Final Project Report

OEP019-01 – Review of the Monitoring and Regulatory Landscape for Contaminants in UK Marine Waters

10 April 2026

Defra MEL Lot 3 – Marine & Fisheries

OFFICIAL

Document control

Document Title	Review of the Monitoring and Regulatory Landscape for Contaminants in UK Marine Waters - Final Project Report
Service Order No.	OEP019-01
Prepared by	Julian Roberts, Lucy Jenkins (ICF) Charlotte Kipreos-Clarke (HMC)
Checked by	Rupert Haines (ICF)
Date	10 April 2026

This work has been delivered by ICF and Howel Marine Consulting Ltd (HMC) under Defra Monitoring Evaluation and Learning Services Lot 3 (Marine & Fisheries). Defra MEL is a procurement channel available to all organisations in the Defra family. Managed by ICF, it provides rapid access to professional expertise in evaluation, monitoring, research and analysis, strategy, and organisational learning.

Table of Contents

Acronyms

AFFF	Aqueous Film-Forming Foam
BAT	Best Available Technique
CAR	Controlled Activities Regulations
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CHARM	Chemical Hazard and Risk Management
CSO	Combined Sewer Overflow
DDT	Dichlorodiphenyltrichloroethane
Defra	Department for Environment, Food and Rural Affairs
DIN	Dissolved Inorganic Nitrogen
EA	Environment Agency (England)
EDC	Endocrine-Disrupting Compound
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EMODNET	European Marine Observation and Data Network
EPR	Environmental Permitting Regulations (England and Wales)
EQS	Environmental Quality Standard
EU	European Union
EU REACH	EU Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (EC No 1907/2006)
FSA	Food Standards Agency
FRfW	Farming Rules for Water (England, 2018)
GES	Good Environmental Status
HAB	Harmful Algal Bloom
HMCS	Harmonised Mandatory Control System
HSE	Health and Safety Executive
ICES	International Council for the Exploration of the Sea
IED	Industrial Emissions Directive
LCPA	List of Chemicals for Priority Action (OSPAR)
LSPC	List of Substances of Possible Concern (OSPAR)
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships
MCCIP	Marine Climate Change Impacts Partnership
MMO	Marine Management Organisation
MOAT	Marine Online Assessment Tool
MPA	Marine Protected Area

MSFD	Marine Strategy Framework Directive (EU Directive 2008/56/EC; transposed as Marine Strategy Regulations 2010)
N:P ratio	Nitrogen-to-phosphorus ratio
NIEA	Northern Ireland Environment Agency
NRW	Natural Resources Wales
NVZ	Nitrate Vulnerable Zone
OEP	Office for Environmental Protection
OPEs	Organophosphate esters
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic Aromatic Hydrocarbon
PARCOM	Paris Commission
PBDE	Polybrominated Diphenyl Ether
PCB	Polychlorinated Biphenyl
PFAS	Per- and Polyfluoroalkyl Substances
PFOS	Perfluorooctane Sulfonate
PoM	Programme of Measures
POP / POPs	Persistent Organic Pollutant(s)
PPC	Pollution Prevention and Control
PPCP	Pharmaceutical and Personal Care Product
RBMP	River Basin Management Plan
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RCS	Resuspended Contaminated Sediment event
RIFE	Radioactivity in Food and the Environment
SML	Sea-Surface Microlayer
SODRP	Storm Overflows Discharge Reduction Plan
SUP	Single-Use Plastic
TBT	Tributyltin
TFA	Trifluoroacetic acid
UK REACH	UK equivalent of EU REACH following Brexit
UKMS	UK Marine Strategy
UPR	Unfolded Protein Response
UWWTR	Urban Wastewater Treatment Regulations 1994 (and devolved equivalents)
WFD	Water Framework Directive
WwTW	Wastewater Treatment Works
delta-15N	Stable nitrogen isotope ratio

Executive Summary

This report reviews the monitoring and regulatory landscape for contaminants in UK marine waters, finding persistent failures to achieve Good Environmental Status (GES) and significant structural weaknesses in the current regulatory framework. It presents the consolidated findings of a study commissioned by the Office for Environmental Protection (OEP). The project was undertaken by ICF Consulting Services Ltd and Howell Marine Consulting (HMC) under the Defra Monitoring, Evaluation and Learning (MEL) Services framework (Lot 3: Marine and Fisheries).

