used in the calculations, the maximum level of improvement has been achieved by year 8 for most combinations of ecosystem service and habitat type. After this point, the discounting factor applied results in a drop in annual net impact value over time.

There are four ecosystem services that are the main drivers of this socioeconomic gain: Bioremediation of waste, nutrient cycling, leisure and recreation, and gas and climate regulation. As shown in Figure 15, these make up the majority of the overall £6.6 billion improvement in the value of ecosystem services in the offshore benthic MPA network. This reflects the significantly larger financial valuations that were assigned to these ecosystem services.

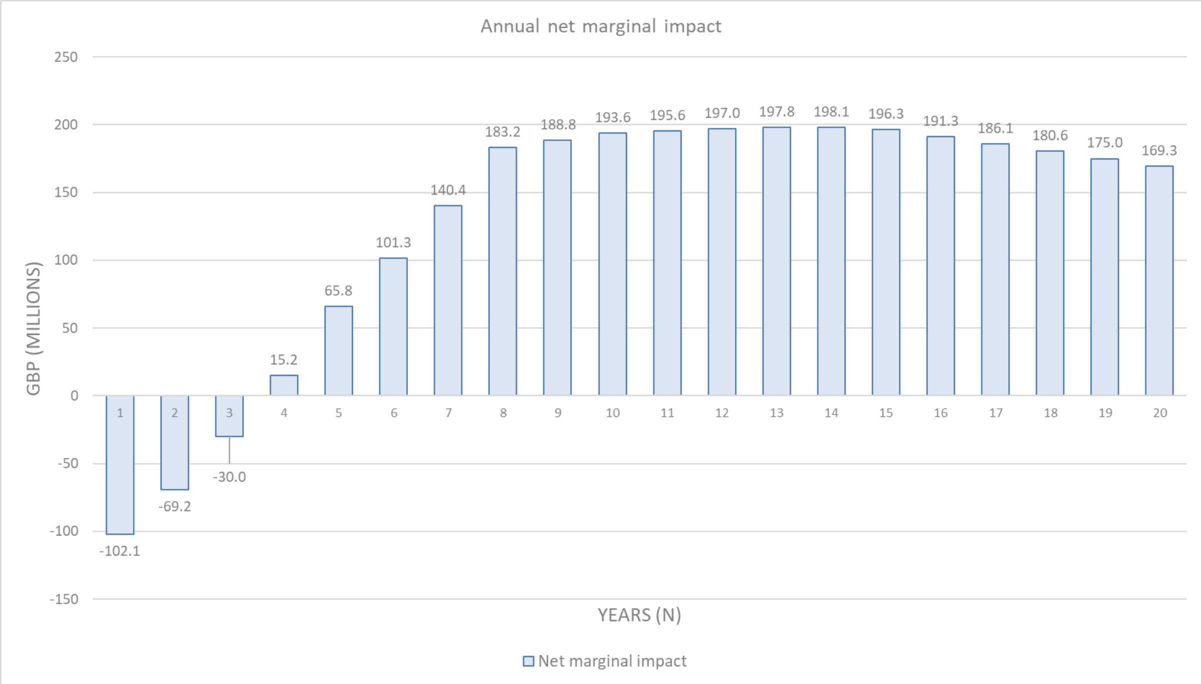


Figure 14: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the UK's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban across the entire UK offshore benthic MPA network.

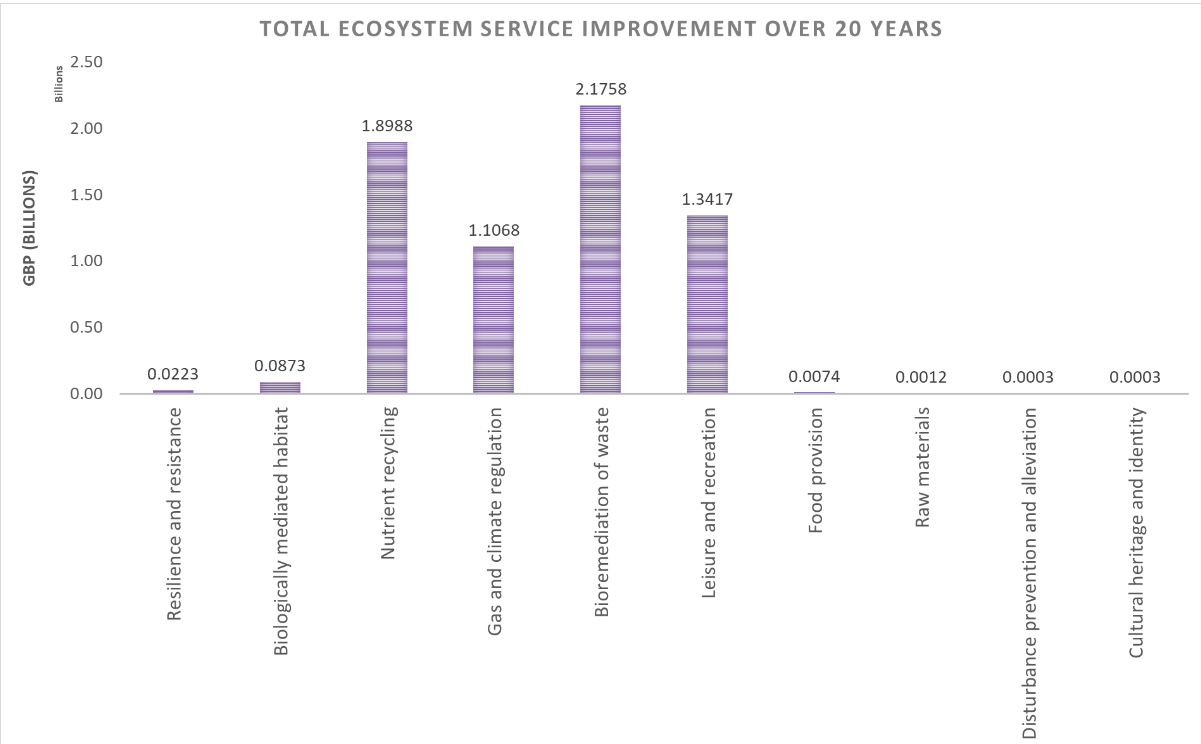


Figure 15: A comparison of the improvement in value of ecosystem services. The majority of the increase in overall value is driven by bioremediation of waste, nutrient recycling, leisure and recreation, and gas & climate regulation.

4.2. Part 2: Results based on costs of protecting benthic MPAs currently open to bottom-towed gear

4.2.1. UK offshore benthic MPA Network

When considering only the costs of protecting the area of offshore benthic MPAs that remain open to bottom-towed gear, there is an overall socioeconomic benefit to society in the UK beginning in the 3rd year following a ban on bottom-gear fishing in the offshore benthic MPA network that rises to £3.5 billion over the 20-year period.

It takes only 3 years for the cumulative gains in ecosystem services value to outstrip the cumulative costs and displacement values following implementation of a ban (see Figure 16 below). There remains a total cumulative gain of £6.6 billion in ecosystem services value across the 20-year period versus £3.1 billion in costs and displacement values.

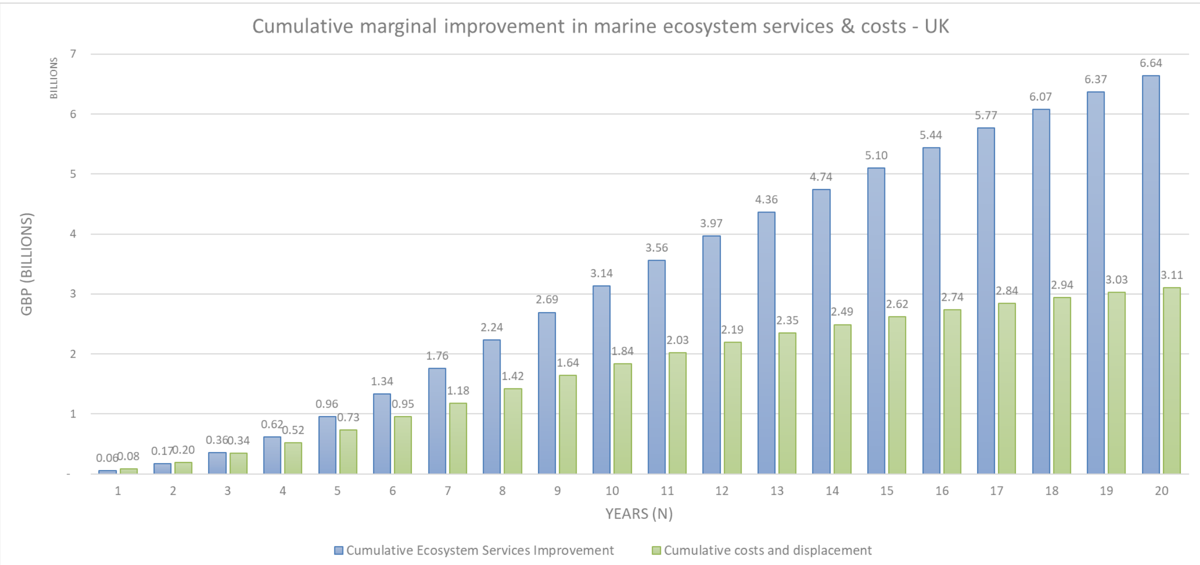


Figure 16: A comparison of the cumulative marginal improvement in ecosystem service value (in blue) versus the cumulative costs and displacement values (in green) across a 20-year period following a ban on bottom-contact fishing within the UK's offshore benthic MPAs. Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPA's that are currently open to bottom-towed gear.*

The net impact of this becomes positive in year 3 and rises steadily to £3.5 billion (see Figure 17). For years 1 and 2, there is a net deficit of only £25 million and £22 million respectively which is marginal given the scale of the figures used in this analysis. Therefore, when considering the costs of implementing a ban in offshore benthic MPAs that remain open to bottom-contacting gear, the socioeconomic net benefit to society is realised in the relative short term and grows substantially over the 20-year period.

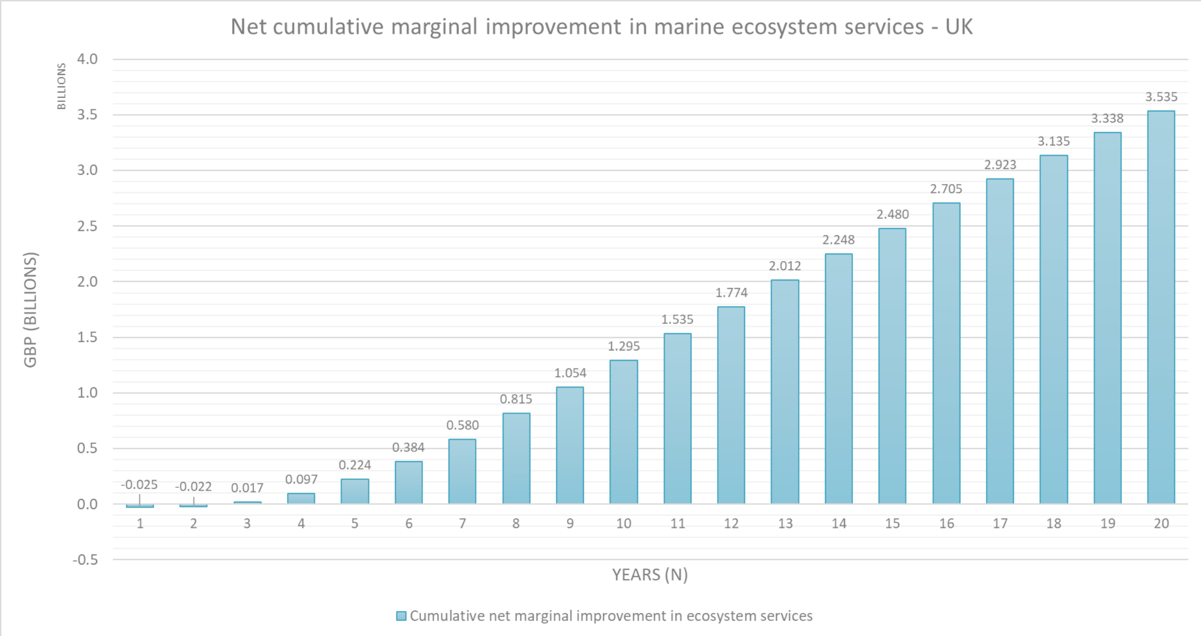


Figure 17: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in the UK offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values. Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPA's that are currently open to bottom-towed gear.*

On a yearly basis, the net annual impact becomes positive in the second year and increases steadily until year 8 before levelling out (see Figure 18). The annual net impact peaks at £240.6 million in year 10 and decreases afterwards due to the discounting value applied.

The drivers of the gain in ecosystem service values remain bioremediation of waste, nutrient cycling, leisure and recreation, and gas and climate regulation. These are shown in Figure 35 in the appendix.

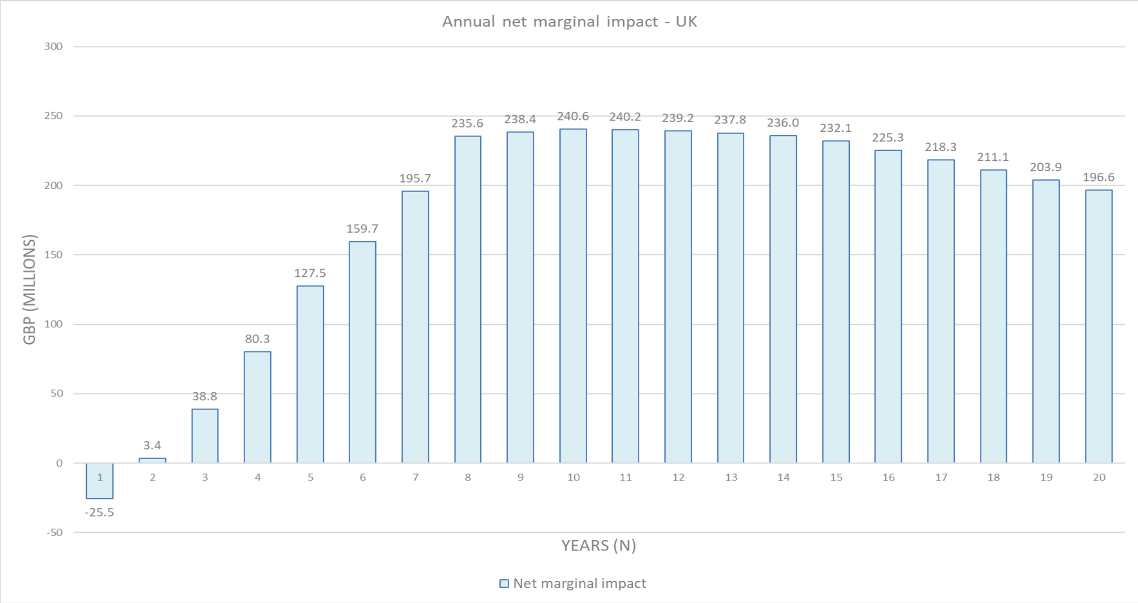


Figure 18: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the UK's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in the UK's offshore benthic MPAs that currently remain open to bottom-contacting gear.

4.2.2. Scottish offshore benthic MPA network

For Scotland, there is an overall socioeconomic benefit to society beginning in the 5th year following a ban on bottom-gear fishing in the offshore benthic MPA network that rises to £0.88 billion over the rest of the 20-year period.

The cumulative gains in ecosystem services value begin to outstrip the cumulative costs and displacement values in the 5th year following implementation of a ban (see Figure 19 below). Across a 20-year period, there is a cumulative gain of £1.76 billion in ecosystem services value versus cumulative costs and displacement values of £0.88 billion.

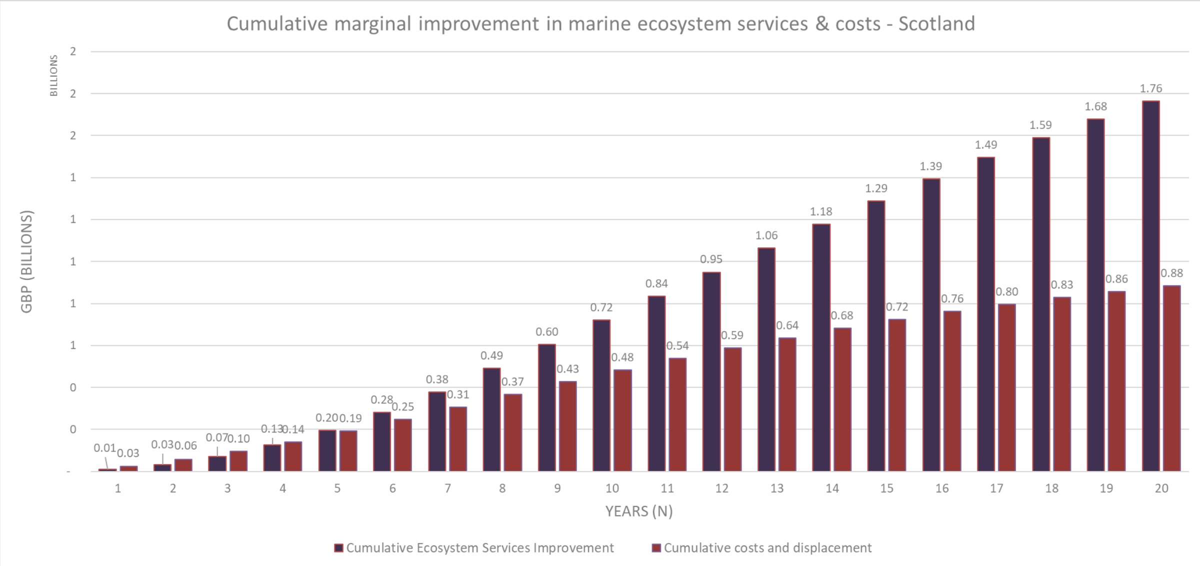


Figure 19: A comparison of the cumulative marginal improvement in ecosystem service value (in blue) versus the cumulative costs and displacement values (in red) across a 20-year period following a ban on bottom-contact fishing within Scotland's offshore benthic MPAs. Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear.*

Figure 20 shows that the overall net socioeconomic impact becomes positive in year 5 and rises to £0.88 billion by year 20. Although it takes 5 years to achieve a net positive impact, the downside for the first 4 years remains below £25 million (see Table 14 in the appendix) which is modest compared to the £888.1 million of net gain by year 20.

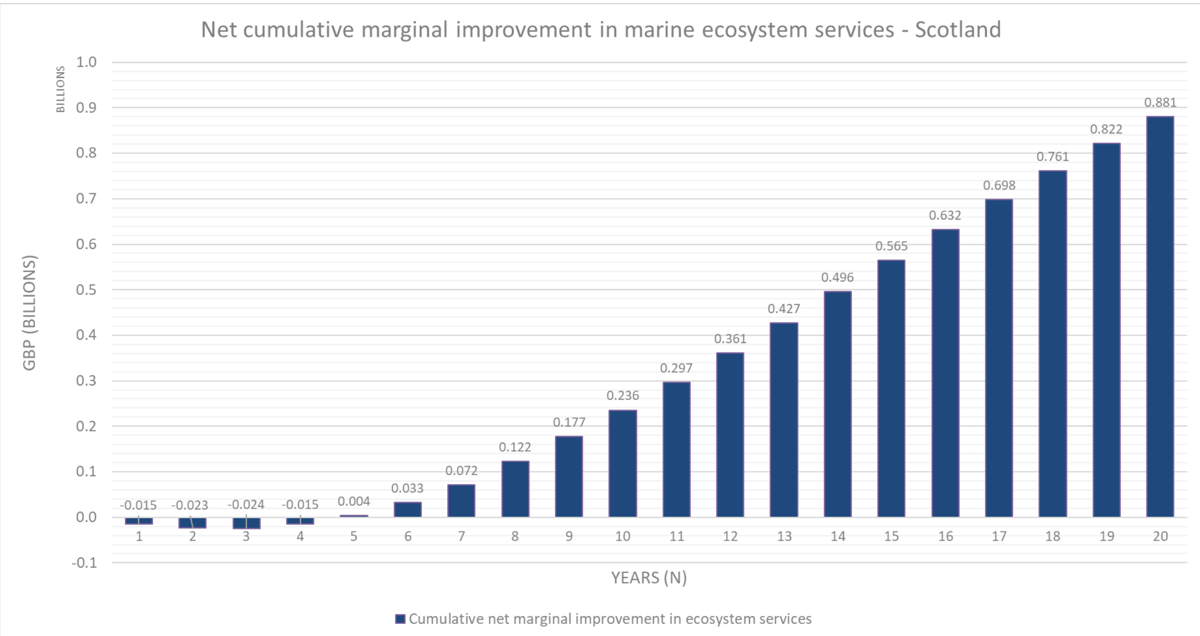


Figure 20: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in the Scottish offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values.*

*Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear.*

Figure 21 shows that the net annual impact becomes positive in year 4, increases steadily until year 8 and then continues with a modest increase until year 15. The annual net impact peaks at £69.3 million in year 15.

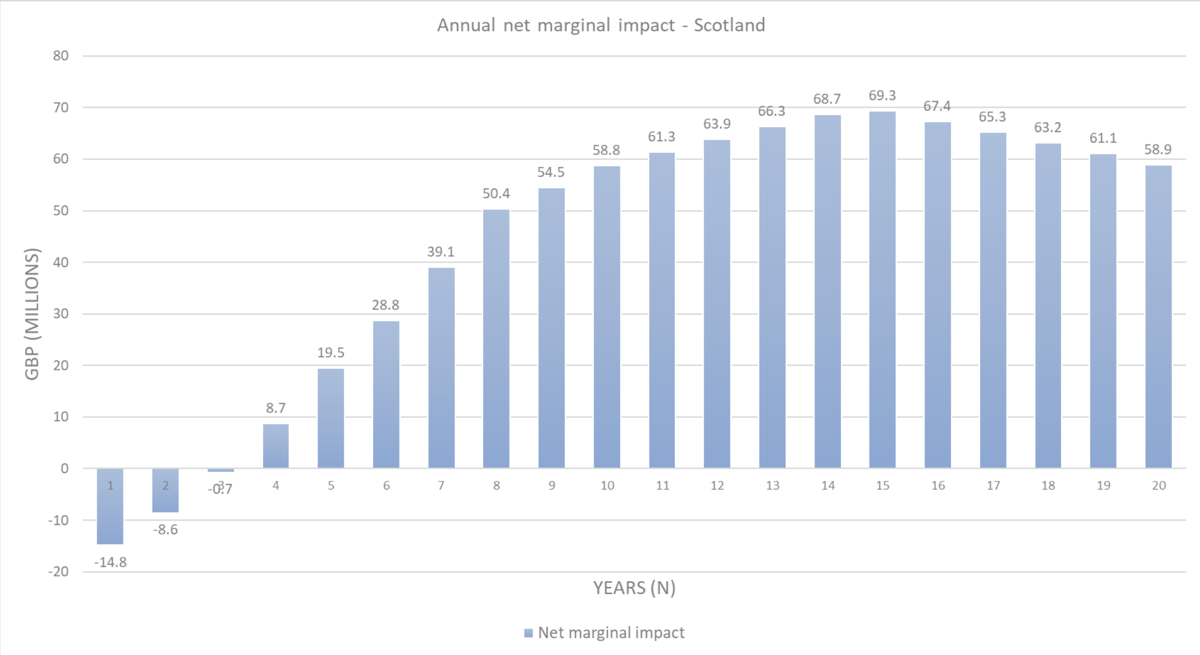


Figure 21: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for Scotland's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in the Scottish offshore benthic MPAs that currently remain open to bottom-contacting gear.

The drivers of the gain in ecosystem service values are the same as for the UK and shown in Figure 37 in the appendix.

4.2.3. English offshore benthic MPA network

For England, there is an overall socioeconomic net benefit to society beginning in the 2nd year following a ban on bottom-gear fishing in the offshore benthic MPA network that reaches £2.60 billion by year 20.

The net cost of implementing the ban in the first year amounts to only £10.8 million (see Table 16 in the appendix). From year 2, the cumulative gains in ecosystem services value begin to outstrip the cumulative costs and displacement values. Across a 20-year period, there is a cumulative gain of £4.78 billion in ecosystem services value. In comparison, cumulative costs and displacement values amount to £2.19 billion (see Figure 22).

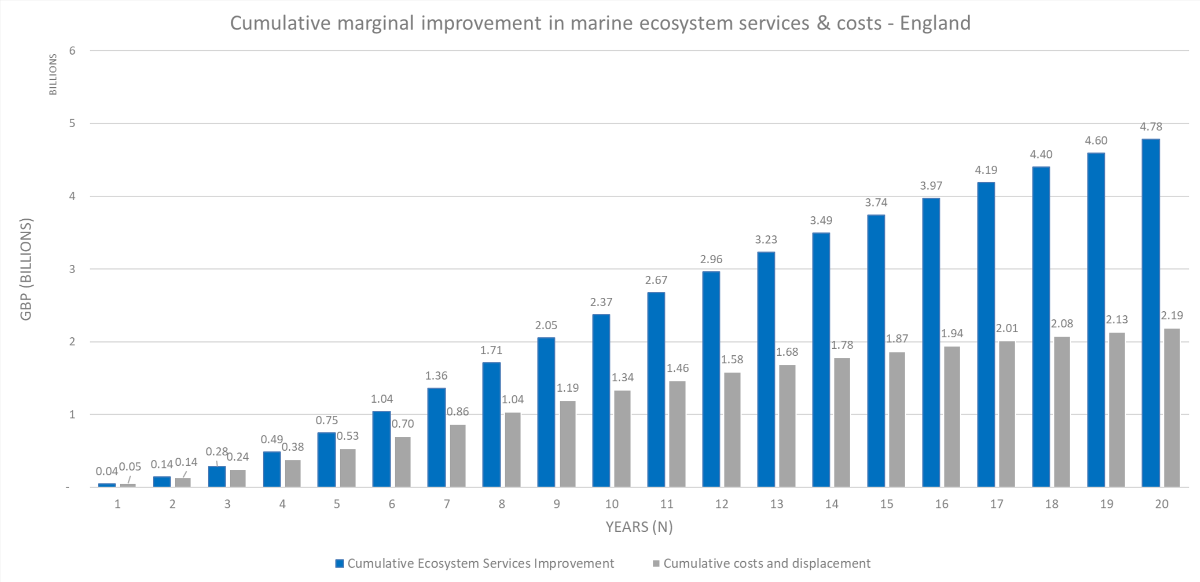


Figure 22: A comparison of the cumulative marginal improvement in ecosystem service value (in blue) versus the cumulative costs and displacement values (in grey) across a 20-year period following a ban on bottom-contact fishing within England's offshore benthic MPAs. Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPA's that are currently open to bottom-towed gear.*

Figure 23 shows a net socioeconomic benefit from the second year following a ban, rising steadily to £2.60 billion over the 20-year period.

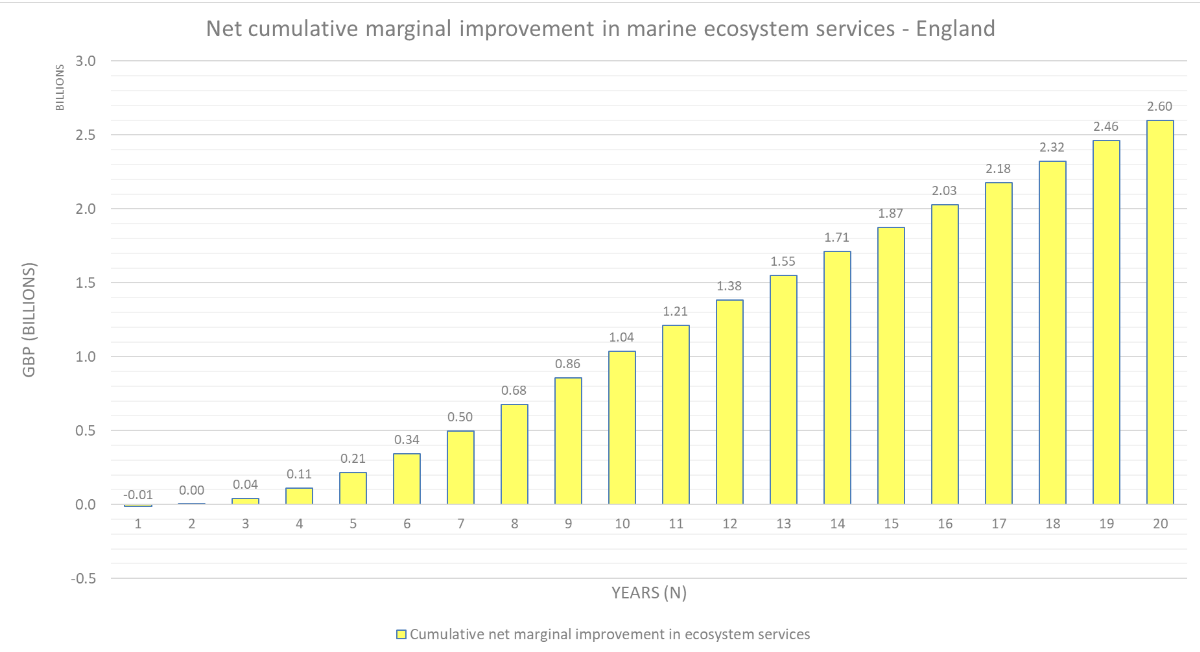


Figure 23: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in England's offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values. Values are shown in £ billions. *Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear.*

The net annual impact for England broadly mirrors that of the UK, as shown in Figure 24. The annual net impact becomes positive in the second year following the ban and rises until year 8 where it peaks at £181.2 million.

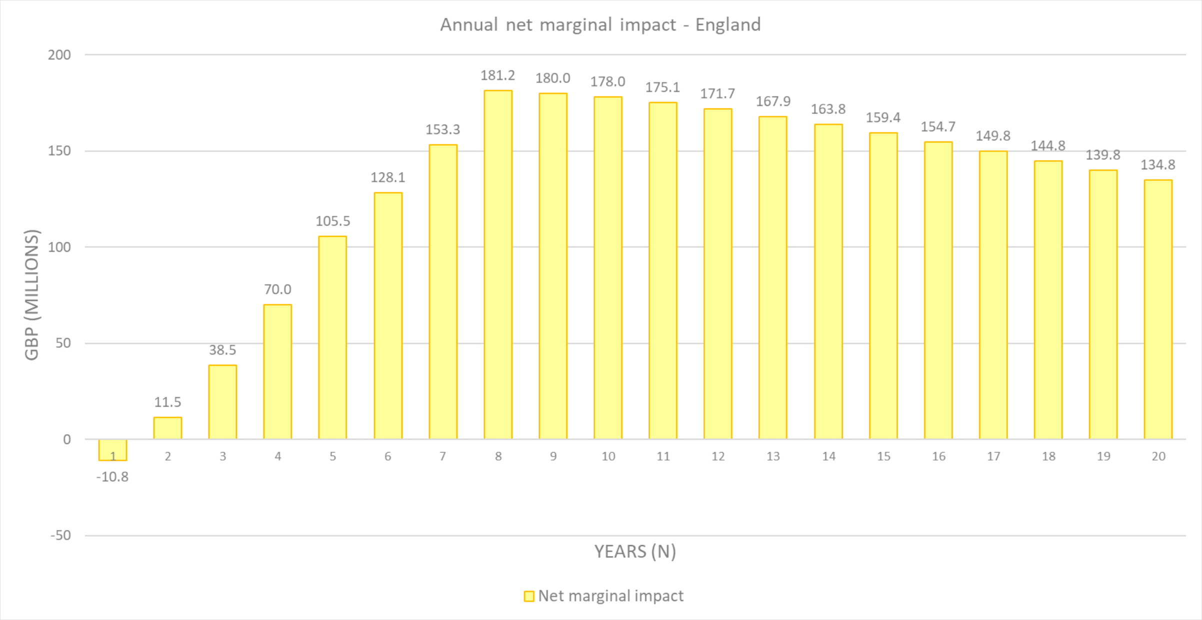


Figure 24: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for England's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in the English offshore benthic MPAs that currently remain open to bottom-contacting gear.

The drivers of the gain in ecosystem service values are the same as for the UK and shown in Figure 39 in the appendix.

4.2.4. Welsh offshore benthic MPA network

For Wales, a net socioeconomic gain is achieved in the second year following a ban on bottom-contact fishing. Ecosystem services would rise in value by £7.66 million over 20 years, while operational costs and losses from displacement activity would equate to a cumulative total of £3.83 million.

This is shown in Figure 25 below. Due to the smaller size of the MPA network and fishing fleet, the results for Wales are on a smaller scale than England, Scotland and the UK. The results presented below are in *millions* rather than *billions*.