The study integrates two analytical components: (i) a semi-systematic literature review; and (ii) a structured regulatory review. Both components are organised around the achievement of Good Environmental Status (GES) as defined under the Marine Strategy Regulations 2010 and the UKMS. The project team prepared synthesis reports for each component, subject to external peer review organised by the OEP and subsequently updated to address review comments. This final project report synthesises the findings of both components and is organised according to the research questions agreed with the OEP at the outset.

Principal findings: Evidence on status and impacts

The literature review confirms that UK marine waters face persistent and, in some cases, worsening contaminant pressures across the four GES descriptors under review. The UK has not met GES for **Descriptor 8 (D8): Contaminants** or **Descriptor 10 (D10): Marine litter**. GES has been met for shellfish under **Descriptor 9 (D9): Contaminants in seafood** and met for 95% of UK marine waters for **Descriptor 5 (D5): Eutrophication**, although significant geographic variations persist in both cases and there has been no GES assessment for fish under D9.

GES has not been achieved for D8: with failure to meet GES driven primarily by sediments contaminated by legacy contaminants that source-control regulation cannot address, as a result of which, concentrations of some metals in marine biota are actively increasing. The most recent UKMS assessment confirms that the environmental thresholds for meeting GES are persistently exceeded for lead, mercury, copper, and zinc in at least one assessed biogeographic region, and for polychlorinated biphenyl (CB118) and polybrominated diphenyl ether (BDE209) in sediments and biota across multiple sub-regions. A shift to a more stringent environmental quality standard for mercury has revealed that concentrations may potentially harm marine life across all assessed UK regions. The primary drivers of ongoing GES failure are the remobilisation of legacy contaminated sediments from historically industrialised estuaries, atmospheric deposition, and oil and gas industry inputs, pathways that ongoing source control regulation cannot reduce. Mercury and copper concentrations in biota are increasing in parts of the Southern North Sea and Irish Sea, indicating growing bioavailability rather than simple legacy persistence.

Several additional D8 contaminants pose serious ecological risks even where GES thresholds are nominally met, and these pressures are likely to be exacerbated by climate change. Polychlorinated biphenyls (PCBs) remain present in UK marine mammal populations (including dolphins and killer whales) at concentrations that are considered toxic to mammals. Polycyclic aromatic hydrocarbons (PAHs) currently meet GES targets but remain elevated in the sea-surface microlayer, causing larval fish mortality and developmental abnormalities; radionuclides meet GES thresholds but require continued monitoring. Climate change will amplify all these pressures: increased storminess will intensify sediment remobilisation; ocean acidification will increase metal solubility and bioavailability; and warming and hypoxic sediment conditions will promote mercury methylation, greatly increasing its bioaccumulation potential.

GES has been met for the majority of UK waters for D5: but localised failures persist and a structural nutrient imbalance in the North Sea is emerging as a new ecological risk. Approximately 95% of UK marine and coastal waters meet GES, but around 3% of coastal waterbodies fail and a further 2% are at risk, concentrated in intensively farmed catchments and urbanised estuaries where agricultural diffuse inputs and combined sewer overflow (CSO) discharges combine with high residence times and restricted tidal exchange. A significant finding is the emergence of nitrogen-to-phosphorus (N:P) ratio imbalances in the North Sea, driven by the greater regulatory success in reducing phosphorus than nitrogen. This shift risks altering phytoplankton community composition, contributing to trophic changes that cascade to zooplankton and higher trophic levels. Harmful algal blooms associated with eutrophication cause toxin production, oxygen depletion, and gill clogging, with documented impacts on marine mammals, fish, seabirds, and aquaculture operations.