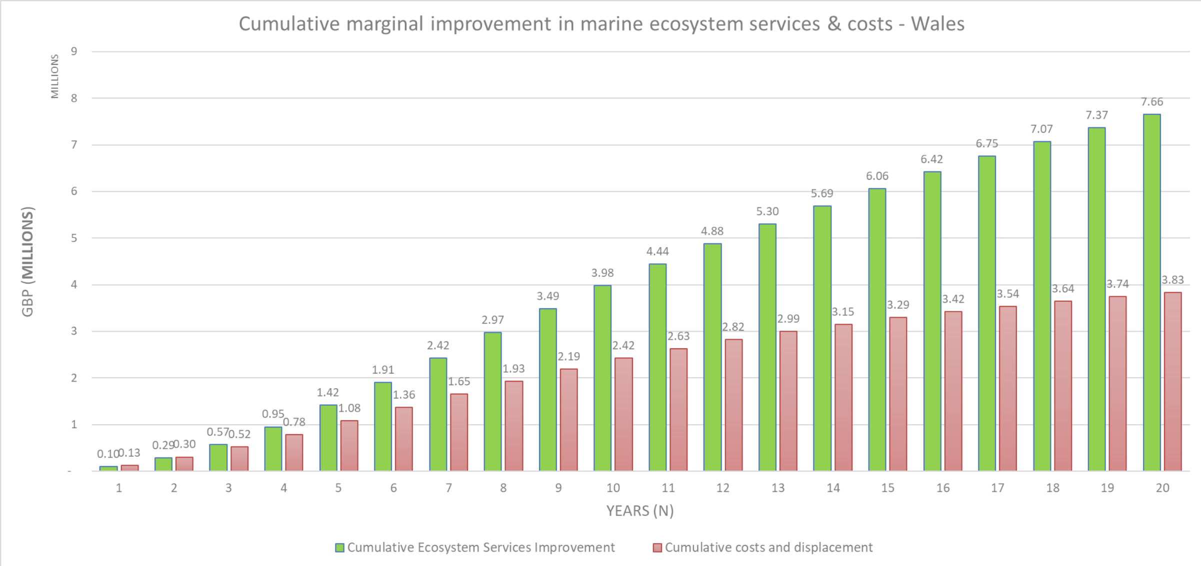


Figure 25: A comparison of the cumulative marginal improvement in ecosystem service value (in green) versus the cumulative costs and displacement values (in red) across a 20-year period following a ban on bottom-contact fishing within Wales's offshore benthic MPAs. Values are shown in £ millions. * Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear – in this case there was only one site included as an offshore benthic MPA.*

Figure 26 shows that the overall net impact rises to £3.83 million in total after 20 years.

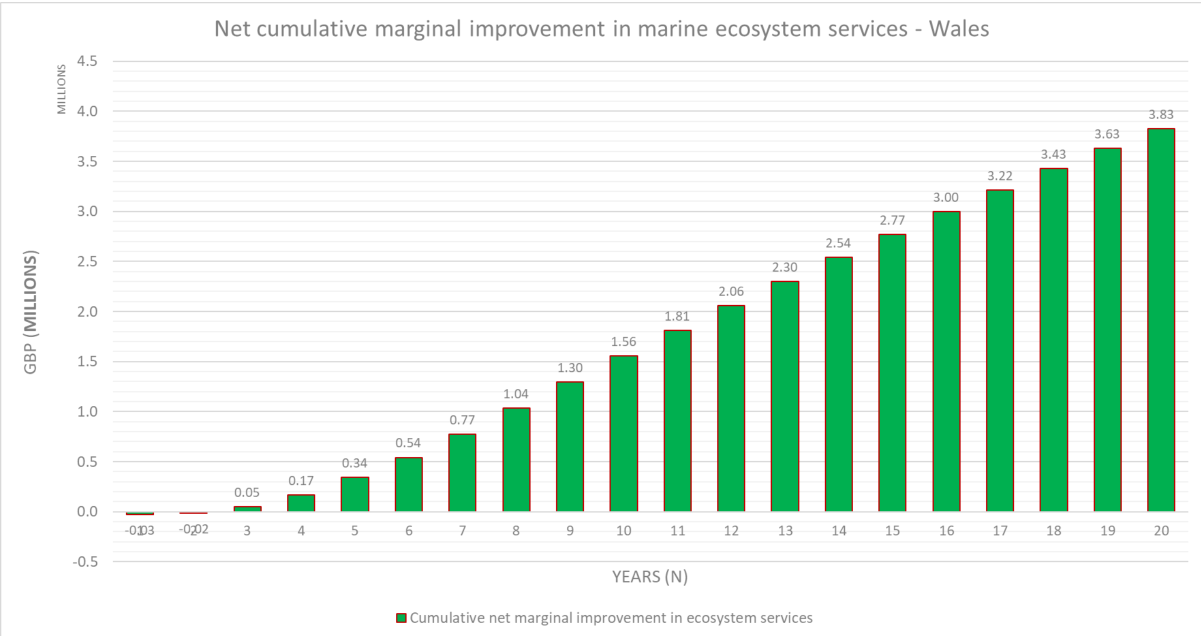


Figure 26: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in the Welsh offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values. Values are shown in £ millions. *Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear – in this case Croker Carbonate Slabs SAC has been included as the one offshore benthic MPA in Welsh waters.*

On a yearly basis, an annual net positive impact for Wales begins in the second year and rises until year 8 where it peaks at £262,900 (see Figure 27).

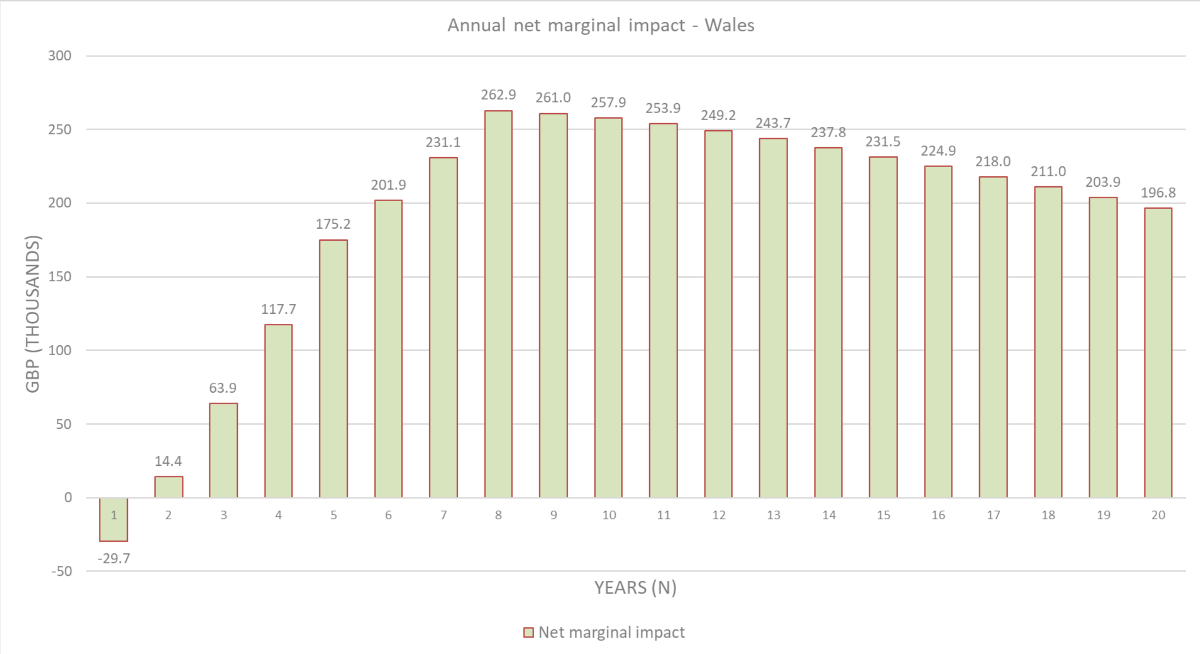


Figure 27: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for offshore benthic MPA network in Welsh waters. Costs are calculated based on the operational cost of enforcing a ban in the Welsh offshore benthic MPAs that currently remain open to bottom-contacting gear.

The main driver of the gain in ecosystem service values is bioremediation of waste, following by leisure and recreation, nutrient cycling, and then gas and climate regulation. This is shown in Table 17 and Figure 41 in the appendix.

4.2.5. Northern Irish offshore benthic MPA network

In Northern Ireland's waters, a net socioeconomic gain is predicted to begin from the third year following a ban on bottom-contact fishing, reaching a total cumulative net benefit of £37 million over 20 years. As shown in Figure 28, ecosystem services would increase by a cumulative value of £64.3 million during that time and cumulative costs would reach £27.3 million.

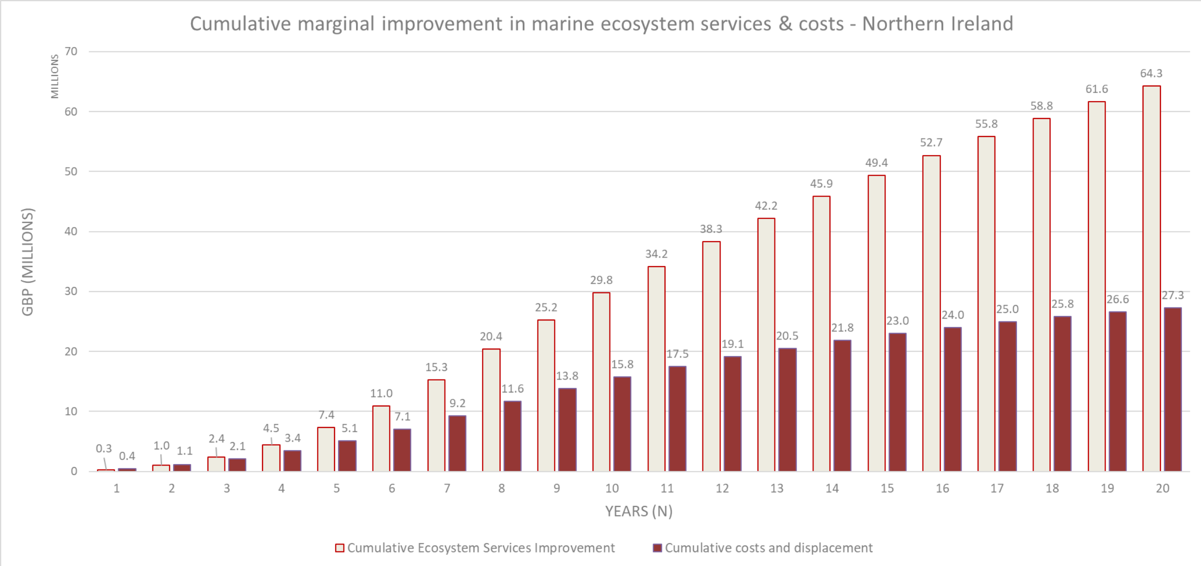


Figure 28: A comparison of the cumulative marginal improvement in ecosystem service value (in green) versus the cumulative costs and displacement values (in red) across a 20-year period following a ban on bottom-contact fishing within Northern Ireland's offshore benthic MPAs. Values are shown in £ millions. * Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear.*

Figure 29 shows this cumulative net gain of £37 million over the 20-year period after introducing the ban.

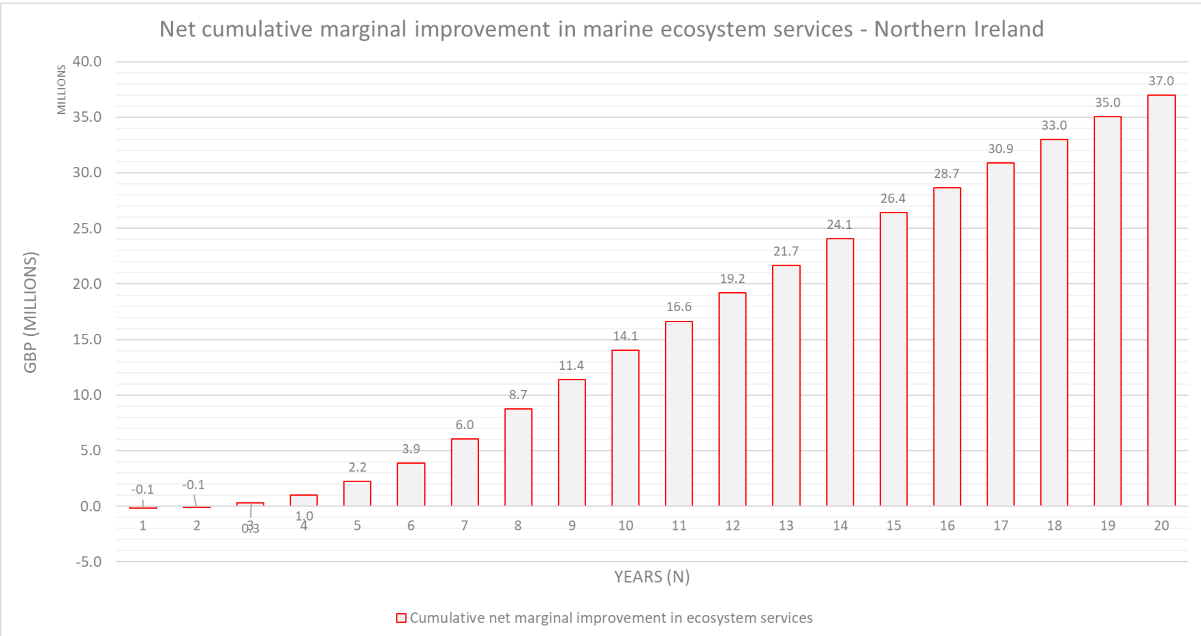


Figure 29: The net marginal improvement in ecosystem services following a bottom-contact fishing ban in Northern Ireland's offshore benthic MPA network. This is calculated by subtracting the cumulative costs and displacement values from the cumulative improvement in ecosystem service values. Values are shown in £ millions. *Administration costs are based on the area of offshore benthic MPAs that are currently open to bottom-towed gear.*

On an annual basis, the net positive impact begins in the second year and climbs to £2.7 million by year 8 (see Figure 30 below).

Figure 30: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for Northern Ireland's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in the Northern Irish offshore benthic MPAs that currently remain open to bottom-contacting gear.

Bioremediation of waste and nutrient cycling remain the biggest drivers of the gain in ecosystem services value. However, gas and climate regulation provides more value than leisure and recreation in the case of Northern Ireland (see Figure 31).

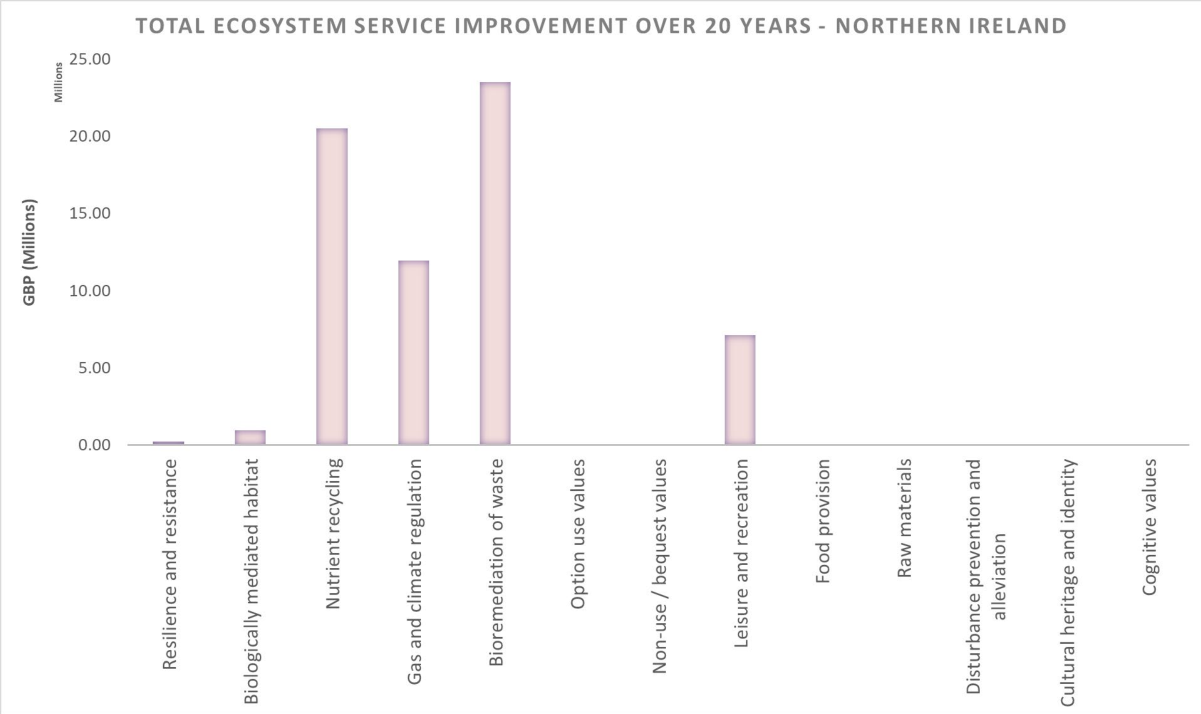


Figure 31: A comparison of the improvement in value of ecosystem services for Northern Ireland. The majority of the overall socioeconomic gains is due to increases in the value of bioremediation of waste, followed by nutrient cycling, leisure and recreation, and gas and climate regulation.

5. Discussion

5.1. Socioeconomic gains

The findings here indicate that society stands to gain much more than we lose by introducing a ban on bottom-contact fishing, particularly when looking beyond a short-term (0 – 5 years) horizon. For the entire UK offshore benthic MPA network, the ratio of benefits to costs is 1.63. For every £1 incurred in costs and displacement values, £1.63 is gained in ecosystem services value. However, considering only the costs of closing offshore benthic areas that remain open to bottom-gear fishing, this ratio rises to 2.14. For Scotland and England, the ratio of benefits to costs is 2.00 and 2.18 respectively. This is consistent with other findings in demonstrating that the benefits of greater protection outweigh the costs (Brander *et al.,* 2015; Davies *et al.,* 2021; Gonzalez-Alvarez, 2012).

Most of the added value found in this model is driven by four ecosystem services: bioremediation of waste, nutrient cycling, marine leisure and recreation, and climate regulation. This reflects the fact that these services were assigned the highest financial valuations in the model. This is logical considering that the Office for National Statistics lists marine recreation, carbon sequestration and wastewater treatment as three of the most valuable marine services in the UK's marine natural capital accounts (ONS, 2021).

Conducting a similar analysis for the EU's network of Nature 2000 sites, Davies *et al.* (2021) found that the costs outweigh the benefits for the first two years, after which the net impact rises to €8.5 billion (roughly £7.5 billion) over 20 years. As with this study, bioremediation of waste, nutrient cycling and gas and climate regulation were responsible for the majority of the predicted net benefits.

Gonzalez-Alvarez (2012) describes the restriction of bottom towed fishing gears as a key factor to fully realising the socioeconomic benefits of a hypothetical MPA network in Scottish waters, valued at up to £10 billion over 20 years. This considered a hypothetical area of MPAs approximately ten times greater than the area assessed for Scotland in this model. As explained by the author, those results are likely to be underestimates due to a lack of reliable economic values to use at the time for some ecosystem services, including bioremediation of waste which was a major driver in the overall net benefit in this study.

Nutrient cycling and bioremediation of waste

As defined by Beaumont *et al.* (2006), nutrient cycling considers the storage, cycling and maintenance of nutrients by living organisms, while bioremediation of waste refers to the *removal of pollutants* through storage, transformation and burial. Despite being two different services, both deal with the problem of anthropogenic waste and pollution entering our seas.

Conventional physical and chemical removal techniques can be prohibitively expensive or ineffective (Mohapatra *et al.,* 2018) and consequently a lot of waste is entered directly into rivers and seas. Marine organisms play a valuable role in storing, burying and transforming waste through assimilation and chemical decomposition (Salomidi *et al.,* 2012). In the seabed in particular, the activity of bioturbators that rework and mix the sediments are key to processing waste materials (Beaumont *et al.,* 2007). The process of detoxification and purification by living organisms is vital to maintaining the wider health of the marine environment and would be expected to increase in line with greater biodiversity (Beaumont *et al.,* 2008). Historically, the UK's oceans had a greater density of filter-feeding organisms better equipped to deal with waste and remove pollutants. Thurstan *et al.* (2013) find that great expanses of the North Sea that are now sand, mud or gravel were previously colonised by oyster beds. This transformation of benthic habitats has altered the functioning of marine ecosystems, including their capacity to filter out toxins, nutrients and pollutants and ultimately improve water quality.

Ferguson *et al.* (2020) found that denitrification can fall by up to 50% following trawling of shelf sediments. If those benthic habitats were allowed to recover, this presents a substantial upside in the capacity of affected habitats to remove excess nitrogen. Hughes *et al.* (2022) highlighted the value that properly managing an MPA can have in boosting nutrient regulation and mitigating nutrient enrichment. They estimated that an annual denitrification rate of 800 kg of N per km^2 for shelf sediments would increase to 880-4000 kg N km^{-2} yr^{-1} if sediments were safeguarded from disturbances such as bottom-trawling. Given that eutrophication is one of the biggest threats to valuable coastal habitats (Nixon, 1998) and a primary water quality issue (Smith, 2003), an improvement in the capacity of benthic habitats to remove excess nitrogen has a clear value in mitigating this anthropogenic impact.

The economic value of marine organisms for remediation of waste and nutrients is gaining increasing recognition. As one example, the cultivation of bivalve filter feeders alone has been estimated to provide services worth billions of dollars in removal of nitrogen and phosphorus (van der Schatte Olivier *et al.,* 2020). Gifford *et al.* (2004) proposed pearl oyster development as a bioremediation technique for sites particularly effected by toxic pollutants, nutrients and pathogens. The valuation of the removal of pollutants has not been extensively studied. It is therefore possible that bioremediation is undervalued here as we do not know the full extent to which the marine environment can deal with chemical pollutants and other contaminants (Sagebiel *et al.,* 2016).

Unfortunately, the high value of nutrient cycling and bioremediation services may be indicative of the vast amounts of waste, nutrients and pollutants that are entering the marine environment. Continued effects of eutrophication, waste and pollutants will further weaken marine ecosystems and the ecosystem services they provide (Carstensen, 2014; Kermagoret *et al.,* 2019). This stress is exacerbated by physical disturbance from bottom-gear fishing (Scheffer *et al.,* 2005). Both stressors need to be addressed and the high value shown here should not justify the use of the marine environment to deal with excess nutrients and waste.

Leisure and recreation

The results show that substantial gains can be achieved through the provision of marine leisure and recreation, which also extends to marine tourism. The marine leisure and recreation industry relies on the presence of healthy natural resources to generate revenue (Rees *et al.,* 2010) as well as aesthetic qualities (Klinger *et al.,* 2018). Second only to the oil and gas sector, Stebbings *et al.* (2020) estimate leisure and recreation to be the sector of the marine economy with the highest economic value. In the UK's marine natural capital accounts, the Office for National Statistics have valued marine recreation as the most valuable service derived from the marine environment (ONS, 2021). Unlike other marine sectors, the economic gains of the leisure and recreation sector extend to increased visits to - and job creation within - coastal communities, thereby boosting local economies (Hall, 2021; Schratzberger *et al.,* 2019). As shown in Figure 32 the marine leisure and recreation sector provides the most jobs out of all marine economy sectors, accounting for over half of all FTE's in the marine economy (Stebbings *et al.,* 2020).

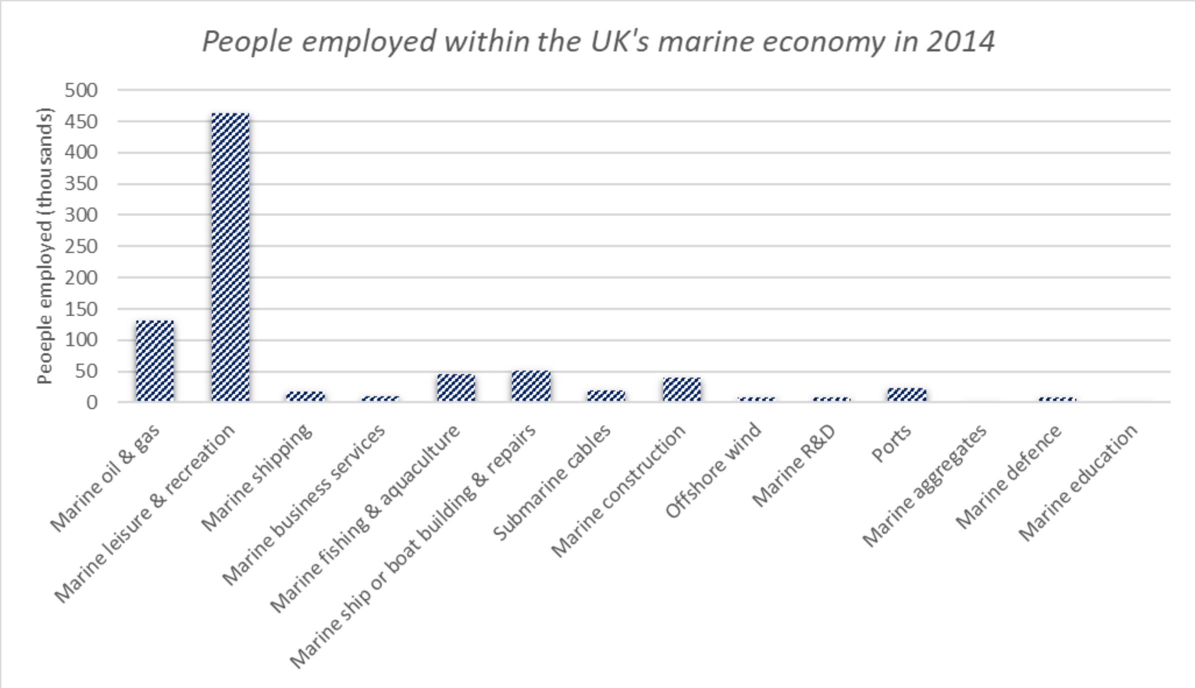


Figure 32: The marine leisure & recreation sector employs 462,500 out of a total of 823,500 people employed in the UK's marine economy in 2014, by far the biggest contributor to jobs in the marine economy. Source: Adapted from Stebbings et al. (2020).

Recreation and leisure was the ecosystem service with the highest financial valuation in this study, so a given percentage increase in service provision would yield a much higher economic gain than any other ecosystem service. This high value is supported by previous research. For example, Kenter *et al.* (2013) examined the value of recreational ecosystem services in the UK and found annual benefits of £1.87 – £3.39 billon for England, £68 – £112 million for Wales and £67 – £117 million in annual benefits for Scotland. The attraction of visitors to coastal areas is lucrative for coastal communities. The UK National Ecosystem Assessment (NEA, 2011) has previously calculated that the estimated 250 million annual visits to the coast provide an economic value of £17 billion.

The key difference in this study, however, is the focus on offshore MPAs. Most of the activities that drive the value of marine leisure and recreation will be concentrated within coastal areas, as access to deeper offshore waters becomes limited (Jobstvogt *et al.,* 2014b; Ruiz-Frau *et al.,* 2019). It may be assumed that most direct use of the marine environment for leisure, recreation and tourism is focused on the first 2 – 5 nautical miles from the coastline.

The prominence of marine leisure and recreation in these results for offshore benthic MPAs will therefore be subject to scrutiny. However, the low impact of offshore habitats on marine leisure and recreation was reflected in the impact coding assigned to the habitat types. Of the total areas mapped for the UK, 64%

were assigned as low or very low impact for marine leisure and recreation, with only 4% being attributed with a very high (70% improvement) impact. Furthermore, although the monetary value assigned to marine leisure and recreation was high, it remained conservative compared to other valuations in the ESVD (e.g. Beaumont *et al.,* 2008).

It is also worth noting that although direct use would be concentrated in inshore waters, the provision of leisure, recreation (and tourism) activities also depends on the quality of the marine environment, whether it is water quality (Pouso *et al.,* 2018), scenic value (Voke *et al.,* 2013) or presence of desired species (Rees *et al.,* 2015). This means that the value of this sector is often eroded by competing activities that compromise the quality of the wider marine ecosystem, even if those activities do not directly overlap with areas of leisure and recreation. Allowing the wider ecosystem to recover by removing such a significant stressor in bottom-contact fishing can therefore be expected to contribute towards an increase in the value of leisure and recreation services.

The findings here suggest that further research into the socioeconomic impact in *inshore* MPAs could find great value in the improvements in marine leisure and recreation in coastal areas. Within the Lyme Bay MPA, in which bottom-contact fishing was excluded, Rees *et al.* (2015) reported a positive effect on marine leisure and recreation both inside and outside the MPA. This included a range of activities such as diving and recreational boating, while other activities such as sea angling increased within the MPA. This indicates that gains from leisure and recreation can be expected within the MPA network following greater protection, but potentially also outside of the MPA network. It is recommended therefore that future studies examine the significant economic gains that could be achieved by introducing greater protection within inshore MPAs.

Climate regulation

The large contribution of gas and climate regulation to the overall improvement in ecosystem services is logical considering that marine sediments are the largest pool of buried organic carbon and store 1.75 times more than the top 1 metre of terrestrial soils (Atwood *et al.,* 2020; Köchy *et al.,* 2015). The Office for National Statistics values carbon sequestration as the second most valuable marine service in the UK's marine natural capital accounts (ONS, 2021). Allowing benthic communities and biomass to recover would enhance the capacity of the UK's marine sediments to sequester carbon (Roberts *et al.,* 2017; Tillin *et al.,* 2006) where it could remain (if undisturbed) for thousands of years (Estes *et al.*, 2019). This makes MPAs a valuable tool in climate mitigation, particularly when protected from bottom-gear fishing (Jankowska *et al.,* 2022).

It is worth noting that the model looks at socioeconomic gains, but does not consider the cost-savings that would also occur by allowing the seabed to recover. Luisetti *et al.* (2019) estimate that 93% of the UK's marine carbon stores lie within offshore areas where trawling is still permitted. The authors predict that the cost of mitigating the release of carbon stores in the seabed through continued disturbance could reach $12 billion between 2016 and 2040. Previous research by the Marine Conservation Society estimated that to mitigate the emissions from benthic disturbance within the offshore MPA network would cost £980 million over 25 years to the UK economy (Dunkley and Solandt, 2021). This is similar in scale to the £1.1 billion increase in the value of gas and climate regulation services calculated in this model over a similar time frame for the UK. This suggests that if such cost-savings were factored in, the socioeconomic benefits would rise substantially, further strengthening the economic case for the proposed ban on bottom-gear fishing in our MPAs.

The UK's shelf seas extend to over 500,000 km^2 and store an estimated 205 million tonnes of carbon - more than the UK's entire stock of forests (Luisetti *et al.*, 2019). Given the relatively large extent of UK shelf seas compared to other nations, cutting emissions through sediment disturbance (particularly of muddy sediments) should be in line with the UK Government's commitments to the Paris Climate Agreement and to cutting emissions by 2030.

5.2. Conservative estimates

The estimates generated by this analysis should be considered as conservative for a number of reasons outlined below.

Financial proxies

The financial valuations used to put a monetary value on ecosystem services were chosen conservatively. Even ecosystem services with the highest financial proxies (e.g. leisure and recreation, bioremediation of waste, or gas and climate regulation) have financial valuations on the ESVD several orders of magnitude higher than the proxies chosen in this analysis.

Furthermore, the natural capital approach is limited in how far it can accurately put a value on nature. As highlighted by Costanza *et al.* (1997) who brought the concept of natural capital into the mainstream, there is a strong argument that natural capital has an infinite value. This reflects that the marine environment forms part of the planet's life support system on which we depend for survival.

Fishing values

The UK and its devolved nations do not account for all fishing activity within the offshore benthic MPA network. Fishing values (and losses following the ban) are likely over-representative because some of this value will be accounted for by the economies of other nations within the EU.

Displacement values

The value of ecosystem services in unprotected areas where displacement activity could occur was assumed to be 90% of the value of protected areas. There is a lack of comprehensive research comparing the value of ecosystem health in protected areas to unprotected areas across a range of ecosystem services.

Studies into specific indicators of ecosystem health, such as fish biomass, have found notable differences between areas of strong protection and adjacent areas of unprotected or partially protected areas (Friedlander *et al.,* 2017; Sala and Giakoumi *et al.,* 2018). Davies *et al*. (2022) report a 38.9% and 64.6% respective increase in number of taxa and functional richness in the Lyme Bay MPA compared to unprotected areas. Functional richness is a key driver for ecosystem stability, resilience and provision of services (Canning-Clode *et al.,* 2010; Davies *et al.,* 2022; Wahl *et al.,* 2011). It could therefore be argued that the value of ecosystem services in unprotected areas would be less than 90%, owing to the higher functional richness within areas of protection, particularly where there are restrictions on bottom-gear fishing.

In reality, even if 90% is initially an accurate assumption, it could be expected that this would decline over time as the protected sites improve in quality and unprotected areas become degraded, thereby increasing the disparity in ecosystem quality between protected and unprotected sites. The model does not account for this and therefore may increasingly overestimate the displacement values in the passage of the 20-year period.

Additionally, the assumed percentage of displacement (75%) is also high compared to previous studies. Murawski *et al.* (2005) analysed the spatial distribution of otter trawling and catches following year-round and seasonal groundfish closures in a temperate MPA off the northeast USA. They found that 31% of trawling effort was displaced, and overall fishing effort fell by 50% compared to pre-closure levels. There is, however, an overall lack of data on the displacement of fishing effort following the implementation of MPAs (Vaughan, 2017).

Ecosystem services included

There may be several more ecosystem services that provide significant economic value but are not included in the model. Non-use values of marine protected areas, such as option values and bequest values, were not included as they are difficult to quantify in monetary terms. If they had been included, each of these would have had a value of 46.23 €/ha/year (Jobstvogt *et al.,* 2014a) which would have raised the total value gain in ecosystem services.

There are other non-material benefits that society derives from a healthy marine environment that are not quantifiable (Garcia Rodrigues *et al.*, 2022). Nevertheless, these non-use benefits do have a value that, if quantifiable, would add to the socioeconomic benefits outlined above.

A case could be made for other ecosystem services that were not included. The use of the marine environment for blue biotechnology and research are growing sectors that could benefit – providing they are not exploitative – from more resilient and diverse ecosystems, creating added value and employment (Russi *et al.,* 2016).

Baselines

Finally, the model looks at the improvement in ecosystem services versus a baseline scenario where the quality of ecosystem services remains the same. As referenced in the previous section, the quality of ecosystem services may be expected to decline further with continued disturbance from bottom-contact fishing. In this case, the difference between the declining quality of the ecosystem services in a business-as-usual scenario and the improvements found in this model would be even higher, as would the disparity in economic value observed between the two scenarios.