GES is only partially achieved for D9: shellfish compliance has been demonstrated, but a significant monitoring gap for finfish and the absence of regulatory standards for PFAS leave important risks unassessed. GES has been achieved for shellfish based on 2016–2020 surveys confirming compliance with regulatory maximum levels for heavy metals, PAHs, and dioxins and dioxin-like PCBs. However, overall GES is only partially met, mainly due to the lack of finfish monitoring data, an evidence gap and regulatory blind spot. Fatty finfish such as sea bass, sprats, mackerel, sardines, and herring show elevated PCBs, PBDEs, and dioxins, especially from the Southern UK, Northern French coasts, and the Irish Sea. Existing shellfish survey sites are geographically biased towards North-West Scotland, which has the least heavy metal contamination, potentially understating compliance risks. PFAS lack maximum level standards in UK seafood, leaving an unmonitored pathway for human exposure.

GES has not been achieved for D10: despite improvements on beaches and surface waters, seafloor litter is increasing and the risks from microplastics and nanoplastics remain largely unmonitored. Plastics account for around 90% of monitored marine litter in UK waters, and GES remains unachieved. Although beach and floating litter are showing downward trends, seafloor litter is rising, due to the prolonged persistence of plastics in deep waters. Macro-plastic entanglement leads to drowning, strangulation, or severe injury in turtles, seabirds, and marine mammals, with 79% of recorded cases causing harm or death; ingestion results in blockages, false satiation, and reproductive issues. Microplastics, not yet formally assessed for D10, act as vectors for persistent organic pollutants and plastic additives, concentrating these in marine organisms. Nano-plastics, which can cross biological membranes and enter the food web at its base, pose an additional risk that current monitoring cannot address. Climate change is expected to worsen these challenges through increased flooding, more storms, and faster plastic breakdown and leaching.

A substantial and growing group of emerging contaminants (led by PFAS) falls entirely outside the current GES assessment framework, with monitoring and regulatory action running well behind the pace of environmental accumulation. Across all four descriptors, PFAS are prevalent at all trophic levels in UK coastal and marine environments, causing immunotoxicity, endocrine disruption, and reproductive issues in marine mammals, seabirds, and fish. Of more than 4,700 known PFAS variants, only a handful are routinely monitored, and a GES indicator for PFAS in sediments and biota remains under development. As legacy long-chain PFAS are regulated out, they are replaced by shorter-chain and novel alternatives, often present in marine environments but generally lacking established quality standards. The tyre-derived compound 6PPD-quinone, which causes acute fish mortality at low levels, also lacks an agreed Environmental Quality Standard (EQS) and has limited marine monitoring data. Bioactivity-based research has identified an ‘unknown pool’ of chemically active substances in UK waters, indicating that current targeted monitoring assesses only a fraction of the total biologically active chemical contamination present.

Principal findings: Regulatory and policy landscape

The regulatory framework for marine contaminants is extensive but structurally imbalanced: of 81 identified instruments, 70 carry a preventative function, while only two carry explicit remediation mandates, leaving the framework ill-equipped to address legacy contamination. The regulatory review identified 81 instruments ranging from international treaty obligations to agency-level monitoring programmes, involving at least seven UK government departments and agencies, with equivalent bodies across the devolved administrations. The Marine Strategy Regulations 2010 and the OSPAR Convention provide the overarching governance architecture, with the Water Environment (Water Framework Directive) Regulations 2017, the Environmental Permitting Regulations, UK REACH, the Urban Wastewater Treatment Regulations 1994, and MARPOL 73/78 constituting the core operating framework. Of the 81 instruments identified, 70 are preventative and only two explicitly address remediation, highlighting a structural imbalance that hinders the framework's effectiveness in resolving legacy contamination issues.