5.3. Longer-term socioeconomic analysis to inform decision making

Rees *et al.* (2022) find that current governance strategies are insufficient for protecting biodiversity and avoiding the loss of ecosystem services. They call for the use of marine natural capital approaches to better support policy and decision makers. The results in this study here have suggested that the socioeconomic gains from a bottom-contact ban eclipse the short-term costs. Despite this, bottom-contact fishing occurs in the vast majority of the UK's MPA network. It is therefore suggested that decision making relating to MPAs should be better informed by natural capital analysis that appropriately factors in the socioeconomic impacts of policies, strategies, and key decisions. Most research has focused on how to quantify ecosystem services, but there would also be added benefit in research that looks specifically at the impacts of specific policies and decisions on those ecosystem services (Martinez-Harms *et al.,* 2015).

As outlined previously, bottom-gear fishing weakens the overall diversity, structure and complexity of marine habitats. Due to the time taken for marine ecosystems to recover following the end of the disturbance (Moran *et al.,* 2008), most combinations of ecosystem services and habitat types took at least 5 years to achieve their improvement in value (see Table 9 in the appendix). However, the administration costs of implementing the ban, and the losses in fishing value, would occur immediately. This explains why across the different scenarios assessed here it can take up to seven years before the cumulative net benefits of such a ban start to kick-in. However, the annual and cumulative costs during this time are limited to an order of millions, with the cumulative net deficit peaking in year three at £201 million when considering the whole UK offshore benthic MPA network (see Table 7). By contrast, the cumulative net gains achieved over the full 20-year period are in an order of billions, reaching up to £2.57 billion overall for the UK (and over £3.5 billion when considering only the costs of closing MPAs that remain open to bottom-contact fishing).

The results therefore stress the importance of using mid to long-term analysis when informing decisions concerning the marine environment. Long term benefits to society should not be sacrificed to avoid short term costs of a much smaller magnitude. Equally, short term private gain should not be prioritised over the long-term public interest.

5.4. Other seabed activities

It should be noted that ecosystem services are allowed to improve by removing stressors. Bottom contact-fishing is one of many activities that impact on the marine environment and impair the provision of ecosystem services.

For example, marine development, including the construction of offshore wind farms, anchoring for oil and gas rigs and the laying of cables or pipelines can also cause significant disturbance to the seabed – though not at such a great spatial footprint as from bottom-towed fishing gear in the UK continental shelf. A number of plans outlined in the annex to The Growth Plan 2022 and the British Energy Security Strategy by the UK Government threaten to cause disturbance to marine ecosystems within the UK's MPAs. To illustrate, Figure 33 shows how new oil and gas extraction licensing areas overlap considerably with UK Marine Protected Areas. A review of studies into the impacts of energy systems on ecosystem services by Papathanasopoulou *et al.* (2015) reported that oil and gas activity had predominantly negative effects across all four classes of ecosystem services.

The installation and presence of offshore wind farms can also alter the provision of marine ecosystem services (Mangi, 2013) and affect the economic value identified in this report. Such impacts include disturbance to the seabed during construction, impact on species living in the marine space and an aesthetic impact on the seascape (Hooper *et al.,* 2017). Considering the results shown in this report, these impacts could be of particular concern for some of the highest value ecosystem services such as recreation and leisure, which could lose value due to the aesthetic impact of introducing offshore infrastructure into an MPA and potential impact on species around those sites.

Therefore, it should be expected that the full socioeconomic gains demonstrated in the analysis above would not be realised by allowing other impactful activities to take place within marine protected areas. The report should therefore not be used to justify the addition of new activities within marine protected areas following a ban on bottom-contact fishing.

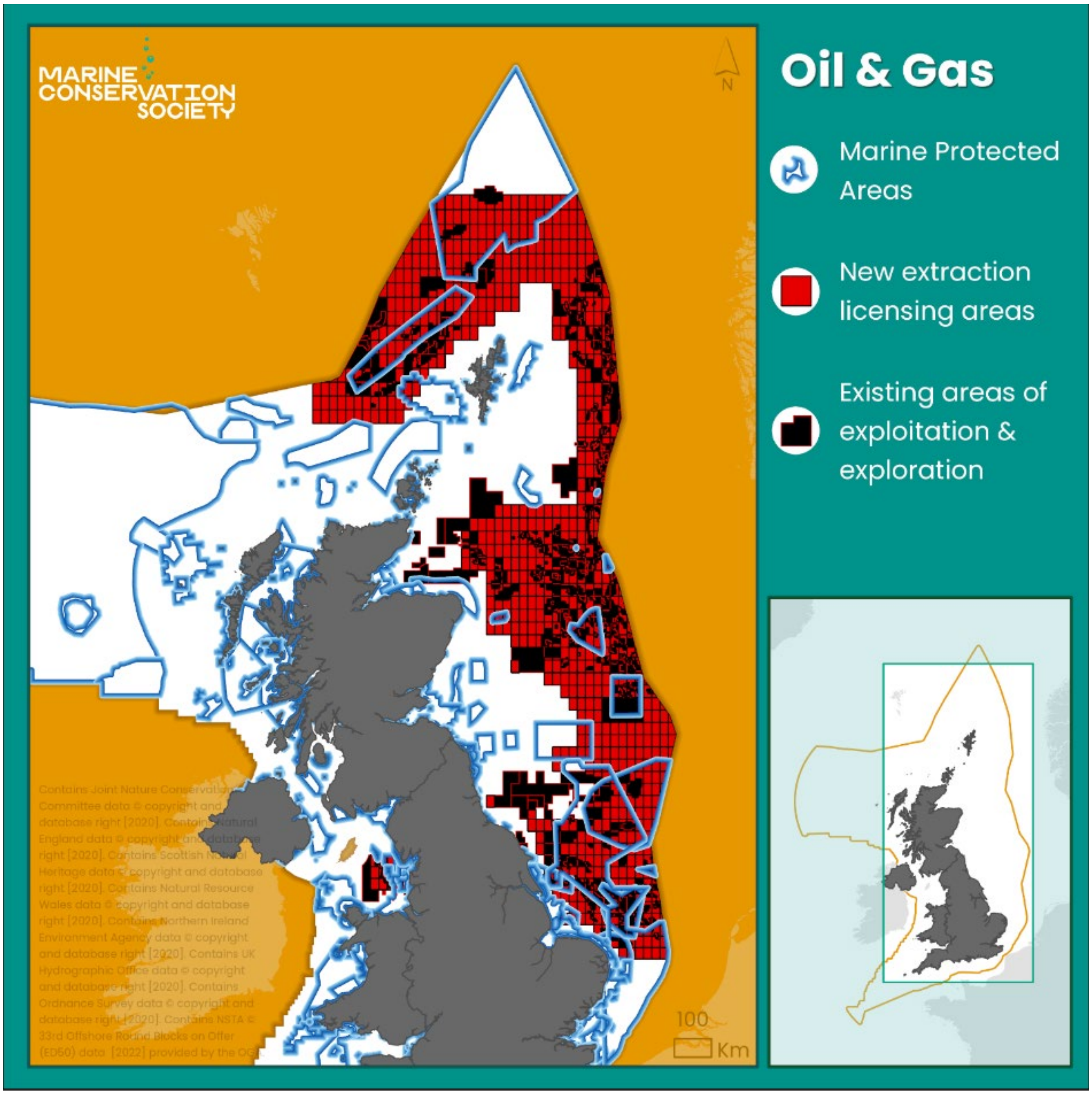


Figure 33: North Sea Oil & Gas licensing areas and Marine Protected Areas. Map created by the Marine Conservation Society, with new extraction licensing areas and existing areas of exploitation or exploration sourced from the North Sea Transition Authority Open Data site. The map shows considerable overlap of new licensing areas on Marine Protected Areas.

5.5. Limitations

There are certain limitations to be aware of when applying the model used here:

- The model considers only offshore benthic MPAs. Bottom-contact fishing may also be taking place in inshore MPAs and in areas designated for other purposes. Further research could benefit from looking at the *entire* MPA network. Only with effective monitoring of inshore (<10m) vessels will this analysis be possible. Such analysis could be expected to find significant gains from leisure and recreation services in particular, while these could be argued to be overrepresented in this study as there is little direct use of offshore sites for this activity.

- Fishing fleets are mobile and move between national boundaries. As a result, calculated fishing values for the UK and its devolved nations will not be completely accurate, as fish landed in a particular jurisdiction may have been caught elsewhere, while there are also fishing fleets from other nations (e.g. from within the EU) present in UK waters.

- The model treats all MPAs and habitats equally in terms of ecosystem service provision. There are complex interactions between habitats and a multitude of factors that may influence the quality of ecosystem services in a particular MPA, including the size and age of the MPA (Vandeperre *et al.,* 2011; Woodcock *et al.,* 2017). The model does not factor in this spatial variability in how habitats and MPAs may respond to a bottom-contact fishing ban (Blampied, 2022). A more comprehensive study may look at the respective ecological conditions of each MPA to better ascertain the impact of management measures (Fulton *et al.,* 2015), but this was beyond the scope of this report.

- The monetary values assigned to each ecosystem service are taken from chosen studies in the ESVD database. However, there are many other studies and proxy values that could have been used instead. There is a great deal of variation across the literature in how respective ecosystem services are assigned monetary values, each with different evaluation methods and data sets. That means there is no one valuation that should be considered universally correct for any ecosystem service. Furthermore, ecosystem service assessments and natural capital valuations face their own limitations in quantifying ecological benefits in economic terms (Bateman *et al.,* 2020; Costanza *et al.,* 1997).

6. Conclusion

This report demonstrates that it is within the interests of society and the UK economy to introduce a ban on bottom-contact fishing in the UK's offshore benthic MPA network. The overall net benefit of between £2.57 billion and £3.5 billion for the UK show that there is far more to be gained than lost over a 20-year period. This substantial value also underlines the need to involve socioeconomic analysis and natural capital valuations in management decisions concerning the UK's MPA network.

The findings also emphasise the need for informed decision making that looks beyond short-term costs and prioritises the longer-term, much larger benefits to society. Although costs can initially outweigh the economic gains, these are short lived and are comprehensively outsized by the gains achieved over the mid-to long term. For example, in cases where it takes 2 – 7 years to achieve a net socioeconomic gain, the net costs in that period are modest relative to the long-term benefits achieved - in the order of hundreds of millions versus several billions in the mid-to-longer term.

Finally, it is important that these findings reflect not just the impact of removing bottom-contact fishing, but the impact of removing all stressors that impact the marine environment. For ecosystems to recover and increase in value, our Marine Protected Areas need to be free from disturbances, extending from pollution to offshore infrastructure. If the introduction of a bottom-contact fishing ban were to be followed by the introduction of other activities to those protected areas, the net gain found in this analysis would be diminished.

Appendix

Habitat data

Table 8: This report used the 2018 version of the UKSeaMap for mapping habitat types.

MARINE HABITAT - JNCC classification	
JNCC habitat code	**JNCC habitat name**
M.ArLB.Mx	Arctic lower bathyal Mixed sediment
M.ArLB.Sa	Arctic lower bathyal Sand
M.ArMB.Co	Arctic mid bathyal coarse sediment
M.ArMB.Mx	Arctic mid bathyal Mixed sediment
M.ArMB.Sa	Arctic mid bathyal Sand
M.AtLB.Co	Atlantic lower bathyal coarse sediment
M.AtLB.Mx	Atlantic lower bathyal Mixed sediment
M.AtLB.Mu	Atlantic lower bathyal mud or sandy mud to muddy sand
M.AtLB.Ro	Atlantic lower bathyal rock or other hard substrata
M.AtLB.Sa	Atlantic lower bathyal Sand
M.AtMA.Mu	Atlantic mid abyssal mud or sandy mud to muddy sand
M.AtMB.Co	Atlantic mid bathyal coarse sediment
M.AtMB.Mx	Atlantic mid bathyal Mixed sediment
M.AtMB.Mu	Atlantic mid bathyal mud or sandy mud to muddy sand
M.AtMB.Ro	Atlantic mid bathyal rock or other hard substrata
M.AtMB.Sa	Atlantic mid bathyal Sand
M.AtUA.Mx	Atlantic upper abyssal Mixed sediment
M.AtUA.Mu	Atlantic upper abyssal mud or sandy mud to muddy sand
M.AtUA.Ro	Atlantic upper abyssal rock or other hard substrata
M.AtUA.Sa	Atlantic upper abyssal Sand
M.AtUB.Co	Atlantic upper bathyal coarse sediment
M.AtUB.Mx	Atlantic upper bathyal Mixed sediment
M.AtUB.Mu	Atlantic upper bathyal mud
M.AtUB.Ro	Atlantic upper bathyal rock or other hard substrata
M.AtUB.Sa	Atlantic upper bathyal sand
M.AAUB.Co	Atlanto-Arctic upper bathyal coarse sediment
M.AAUB.Mx	Atlanto-Arctic upper bathyal Mixed sediment
M.AAUB.Mu	Atlanto-Arctic upper bathyal mud
M.AAUB.Sa	Atlanto-Arctic upper bathyal sand
SS.SCS.CCS	Circalittoral coarse sediment
SS.SMu.CFiMu	Circalittoral fine mud
SS.SMx.CMx	Circalittoral mixed sediment
SS.SMu.CSaMu	Circalittoral sandy mud
SS.SMu.CSaMu Or SS.SMu.CFiMu	Circalittoral sandy mud or Circalittoral fine mud
CR.HCR.DpSp	Deep sponge communities
CR.HCR	High energy circalittoral rock
IR.HIR	High energy infralittoral rock
SS.SCS.ICS	Infralittoral coarse sediment
SS.SMu.IFiMu	Infralittoral fine mud
SS.SMx.IMx	Infralittoral mixed sediment
SS.SMu.ISaMu	Infralittoral sandy mud
SS.SMu.ISaMu or SS.SMu.IFiMu	Infralittoral sandy mud or Infralittoral fine mud
CR.LCR	Low energy circalittoral rock
IR.LIR	Low energy infralittoral rock
CR.MCR	Moderate energy circalittoral rock
IR.MIR	Moderate energy infralittoral rock
SS.SCS.OCS	Offshore circalittoral coarse sediment
SS.SSa.IFiSa or SS.SSa.IMuSa	Offshore circalittoral fine sand or Offshore circalittoral muddy sand
SS.SSa.CFiSa or SS.SSa.CMuSa	Offshore circalittoral fine sand or Offshore circalittoral muddy sand
SS.SMx.OMx	Offshore circalittoral mixed sediment
SS.SMu.OMu	Offshore circalittoral mud
SS.SSa.OSa	Offshore circalittoral sand
SS	Sublittoral sediment
unknown	unknown

Impact coding

Table 9: Impact coding applied to JNCC's latest marine habitat classifications.

Impact coding conversions	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Option use values	Non-use / bequest values	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Cognitive values
Atlantic lower bathyal rock or other hard substrata	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Atlantic mid bathyal rock or other hard substrata	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Atlantic upper abyssal rock or other hard substrata	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Atlantic upper bathyal rock or other hard substrata	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Deep sponge communities	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Arctic mid bathyal coarse sediment	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
lantic lower bathyal coarse sediment	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
tlantic mid bathyal coarse sediment	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
lantic upper bathyal coarse sediment	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Atlanto-Arctic upper bathyal coarse sediment	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	H 10/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 10/20 E
Arctic mid bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
lantic lower bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
rctic lower bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
tlantic mid bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
lantic upper abyssal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
lantic upper bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlanto-Arctic upper bathyal Mixed sediment	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic lower bathyal mud	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic mid bathyal mud	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic upper abyssal mud or sandy mud to muddy sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic upper bathyal mud	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlanto-Arctic upper bathyal mud	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Arctic lower bathyal Sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Arctic mid bathyal Sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic lower bathyal Sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic mid bathyal Sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic upper abyssal Sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic upper bathyal sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlanto-Arctic upper bathyal sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
Atlantic mid abyssal mud or sandy mud to muddy sand	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	H 15/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 15/20 E
High energy circalittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
High energy infralittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Low energy circalittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Low energy infralittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Moderate energy circalittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Moderate energy infralittoral rock	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Infralittoral fine mud	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	L 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 E
Infralittoral sandy mud	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	L 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 E
Infralittoral sandy mud or Infralittoral fine mud	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	M 5/20 E	L 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 E
Infralittoral coarse sediment	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Sublittoral sediment	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Infralittoral mixed sediment	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E
Circalittoral fine mud	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Offshore circalittoral mud	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Circalittoral sandy mud	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Circalittoral sandy mud or Circalittoral fine mud	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Offshore circalittoral fine sand or Offshore circalittoral muddy sand	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Offshore circalittoral fine sand or Offshore circalittoral muddy sand	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Offshore circalittoral sand	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	H 8/20 E	L 8/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 8/20 E
Circalittoral coarse sediment	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 L
ffshore circalittoral coarse sediment	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 L
Circalittoral mixed sediment	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 L
ffshore circalittoral mixed sediment	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	M 5/20 L	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	M 5/20 L
Unknown	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	H 5/20 E	VL 5/20 E	VL 0/20 S	VL 0/20 S	VL 0/20 S	VL 0/20 S	H 5/20 E

Annual ecosystem services improvement and net impacts

Results based on the cost of protecting benthic MPAs currently open to bottom-contacting gear

UK

Table 10: The annual value of improvement (in £ millions) for each ecosystem service for the UK offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Annual total (£ millions)
Years	1	0.147	0.574	12.486	7.278	14.308	19.826	0.589	0.093	0.024	0.024	**55.3**
	2	0.331	1.295	28.165	16.417	32.274	38.485	0.557	0.088	0.022	0.023	**117.7**
	3	0.546	2.135	46.426	27.061	53.200	56.548	0.528	0.083	0.021	0.022	**186.6**
	4	0.784	3.069	66.729	38.896	76.465	73.949	0.500	0.079	0.020	0.021	**260.5**
	5	1.041	4.074	88.593	51.640	101.519	90.637	0.474	0.075	0.019	0.020	**338.1**
	6	1.219	4.769	103.714	60.454	118.845	89.822	0.449	0.071	0.018	0.019	**379.4**
	7	1.411	5.524	120.115	70.013	137.639	89.469	0.425	0.067	0.017	0.018	**424.7**
	8	1.620	6.339	137.837	80.344	157.947	89.562	0.403	0.064	0.016	0.017	**474.1**
	9	1.564	6.119	133.065	77.562	152.479	86.196	0.381	0.060	0.015	0.016	**457.5**
	10	1.512	5.917	128.660	74.995	147.431	83.077	0.361	0.057	0.014	0.015	**442.0**
	11	1.456	5.699	123.932	72.239	142.013	78.694	0.342	0.054	0.014	0.014	**424.5**
	12	1.404	5.496	119.510	69.661	136.947	74.542	0.324	0.051	0.013	0.013	**408.0**
	13	1.356	5.305	115.368	67.247	132.199	70.609	0.307	0.049	0.012	0.013	**392.5**
	14	1.310	5.126	111.478	64.980	127.743	66.884	0.291	0.046	0.012	0.012	**377.9**
	15	1.257	4.918	106.938	62.333	122.539	63.355	0.276	0.044	0.011	0.011	**361.7**
	16	1.190	4.658	101.295	59.044	116.074	60.012	0.261	0.041	0.010	0.011	**342.6**
	17	1.127	4.412	95.951	55.929	109.950	56.846	0.247	0.039	0.010	0.010	**324.5**
	18	1.068	4.180	90.888	52.978	104.149	53.847	0.234	0.037	0.009	0.010	**307.4**
	19	1.012	3.959	86.093	50.183	98.654	51.006	0.222	0.035	0.009	0.009	**291.2**
	20	0.958	3.750	81.551	47.535	93.449	48.315	0.210	0.033	0.008	0.009	**275.8**
	ES Total (£ millions)	**22.312**	**87.318**	**1898.795**	**1106.786**	**2175.823**	**1341.681**	**7.382**	**1.166**	**0.295**	**0.305**	**6641.9**

Table 11: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the UK offshore benthic MPA network. The cumulative net marginal impact shows the economic value in terms of gains in ecosystem services following the bottom-contact fishing ban over a 20-year period. *Costs are calculated considering the administration costs of protecting offshore benthic MPAs in British waters that currently remain open to bottom-gear fishing.*

		Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	Cumulative net marginal impact (£ millions)
Year	1	55.3	55.3	80.8	80.8	-25.5	**-25.5**
	2	117.7	173.0	114.3	195.1	3.4	**-22.1**
	3	186.6	359.6	147.8	343.0	38.8	**16.6**
	4	260.5	620.1	180.2	523.1	80.3	**96.9**
	5	338.1	958.2	210.6	733.8	127.5	**224.4**
	6	379.4	1337.6	219.6	953.4	159.7	**384.1**
	7	424.7	1762.3	229.0	1182.4	195.7	**579.9**
	8	474.1	2236.4	238.5	1420.9	235.6	**815.5**
	9	457.5	2693.9	219.0	1640.0	238.4	**1053.9**
	10	442.0	3135.9	201.4	1841.4	240.6	**1294.5**
	11	424.5	3560.4	184.3	2025.7	240.2	**1534.7**
	12	408.0	3968.3	168.7	2194.4	239.2	**1773.9**
	13	392.5	4360.8	154.7	2349.0	237.8	**2011.8**
	14	377.9	4738.7	141.9	2490.9	236.0	**2247.7**
	15	361.7	5100.3	129.6	2620.5	232.1	**2479.9**
	16	342.6	5442.9	117.3	2737.8	225.3	**2705.2**
	17	324.5	5767.5	106.3	2844.0	218.3	**2923.4**
	18	307.4	6074.9	96.3	2940.3	211.1	**3134.5**
	19	291.2	6366.0	87.3	3027.6	203.9	**3338.4**
	20	275.8	6641.9	79.2	3106.8	196.6	**3535.0**
	Total (£ millions)	6641.9	6641.9	3106.8	3106.8	3535.0	**3535.0**

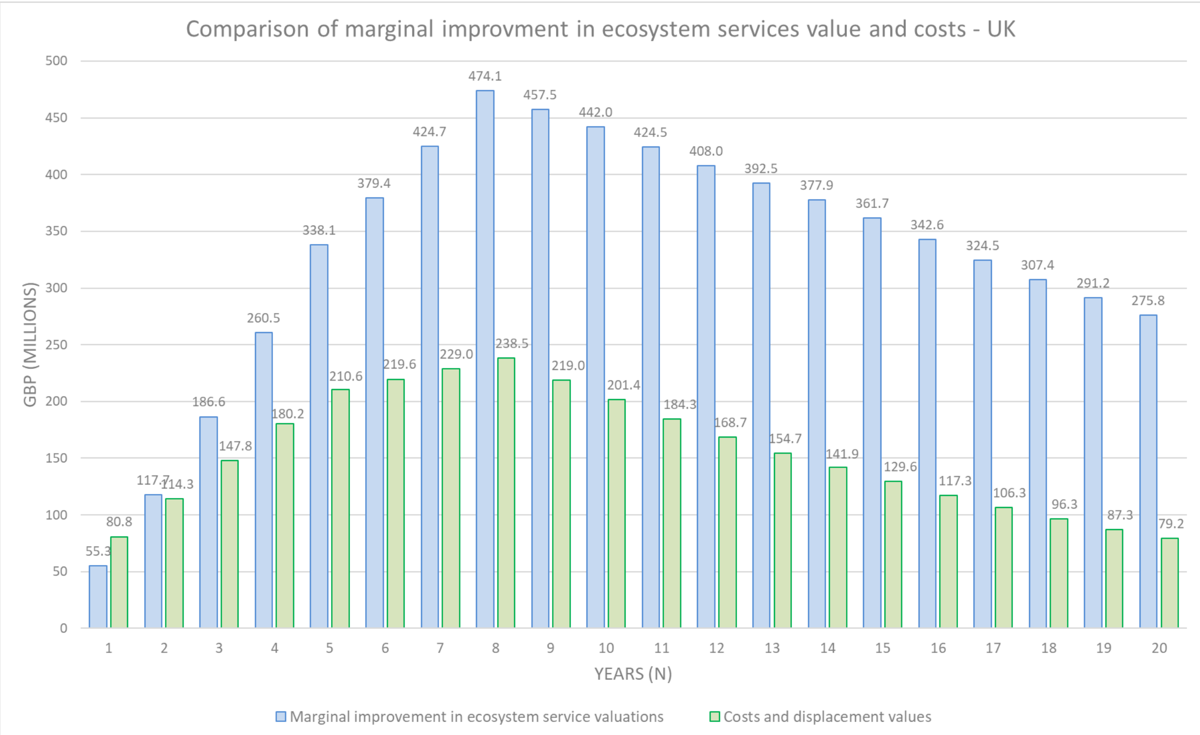


Figure 34: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for the UK offshore benthic MPA network. Costs are

calculated based on the operational cost of enforcing a ban across UK offshore benthic MPAs that remain open to bottom towed gear.

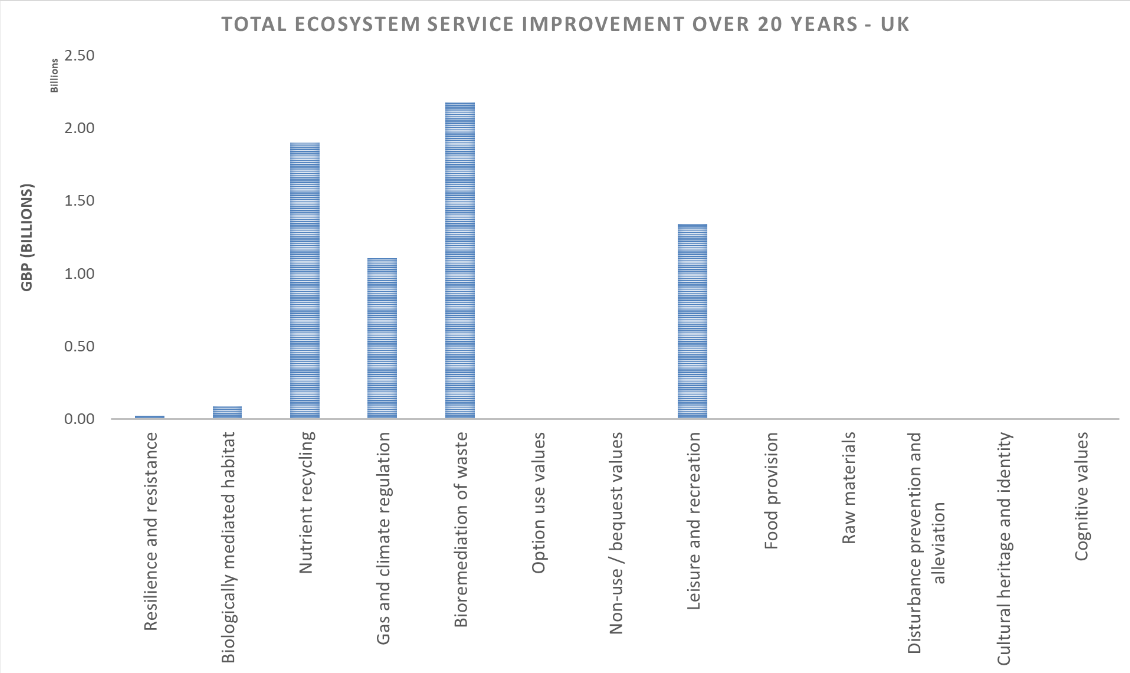


Figure 35: A comparison of the improvement in value of ecosystem services. The majority of the increased value is driven by bioremediation of waste, nutrient recycling, leisure and recreation, and gas & climate regulation.

Scotland

Table 12: The annual value of improvement (in £ millions) for each ecosystem service for the Scottish offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Annual total (£ millions)
Years	1	0.030	0.116	2.516	1.467	2.883	3.493	0.173	0.027	0.007	0.007	**10.7**
	2	0.070	0.273	5.940	3.462	6.806	6.407	0.164	0.026	0.007	0.007	**23.2**
	3	0.119	0.465	10.106	5.891	11.581	9.328	0.155	0.025	0.006	0.006	**37.7**
	4	0.175	0.684	14.869	8.667	17.038	12.228	0.147	0.023	0.006	0.006	**53.8**
	5	0.236	0.924	20.098	11.715	23.030	15.087	0.139	0.022	0.006	0.006	**71.3**
	6	0.287	1.124	24.433	14.242	27.997	15.723	0.132	0.021	0.005	0.005	**84.0**
	7	0.342	1.337	29.085	16.953	33.328	16.475	0.125	0.020	0.005	0.005	**97.7**
	8	0.400	1.565	34.041	19.842	39.007	17.330	0.118	0.019	0.005	0.005	**112.3**
	9	0.406	1.588	34.525	20.124	39.562	17.500	0.112	0.018	0.004	0.005	**113.8**
	10	0.412	1.614	35.088	20.453	40.207	17.717	0.106	0.017	0.004	0.004	**115.6**
	11	0.413	1.618	35.189	20.511	40.323	16.782	0.101	0.016	0.004	0.004	**115.0**
	12	0.415	1.625	35.338	20.598	40.494	15.897	0.095	0.015	0.004	0.004	**114.5**
	13	0.417	1.634	35.523	20.706	40.706	15.058	0.090	0.014	0.004	0.004	**114.2**
	14	0.420	1.643	35.732	20.828	40.945	14.263	0.086	0.014	0.003	0.004	**113.9**
	15	0.413	1.615	35.117	20.469	40.240	13.511	0.081	0.013	0.003	0.003	**111.5**
	16	0.391	1.530	33.264	19.389	38.117	12.798	0.077	0.012	0.003	0.003	**105.6**
	17	0.370	1.449	31.509	18.366	36.106	12.123	0.073	0.011	0.003	0.003	**100.0**
	18	0.351	1.373	29.847	17.397	34.201	11.483	0.069	0.011	0.003	0.003	**94.7**
	19	0.332	1.300	28.272	16.479	32.397	10.877	0.065	0.010	0.003	0.003	**89.7**
	20	0.315	1.232	26.780	15.610	30.687	10.303	0.062	0.010	0.002	0.003	**85.0**
	ES Total (£ millions)	**6.313**	**24.707**	**537.272**	**313.170**	**615.658**	**264.384**	**2.171**	**0.343**	**0.087**	**0.090**	**1764.2**

Table 13: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for Scotland's offshore benthic MPA network. The cumulative*

*net marginal impact shows the economic value in terms of gains in ecosystem services following the bottom-contact fishing ban over a 20-year period. *Costs are calculated considering the administration costs of protecting offshore benthic MPAs in Scottish waters that currently remain open to bottom-gear fishing.*

		Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	Cumulative net marginal impact (£ millions)
Year	1	10.7	10.7	25.6	25.6	-14.8	**-14.8**
	2	23.2	33.9	31.7	57.3	-8.6	**-23.4**
	3	37.7	71.6	38.4	95.7	-0.7	**-24.1**
	4	53.8	125.4	45.2	140.9	8.7	**-15.4**
	5	71.3	196.7	51.7	192.6	19.5	**4.1**
	6	84.0	280.6	55.2	247.8	28.8	**32.8**
	7	97.7	378.3	58.6	306.4	39.1	**71.9**
	8	112.3	490.6	61.9	368.4	50.4	**122.3**
	9	113.8	604.5	59.3	427.7	54.5	**176.8**
	10	115.6	720.1	56.9	484.5	58.8	**235.6**
	11	115.0	835.1	53.6	538.2	61.3	**296.9**
	12	114.5	949.6	50.6	588.8	63.9	**360.8**
	13	114.2	1063.7	47.8	636.6	66.3	**427.1**
	14	113.9	1177.7	45.3	681.9	68.7	**495.8**
	15	111.5	1289.1	42.1	724.0	69.3	**565.1**
	16	105.6	1394.7	38.2	762.2	67.4	**632.5**
	17	100.0	1494.7	34.7	797.0	65.3	**697.8**
	18	94.7	1589.5	31.5	828.5	63.2	**760.9**
	19	89.7	1679.2	28.7	857.2	61.1	**822.0**
	20	85.0	1764.2	26.1	883.3	58.9	**880.9**
	Total (£ millions)	1764.2	1764.2	883.3	883.3	880.9	**880.9**

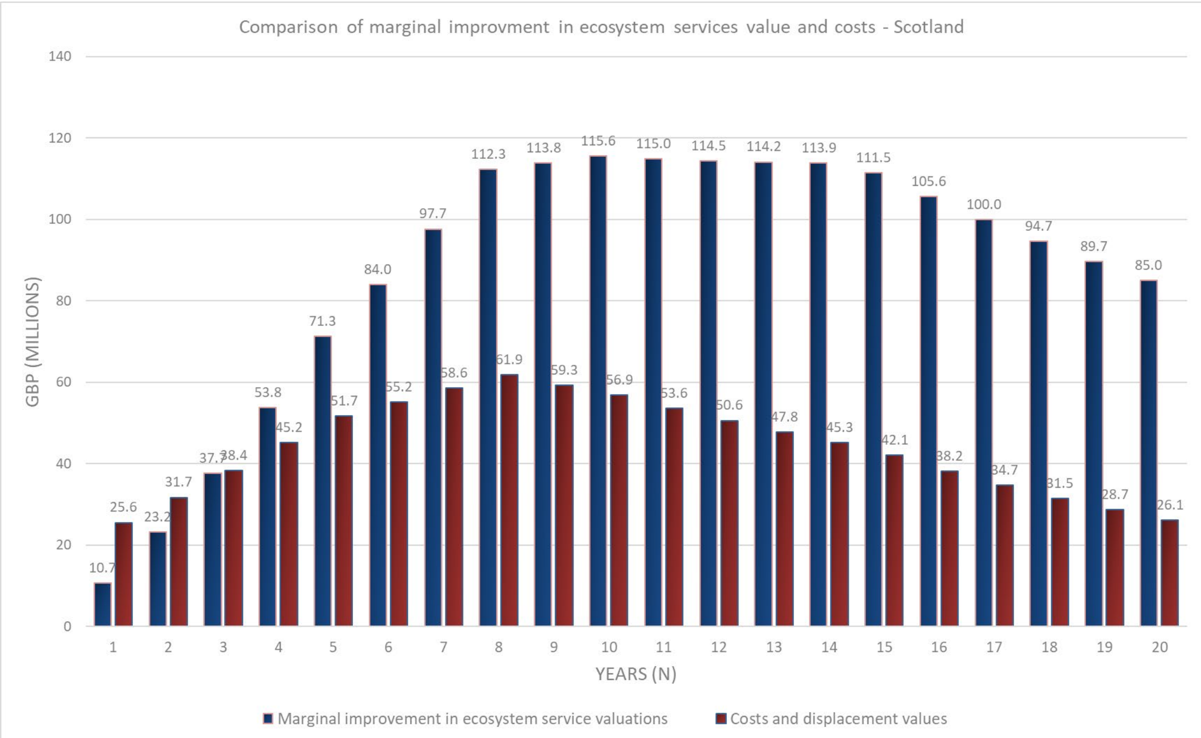


Figure 36: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for Scotland's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in Scotland's offshore benthic MPAs that remain open to bottom towed gear.