Three structural weaknesses collectively explain the persistent gap between the framework's regulatory ambition and GES outcomes:

(1) A prevention-only focus that cannot address legacy contamination: The regulatory landscape is weighted towards preventing new contamination, but has virtually no capacity to address the substantial legacy contamination already present in UK marine sediments, which is a primary driver of ongoing GES failure for D8;

(2) Fragmented institutional mandates: No single authority holds an end-to-end mandate for any major contaminant pathway, resulting in systematic coordination failures at jurisdictional boundaries (particularly in estuaries), and leaving emerging multi-sector contaminants such as PFAS without any cross-regulator management mandate. This is reflected in the disconnect between the Water Framework Directive (WFD), governing inland and coastal waters to one nautical mile, and the UK Marine Strategy (UKMS), covering the wider marine environment. The WFD acts on catchment sources operating under different metrics, objectives, and institutional leads to those governing marine outcomes, weakening the coherence of pathway management from source to sea; and

(3) Regulatory adaptation that is running behind the pace of environmental change: Regulatory responses to new contaminants like PFAS, microplastics, and pharmaceuticals are lagging behind environmental accumulation; while the UK's PFAS Plan (2026) delays action by prioritizing monitoring, the EU is advancing a broad PFAS ban, creating a divergence that directly impacts shared marine protection.

The most significant regulatory gaps include an enforcement deficit undermining well-designed controls, misalignment between EIA and GES objectives, and the lack of any regulatory pathway for microplastics in wastewater effluent. The Farming Rules for Water and Environmental Permitting Regulations are appropriately designed but under-enforced due to EA inspection capacity constraints. The EIA and marine licensing regimes are widely referenced as delivery mechanisms within the UKMS Programme of Measures, but neither requires formal assessment against GES Descriptors, creating a structural accountability gap. Consenting decisions for activities with significant contamination implications (including those with eutrophication implications relevant to D5) are therefore made without formal consideration of their implications for GES achievement, constituting a missed opportunity to embed GES objectives into the decisions of greatest relevance to their delivery. No instrument addresses microplastic concentrations in WwTW effluent, the dominant vector for microplastic inputs to estuarine and coastal waters: no discharge standard, permit condition, or monitoring requirement specifically addresses microplastic concentrations in WwTW discharges, despite the wastewater pathway being a major vector by which plastic particles from washing synthetic textiles and other domestic sources reach the sea.

Overarching conclusions

The gap between the UK's regulatory framework and the measures required to achieve GES is not solely a matter of legislative design, but rather: the extent to which relevant legislation is implemented and enforced; remediation capacity; and the speed of regulatory adaptation to emerging evidence. For established contaminant groups and point-source pathways, the principal instruments are broadly in place but are underdelivering due to enforcement resourcing constraints, jurisdictional fragmentation between the WFD and UKMS frameworks, and inadequate inter-agency coordination. The connection between WFD objectives and marine GES assessments is not always clear in planning and reporting. However, for legacy sediment contamination, PFAS, microplastics, and the coastal litter pathway, the gap is one of coverage: no instrument exists that is capable of addressing these pressures, and the regulatory lifecycle is not adapting at a pace commensurate with the rate of environmental accumulation. The UKMS's six-year review cycle cannot respond to rapidly accumulating emerging contaminants between cycles, creating a structural lag that, for PFAS, has already extended beyond a decade from first detection to any prospect of operational standards.

Achieving GES for D8 and D10 will require a package of targeted interventions that go beyond the current regulatory framework. This will require: a national remediation framework for legacy sediment contamination; accelerated development of marine environmental quality standards for PFAS and other emerging contaminants; instruments addressing dominant diffuse pathways for microplastics; greater alignment between EIA and marine licensing and GES objectives; and, substantially enhanced enforcement capacity and inter-agency coordination.