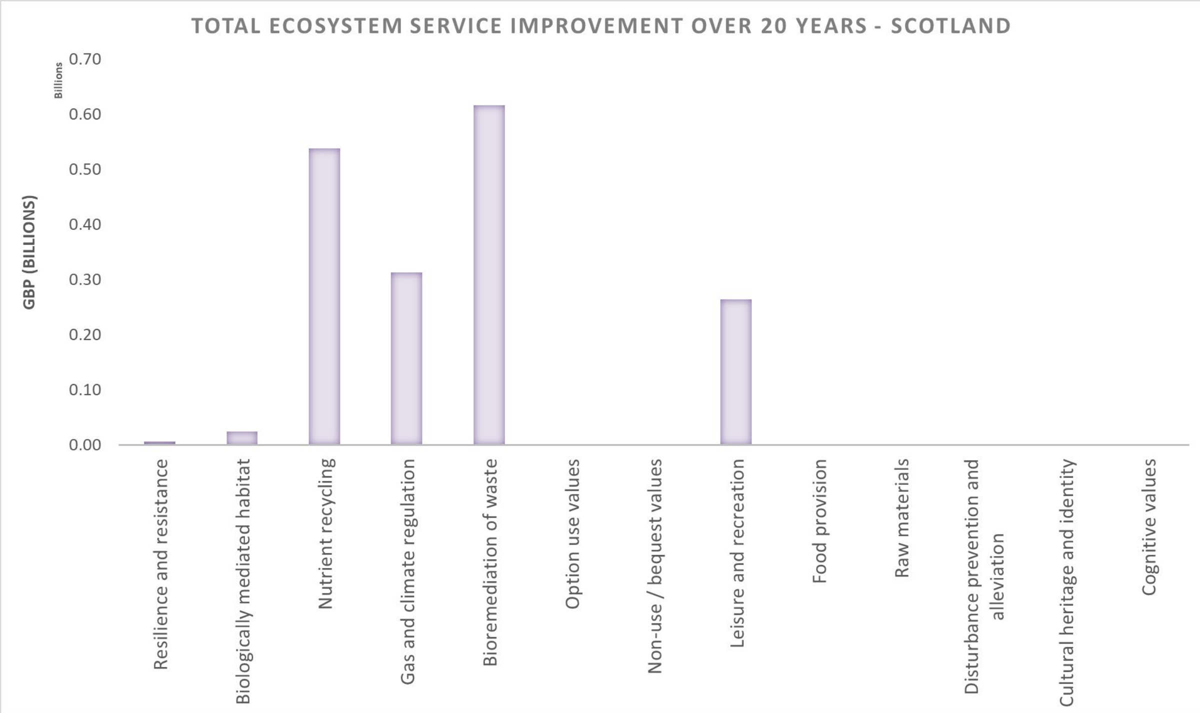


Figure 37: A comparison of the improvement in value of ecosystem services for Scottish offshore benthic MPAs. The majority of the increased value is driven by bioremediation of waste, nutrient recycling, leisure and recreation, and gas & climate regulation.

England

Table 14: The annual value of improvement (in £ millions) for each ecosystem service for the English offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	**Resilience and resistance**	**Biologically mediated habitat**	**Nutrient recycling**	**Gas and climate regulation**	**Bioremediation of waste**	**Leisure and recreation**	**Food provision**	**Raw materials**	**Disturbance prevention and alleviation**	**Cultural heritage and identity**	**Annual total (£ millions)**
Years	1	0.115	0.452	9.826	5.728	11.260	16.236	0.408	0.064	0.016	0.017	**44.1**
	2	0.257	1.004	21.831	12.725	25.016	31.868	0.386	0.061	0.015	0.016	**93.2**
	3	0.418	1.636	35.586	20.743	40.778	46.884	0.366	0.058	0.015	0.015	**146.5**
	4	0.596	2.332	50.715	29.561	58.114	61.250	0.347	0.055	0.014	0.014	**203.0**
	5	0.786	3.076	66.880	38.984	76.638	74.938	0.328	0.052	0.013	0.014	**261.7**
	6	0.910	3.562	77.451	45.146	88.751	73.470	0.311	0.049	0.012	0.013	**289.7**
	7	1.045	4.091	88.965	51.857	101.945	72.345	0.295	0.047	0.012	0.012	**320.6**
	8	1.192	4.666	101.475	59.149	116.280	71.556	0.279	0.044	0.011	0.012	**354.7**
	9	1.132	4.430	96.341	56.156	110.397	68.056	0.264	0.042	0.011	0.011	**336.8**
	10	1.075	4.207	91.489	53.328	104.837	64.755	0.250	0.040	0.010	0.010	**320.0**
	11	1.020	3.990	86.770	50.577	99.430	61.338	0.237	0.037	0.009	0.010	**303.4**
	12	0.967	3.785	82.303	47.974	94.311	58.102	0.225	0.036	0.009	0.009	**287.7**
	13	0.917	3.590	78.074	45.509	89.465	55.037	0.213	0.034	0.009	0.009	**272.9**
	14	0.870	3.406	74.070	43.175	84.877	52.133	0.202	0.032	0.008	0.008	**258.8**
	15	0.825	3.230	70.232	40.938	80.479	49.382	0.191	0.030	0.008	0.008	**245.3**
	16	0.782	3.059	66.527	38.778	76.233	46.777	0.181	0.029	0.007	0.007	**232.4**
	17	0.740	2.898	63.017	36.732	72.211	44.309	0.171	0.027	0.007	0.007	**220.1**
	18	0.701	2.745	59.692	34.794	68.401	41.971	0.162	0.026	0.006	0.007	**208.5**
	19	0.664	2.600	56.542	32.958	64.792	39.757	0.154	0.024	0.006	0.006	**197.5**
	20	0.629	2.463	53.559	31.219	61.373	37.659	0.146	0.023	0.006	0.006	**187.1**
	ES Total (£ millions)	**15.644**	**61.223**	**1331.346**	**776.027**	**1525.586**	**1067.822**	**5.115**	**0.808**	**0.205**	**0.211**	**4784.0**

Table 15: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for England's offshore benthic MPA network. The cumulative net marginal impact shows the economic value in terms of gains in ecosystem services following the bottom-contact fishing ban over a 20-year period. *Costs are calculated considering the administration costs of protecting offshore benthic MPAs in English waters that currently remain open to bottom-gear fishing.*

Year	Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	Cumulative net marginal impact (£ millions)
1	44.1	44.1	54.9	54.9	-10.8	**-10.8**
2	93.2	137.3	81.7	136.6	11.5	**0.7**
3	146.5	283.8	108.0	244.6	38.5	**39.2**
4	203.0	486.8	133.0	377.6	70.0	**109.2**
5	261.7	748.5	156.2	533.8	105.5	**214.7**
6	289.7	1038.2	161.6	695.3	128.1	**342.8**
7	320.6	1358.8	167.4	862.7	153.3	**496.1**
8	354.7	1713.5	173.4	1036.1	181.2	**677.3**
9	336.8	2050.3	156.9	1193.0	180.0	**857.3**
10	320.0	2370.3	142.0	1335.0	178.0	**1035.3**
11	303.4	2673.7	128.3	1463.3	175.1	**1210.4**
12	287.7	2961.4	116.0	1579.4	171.7	**1382.1**
13	272.9	3234.3	105.0	1684.3	167.9	**1550.0**
14	258.8	3493.1	95.0	1779.3	163.8	**1713.8**
15	245.3	3738.4	85.9	1865.2	159.4	**1873.2**
16	232.4	3970.8	77.7	1943.0	154.7	**2027.8**
17	220.1	4190.9	70.3	2013.3	149.8	**2177.6**
18	208.5	4399.4	63.7	2077.0	144.8	**2322.4**
19	197.5	4596.9	57.7	2134.6	139.8	**2462.3**
20	187.1	4784.0	52.2	2186.8	134.8	**2597.1**
Total (£ millions)	4784.0	4784.0	2186.8	2186.8	2597.1	**2597.1**

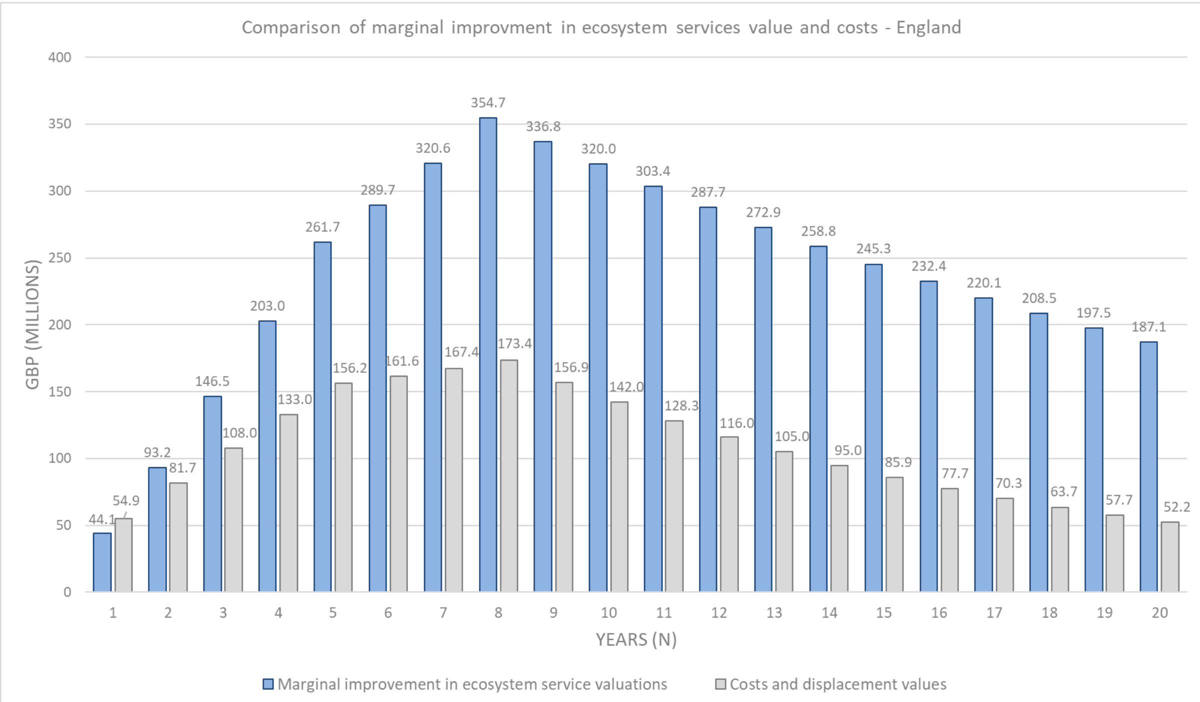


Figure 38: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for England's offshore benthic MPA network. Costs are calculated based on the operational cost of enforcing a ban in England's offshore benthic MPAs that remain open to bottom towed gear.

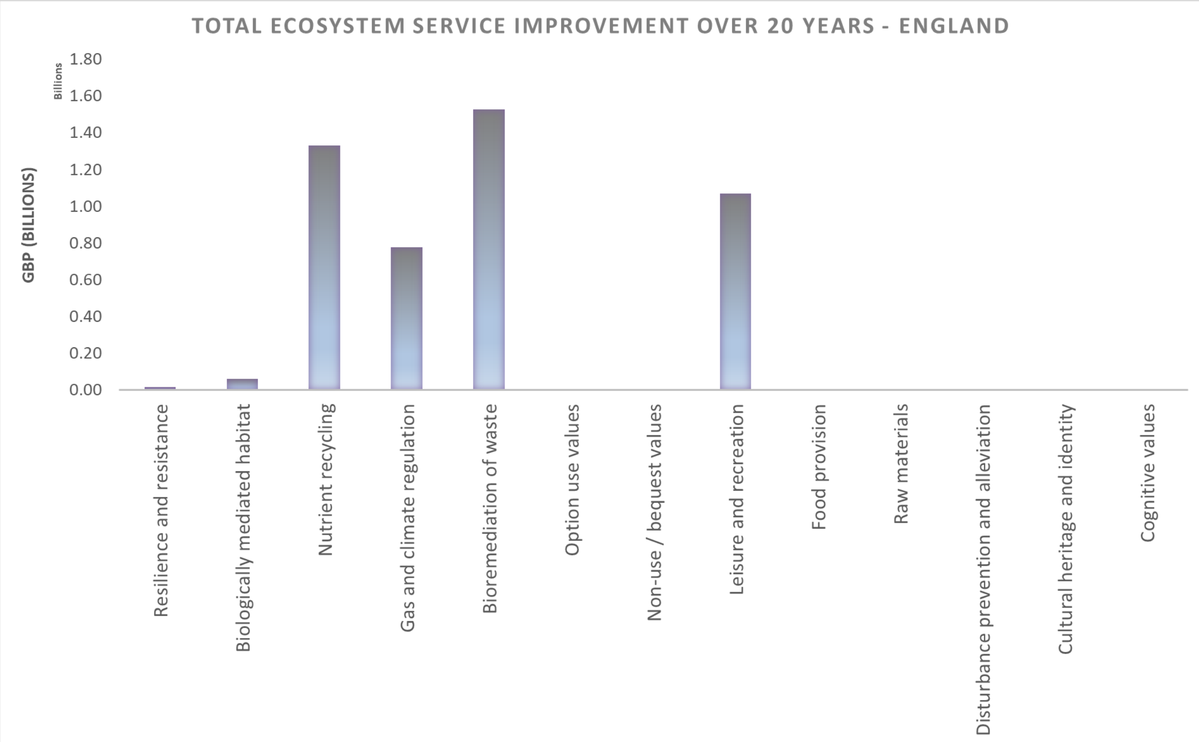


Figure 39: A comparison of the improvement in value of ecosystem services for English benthic offshore MPAs. The majority of the increased value is driven by bioremediation of waste, nutrient recycling, leisure and recreation, and gas & climate regulation.

Wales

Table 16: The annual value of improvement (in £ millions) for each ecosystem service for the Welsh offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Annual total (£ millions)
Years	1	0.000	0.001	0.020	0.012	0.023	0.039	0.001	0.000	0.000	0.000	**0.10**
	2	0.000	0.002	0.042	0.024	0.048	0.075	0.001	0.000	0.000	0.000	**0.19**
	3	0.001	0.003	0.064	0.037	0.073	0.107	0.001	0.000	0.000	0.000	**0.29**
	4	0.001	0.004	0.087	0.050	0.099	0.136	0.001	0.000	0.000	0.000	**0.38**
	5	0.001	0.005	0.110	0.064	0.125	0.162	0.001	0.000	0.000	0.000	**0.47**
	6	0.001	0.005	0.120	0.070	0.137	0.156	0.001	0.000	0.000	0.000	**0.49**
	7	0.002	0.006	0.131	0.076	0.150	0.151	0.000	0.000	0.000	0.000	**0.52**
	8	0.002	0.007	0.143	0.084	0.164	0.146	0.000	0.000	0.000	0.000	**0.55**
	9	0.002	0.006	0.136	0.079	0.156	0.138	0.000	0.000	0.000	0.000	**0.52**
	10	0.002	0.006	0.129	0.075	0.147	0.131	0.000	0.000	0.000	0.000	**0.49**
	11	0.001	0.006	0.122	0.071	0.140	0.124	0.000	0.000	0.000	0.000	**0.46**
	12	0.001	0.005	0.115	0.067	0.132	0.117	0.000	0.000	0.000	0.000	**0.44**
	13	0.001	0.005	0.109	0.064	0.125	0.111	0.000	0.000	0.000	0.000	**0.42**
	14	0.001	0.005	0.104	0.060	0.119	0.105	0.000	0.000	0.000	0.000	**0.39**
	15	0.001	0.005	0.098	0.057	0.112	0.100	0.000	0.000	0.000	0.000	**0.37**
	16	0.001	0.004	0.093	0.054	0.106	0.095	0.000	0.000	0.000	0.000	**0.35**
	17	0.001	0.004	0.088	0.051	0.101	0.090	0.000	0.000	0.000	0.000	**0.34**
	18	0.001	0.004	0.083	0.049	0.096	0.085	0.000	0.000	0.000	0.000	**0.32**
	19	0.001	0.004	0.079	0.046	0.090	0.080	0.000	0.000	0.000	0.000	**0.30**
	20	0.001	0.003	0.075	0.044	0.086	0.076	0.000	0.000	0.000	0.000	**0.28**
	ES Total (£ millions)	**0.023**	**0.089**	**1.946**	**1.134**	**2.230**	**2.223**	**0.008**	**0.001**	**0.000**	**0.000**	**7.66**

Table 17: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the Welsh offshore benthic MPA network. The cumulative net marginal impact shows the economic value in terms of gains in ecosystem services following*

*the bottom-contact fishing ban over a 20-year period. *Costs calculated consider the administration costs of protecting offshore benthic MPAs that currently remain open to bottom-gear fishing.*

		Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	Cumulative net marginal impact (£ millions)
Year	1	0.10	0.10	0.13	0.13	-0.03	**-0.03**
	2	0.19	0.29	0.18	0.30	0.01	**-0.02**
	3	0.29	0.57	0.22	0.52	0.06	**0.05**
	4	0.38	0.95	0.26	0.78	0.12	**0.17**
	5	0.47	1.42	0.29	1.08	0.18	**0.34**
	6	0.49	1.91	0.29	1.36	0.20	**0.54**
	7	0.52	2.42	0.28	1.65	0.23	**0.77**
	8	0.55	2.97	0.28	1.93	0.26	**1.04**
	9	0.52	3.49	0.26	2.19	0.26	**1.30**
	10	0.49	3.98	0.23	2.42	0.26	**1.56**
	11	0.46	4.44	0.21	2.63	0.25	**1.81**
	12	0.44	4.88	0.19	2.82	0.25	**2.06**
	13	0.42	5.30	0.17	2.99	0.24	**2.30**
	14	0.39	5.69	0.16	3.15	0.24	**2.54**
	15	0.37	6.06	0.14	3.29	0.23	**2.77**
	16	0.35	6.42	0.13	3.42	0.22	**3.00**
	17	0.34	6.75	0.12	3.54	0.22	**3.22**
	18	0.32	7.07	0.11	3.64	0.21	**3.43**
	19	0.30	7.37	0.10	3.74	0.20	**3.63**
	20	0.28	7.66	0.09	3.83	0.20	**3.83**
	Total (£ millions)	7.66	7.66	3.83	3.83	3.83	**3.83**

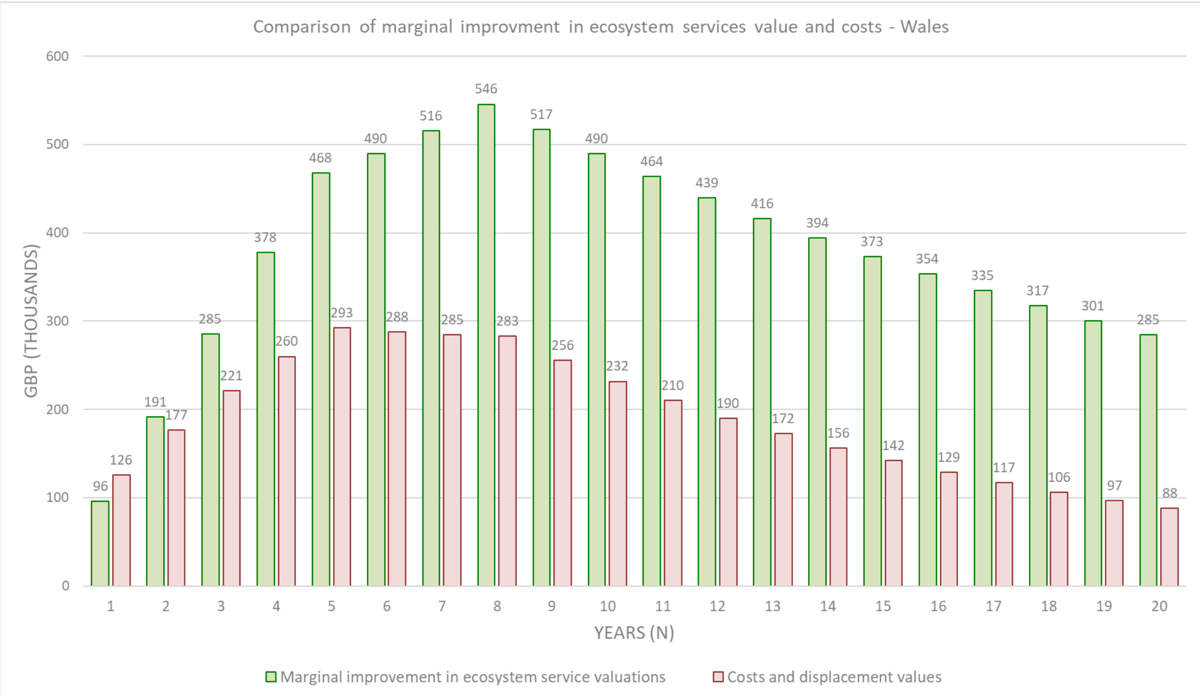


Figure 40: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for the offshore benthic MPA network in Wales. Costs are calculated based on the operational cost of enforcing a ban in the offshore benthic MPAs that remain open to bottom towed gear in Welsh waters.

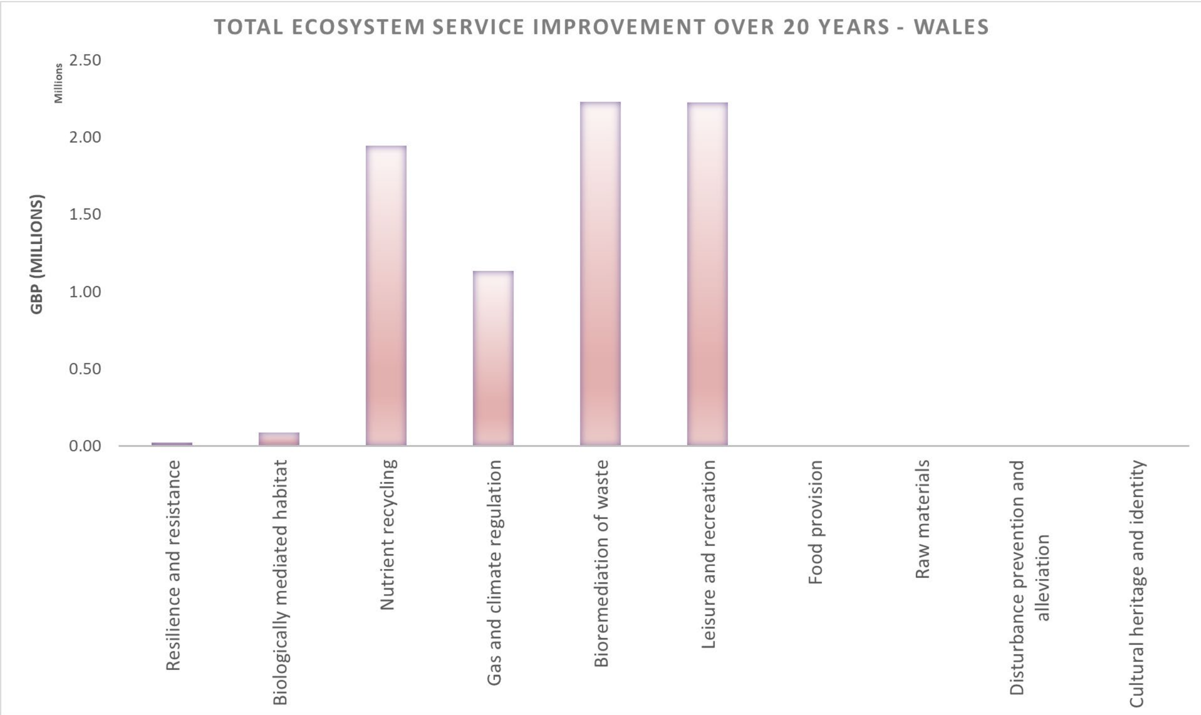


Figure 41: A comparison of the improvement in value of ecosystem services for Welsh offshore benthic MPAs. The majority of the increased value is driven by leisure and recreation, bioremediation of waste, nutrient recycling and gas & climate regulation.

Northern Ireland

Table 18: The annual value of improvement (in £ millions) for each ecosystem service for the Northern Ireland's offshore benthic MPA network, based on areas subject to demersal fishing.

	Ecosystem service	Resilience and resistance	Biologically mediated habitat	Nutrient recycling	Gas and climate regulation	Bioremediation of waste	Leisure and recreation	Food provision	Raw materials	Disturbance prevention and alleviation	Cultural heritage and identity	Annual total (£ millions)
Years	1	0.001	0.004	0.080	0.047	0.092	0.058	0.005	0.001	0.000	0.000	**0.3**
	2	0.003	0.010	0.218	0.127	0.249	0.134	0.005	0.001	0.000	0.000	**0.7**
	3	0.005	0.019	0.403	0.235	0.462	0.225	0.005	0.001	0.000	0.000	**1.4**
	4	0.007	0.029	0.627	0.365	0.718	0.328	0.004	0.001	0.000	0.000	**2.1**
	5	0.010	0.041	0.882	0.514	1.010	0.440	0.004	0.001	0.000	0.000	**2.9**
	6	0.013	0.051	1.119	0.652	1.282	0.463	0.004	0.001	0.000	0.000	**3.6**
	7	0.016	0.063	1.373	0.801	1.574	0.490	0.004	0.001	0.000	0.000	**4.3**
	8	0.019	0.076	1.647	0.960	1.887	0.520	0.004	0.001	0.000	0.000	**5.1**
	9	0.018	0.072	1.560	0.909	1.788	0.493	0.003	0.001	0.000	0.000	**4.8**
	10	0.017	0.068	1.478	0.861	1.693	0.467	0.003	0.001	0.000	0.000	**4.6**
	11	0.016	0.064	1.400	0.816	1.604	0.442	0.003	0.000	0.000	0.000	**4.3**
	12	0.016	0.061	1.326	0.773	1.520	0.419	0.003	0.000	0.000	0.000	**4.1**
	13	0.015	0.058	1.256	0.732	1.439	0.397	0.003	0.000	0.000	0.000	**3.9**
	14	0.014	0.055	1.190	0.694	1.363	0.376	0.003	0.000	0.000	0.000	**3.7**
	15	0.013	0.052	1.127	0.657	1.291	0.356	0.002	0.000	0.000	0.000	**3.5**
	16	0.013	0.049	1.068	0.622	1.223	0.337	0.002	0.000	0.000	0.000	**3.3**
	17	0.012	0.047	1.011	0.589	1.159	0.319	0.002	0.000	0.000	0.000	**3.1**
	18	0.011	0.044	0.958	0.558	1.098	0.303	0.002	0.000	0.000	0.000	**3.0**
	19	0.011	0.042	0.907	0.529	1.040	0.287	0.002	0.000	0.000	0.000	**2.8**
	20	0.010	0.040	0.859	0.501	0.985	0.272	0.002	0.000	0.000	0.000	**2.7**
	ES Total (£ millions)	**0.241**	**0.942**	**20.488**	**11.942**	**23.478**	**7.125**	**0.066**	**0.010**	**0.003**	**0.003**	**64.3**

Table 19: The annual net value (in £ millions) of improvement in the value of ecosystem services minus costs and displacement values for the Northern Irish offshore benthic MPA network. The cumulative net marginal impact shows the economic value in terms of gains in ecosystem services following the bottom-contact fishing ban over a 20-year period. *Costs calculated consider the*

administration costs of protecting offshore benthic MPAs that currently remain open to bottom-gear fishing.

		Marginal improvement in ecosystem service valuations	Cumulative improvements in ecosystem service valuations	Annual costs & displacement	Cumulative costs & displacement	Net Marginal Impact	Cumulative net marginal impact (£ millions)
Year	1	0.3	0.3	0.4	0.4	-0.1	**-0.1**
	2	0.7	1.0	0.7	1.1	0.1	**-0.1**
	3	1.4	2.4	1.0	2.1	0.4	**0.3**
	4	2.1	4.5	1.3	3.4	0.7	**1.0**
	5	2.9	7.4	1.7	5.1	1.2	**2.2**
	6	3.6	11.0	1.9	7.1	1.7	**3.9**
	7	4.3	15.3	2.2	9.2	2.1	**6.0**
	8	5.1	20.4	2.4	11.6	2.7	**8.7**
	9	4.8	25.2	2.2	13.8	2.7	**11.4**
	10	4.6	29.8	2.0	15.8	2.6	**14.1**
	11	4.3	34.2	1.8	17.5	2.6	**16.6**
	12	4.1	38.3	1.6	19.1	2.5	**19.2**
	13	3.9	42.2	1.4	20.5	2.5	**21.7**
	14	3.7	45.9	1.3	21.8	2.4	**24.1**
	15	3.5	49.4	1.2	23.0	2.3	**26.4**
	16	3.3	52.7	1.0	24.0	2.3	**28.7**
	17	3.1	55.8	0.9	25.0	2.2	**30.9**
	18	3.0	58.8	0.9	25.8	2.1	**33.0**
	19	2.8	61.6	0.8	26.6	2.0	**35.0**
	20	2.7	64.3	0.7	27.3	2.0	**37.0**
	Total (£ millions)	64.3	64.3	27.3	27.3	37.0	**37.0**

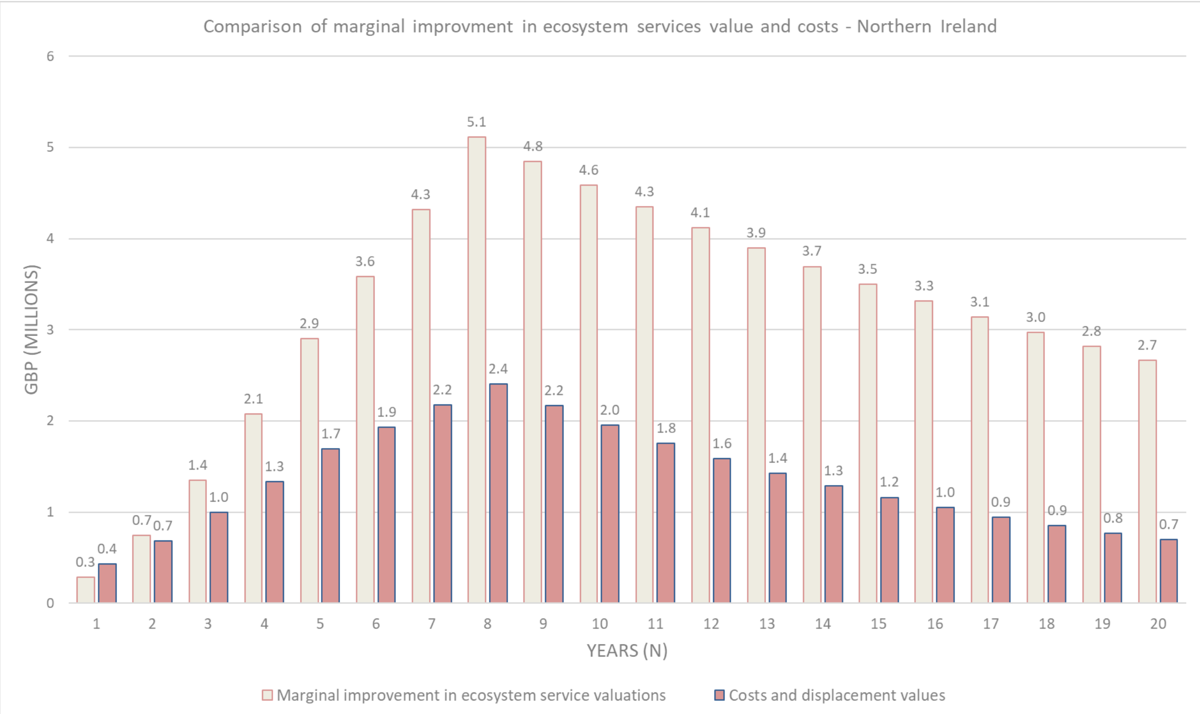


Figure 42: A comparison (in £ millions) of annual improvements in the value of ecosystem services versus annual costs and displacement values for the offshore benthic MPA network in Northern Ireland waters. Costs are calculated based on the operational cost of enforcing a ban in Northern Ireland's offshore benthic MPAs that remain open to bottom towed gear.

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