1 Introduction

1.1 Background and scope of the study

The Office for Environmental Protection (OEP), a public body created under the Environment Act 2021, protects and improves the environment by holding government and other public authorities to account. In this context, the OEP has developed a marine programme, focused on assessing progress towards the achievement of Good Environmental Status (GES) of UK marine waters under the Marine Strategy Regulations 2010. Evidence assembled as part of this programme, has identified that contaminants represent a key pressure on the health, productivity and resilience of UK seas. Substances including heavy metals, pesticides, hydrocarbons, persistent organic pollutants (POPs), excess nutrients, and emerging contaminants (such as per- and polyfluoroalkyl substances (PFAS), pharmaceuticals and microplastics), are shown to harm marine life, disrupt ecosystem functioning, and pose risks to water quality and human health. Critically, current evidence suggests that, for many GES indicators, the condition of UK seas is not improving against a background of persistent and, in some cases, increasing pressures.

In December 2025, the OEP commissioned ICF Consulting Services Ltd (ICF) and Howell Marine Consulting (HMC) to undertake a rapid but systematic review of the monitoring and regulatory landscape for contaminants in UK marine waters. The results are intended to support the OEP to develop an independent, evidence-based view of the challenges to achieving and maintaining GES that are associated with marine contaminants, and to inform its wider scrutiny and reporting functions.

The review encompasses substances introduced into, or existing beyond permissible limits within the marine environment, that may cause harm to marine ecosystems or interfere with legitimate uses of the sea - including synthetic chemicals, heavy metals, persistent organic pollutants, excess nutrients, and emerging contaminants. The geographic scope covers UK marine waters as defined by the UK Marine Strategy, encompassing the Celtic Seas and Greater North Sea biogeographic sub-regions. The temporal scope is primarily post-2000, reflecting landmark regulatory developments including the Water Framework Directive (2000) and the Stockholm Convention (2001), as well as the significant increase in marine contaminant research over this period. The review focuses on instruments operating in England, with devolved equivalents noted where relevant.

The review consists of the following two key outputs and a final summary report:

(i) a literature review summarising the existing evidence concerning the impacts of contaminants on the marine environment, with respect to GES; and

(ii) an analysis of current regulatory and policy frameworks that influence the pathways and management of contaminants affecting progress towards achievement of GES under the UKMS.

Both outputs were subject to independent peer review by members of the OEP's College of Experts.

1.2 Definitions and conceptual framing

Good Environmental Status (GES) is the primary environmental objective of the UK Marine Strategy (UKMS). For this review, GES is assessed primarily through four descriptors: **Descriptor 5 (D5): Eutrophication**; **Descriptor 8 (D8): Contaminants**; **Descriptor 9 (D9): Contaminants in Seafood**; and **Descriptor 10 (D10): Marine Litter**. The review also addresses potential **emerging contaminants** not yet embedded within these descriptors.

The review uses a '**source-pathway-receptor**' framework to organise evidence and regulatory analysis. Contaminant sources include land- and marine-based activities; pathways include river input, direct discharge, atmospheric deposition, and sediment remobilisation; and receptors include water, sediment, marine life, and seafood eaten by humans. This framework enables assessment of both contaminant pressures and regulatory coverage at each pathway stage.

1.3 Research questions

The project is organised around two sets of research questions, one for each analytical component.

Literature review research questions:

LRQ1: What are the main contaminants affecting the health of UK marine ecosystems as assessed within the GES indicator framework (including emerging contaminants not currently in the GES framework)?

LRQ2: What are the sources and pathways of the identified contaminants into the marine environment?

LRQ3: What are the impacts of the identified contaminants on the health of marine ecosystems?

LRQ4: What are the primary drivers and risks relating to the achievement of GES for contaminants?

Regulatory Review Research Questions:

RRQ1: What are the key regulatory and policy levers used to control contaminants affecting UK marine waters?

RRQ2: How do these levers operate across different contaminant sources and pathways?

RRQ3: To what extent do existing regulations and policies support the achievement or maintenance of GES?

RRQ4: Where are there gaps, overlaps, exemptions, or enforcement challenges that may undermine effectiveness?

RRQ5: Are emerging contaminants adequately addressed within current regulatory frameworks?

1.4 Purpose and structure of the report

This final report summarises the project's consolidated findings, integrating literature and regulatory reviews to address the research questions. It should be read with the two synthesis reports referenced in section 1.1.

This report is structured as follows.

Section 2 describes the methods for both review components.

Section 3 presents the findings of the literature review, structured according to the four literature research questions.

Section 4 presents the findings of the regulatory review, structured according to the five regulatory research questions.

Section 5 provides a synthesis of findings across both components.

2 Overall approach

The project employed two complementary methodologies, aligned to the source-pathway-receptor framing used in the UK Marine Strategy and the OEP's prior evidence base on drivers and pressures affecting GES achievability (Opergy Ltd, 2024).

1. The literature review used a semi-systematic approach to assemble, organise, and critically appraise evidence on contaminant status, sources, pathways, and ecological impacts.
2. The regulatory review used a structured qualitative approach to compile, classify, and evaluate the instruments, strategies, and commitments governing contaminant management in UK marine waters.

Both components were specifically scoped to support an integrated synthesis, thereby enabling the OEP to relate the strength and direction of current scientific evidence to the adequacy and implementation of regulatory measures.

2.1 Literature review approach

2.1.1 Literature review methods

The literature review followed the following four stages:

1. Developing the search protocol;
2. Screening and retrieval of materials;
3. Evidence synthesis and data extraction; and
4. Reporting.

The literature search was conducted in three parts: an academic search using ICF's AI-based tool 'Lexora', which covers arXiv, MEDLINE, OpenAlex, PubMed, Scopus, Semantic Scholar, and Springer OA; a complementary search via Google Scholar; and a grey literature search via Google. Searches were structured around four analytical domains aligned to the research questions:

Domain 1: Key pressures/contaminants

Domain 2: Sources and pathways

Domain 3: Impacts and evidence of effects on marine ecosystems

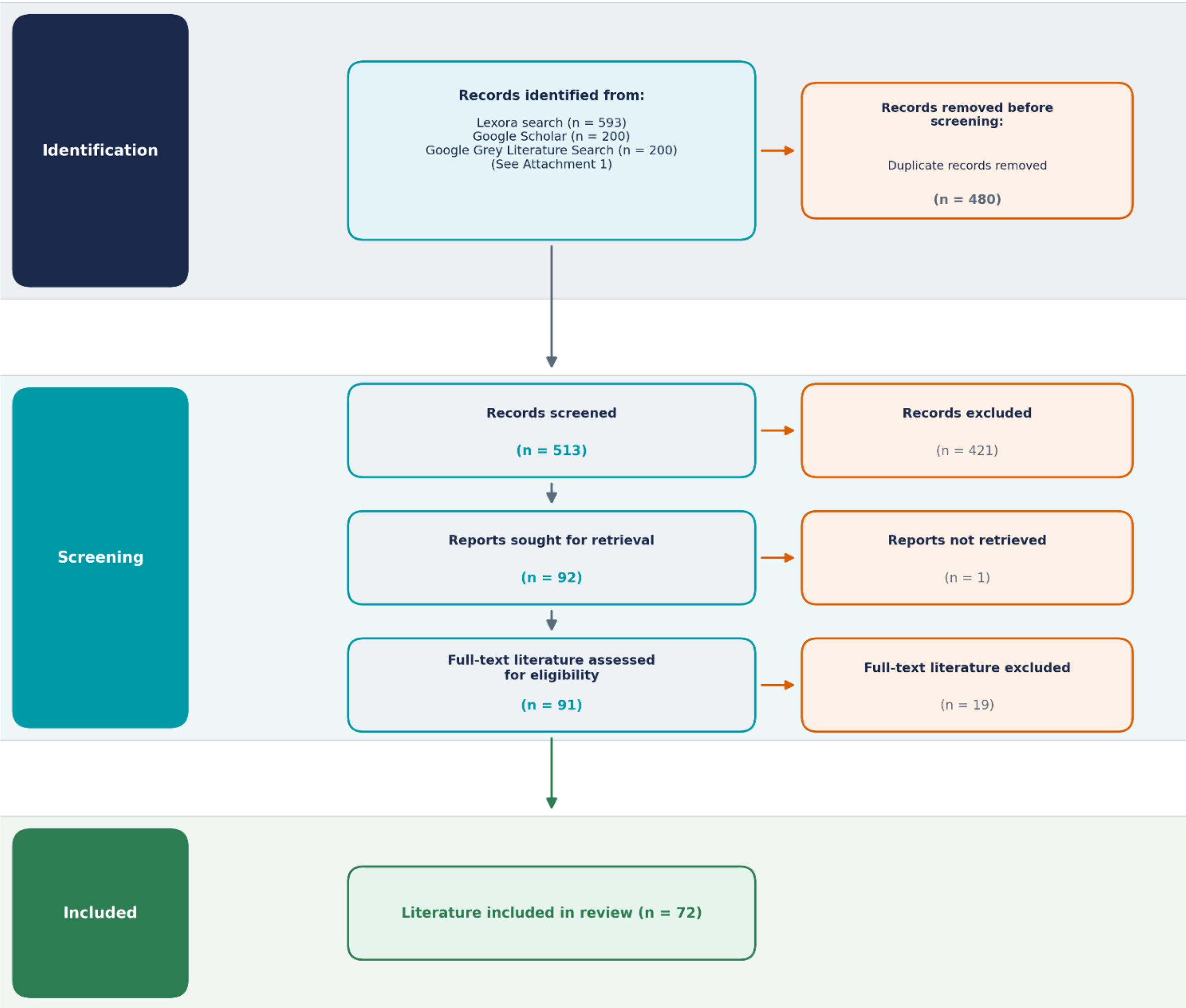
Domain 4: Risks and management effectiveness

One search string per domain was developed for each of the four GES descriptor groups and for emerging contaminants, yielding twenty primary search strings. Search results were capped at ten results per search per database.

Sources were included if they addressed contaminants relevant to GES Descriptors 5, 8, 9, or 10; provided evidence on contaminant status, sources, pathways, ecological impacts, or management in UK or North East Atlantic marine environments; were published after 2000 (unless landmark studies); and were available in English. Sources focused only on freshwater systems, non-UK regions without transferable relevance, or replaced by more authoritative assessments were excluded.

After removing duplicates, literature was screened for relevance by title according to the stated inclusion and exclusion criteria. Abstracts were then reviewed, and further screening occurred during full text assessment. Screened sources were coded against the four analytical domains using an Excel-based synthesis matrix. All included sources are listed in the literature review synthesis matrix (Annex B). **Error! Reference source not found.** below details the literature identified, screened, and included in the literature review.

Figure 1 Prisma diagram displaying the literature identification and screening process



2.1.2 Evidence synthesis and analysis

Screened sources were coded using an Excel-based synthesis matrix against the four analytical domains. Standard bibliographic information, evidence type, scope, and study conclusions were recorded for each source. Synthesis was undertaken by theme, mapping the distribution of evidence across contaminant groups, geographic areas, and analytical domains. Where evidence was limited, uncertain, or contested, this is noted explicitly in the narrative. **Error! Reference source not found.** provides an integrated synthesis of the main contaminant groups covered by the review, drawing on the coded evidence from the synthesis matrix. It summarises current GES status, primary sources and pathways, documented ecological impacts, and key evidence gaps for each group.

Table 1 Synthesis of the main contaminant covered by the literature review

Contaminant Group (Descriptor)	GES Status (UK, 2024-25)	Primary Sources & Pathways	Documented Ecological Impacts	Key Evidence Gaps
Heavy Metals (D8): Hg, Pb, Cu, Zn, Cd	**NOT ACHIEVED** (Pb, Hg, Cu, Zn exceed criteria in ≥1 region)	Industrial discharges; legacy mining; antifouling paints; atmospheric deposition; sediment remobilisation	Neurotoxicity; immunosuppression; reproductive failure in marine mammals; trophic biomagnification; larval abnormalities in SML	Reasons for increasing Hg/Pb trends in S. North Sea unclear; insufficient EQS updates for some metals
PCBs & PBDEs (D8): CB118, BDE209	**NOT ACHIEVED** (CB118, BDE209 exceed thresholds in ≥1 region)	Legacy industrial chemicals; sediment remobilisation; continued leaching from older products	Reproductive organ damage and immune suppression in dolphins and killer whales; UPR activation in Atlantic cod; population-level decline risk	Relative contribution of marine vs freshwater sediment remobilisation unknown; EQS may not protect top predators
PAHs (D8/D9)	**GES MET** (currently within thresholds)	Petroleum spills; shipping; atmospheric deposition; oil/gas drill cuttings	High concentrations in SML causing larval fish mortality; benthic impact near offshore platforms; carcinogenic potential	SML monitoring largely absent from GES framework; long-term trends in biota limited for some regions
TBT and Organotins (D8)	**PARTIALLY ASSESSED** (assessed via imposex indicator)	Legacy antifouling paints; sediment persistence; boat maintenance activities	Imposex in dogwhelks; endocrine disruption; potential remobilisation from disturbed sediments	Long-term fate in sediments under changing conditions; interaction with climate-driven disturbance
Nutrients: N & P (D5)	**LARGELY MET** (~3% coastal waterbodies failing)	Agricultural runoff (dominant); wastewater/CSO discharges; atmospheric deposition; aquaculture; remobilisation	Hypoxia and benthic mortality; loss of seagrass habitats; N:P imbalances altering trophic structure; algal toxins; HABs	Attribution between agricultural vs wastewater sources; climate change effects on nutrient cycling
Marine Litter / Plastics (D10)	**NOT FULLY MET** (some encouraging beach litter trends; beach litter/nano-plastic monitoring poor)	Land-based waste (~80%); lost fishing gear; shipping; synthetic laundry fibres; tyre wear particles	Entanglement; ingestion and starvation; chemical vector for POPs and plastic additives; habitat smothering	Nano-plastic monitoring absent; chemical additives not assessed; beach litter under monitored
Contaminants in Seafood (D9)	**PARTIALLY MET** (shellfish GES met; finfish data absent)	Food chain bioaccumulation from D8 contaminants; antifouling chemicals; dredge-related sediment disturbance	Elevated metals in Southern North Sea finfish; PCB/dioxin loads in pelagic species; human health exposure via seafood consumption	No finfish data in current UK D9 assessment; geographic bias in sampling towards N. UK waters

PFAS (Emerging)	**NOT ASSESSED** (GES indicator under development)	Wastewater; firefighting foams (AFFF); industrial manufacturing; atmospheric transport	Immune and endocrine disruption; extreme environmental persistence; wide detection in biota; cocktail effects with legacy POPs	Most PFAS variants lack EQS; emerging alternatives largely unmonitored; mixture toxicity not characterised
6PPD-quinone, PPCPs, plastic additives (Emerging)	**NOT ASSESSED** (no GES indicator)	Urban runoff (tyre particles); wastewater treatment; plastic leaching	Acute fish mortality at very low concentrations (6PPD-q); potential endocrine disruption from PPCPs and plastic additives	No EQS; very limited marine monitoring data; synergistic effects unknown; pathways to marine environment poorly quantified

2.1.3 Regulatory and policy review methods

The regulatory review was structured as a narrative analysis of how the current body of UK legislation, international commitments, policy strategies, and regulatory programmes collectively addresses contaminant pressures in marine waters. The initial source for the review was the OEP's Chemical Regulation Database (Unpublished), which was cross-checked against primary legislative sources and supplemented by review of UKMS Parts 1–3 (Defra, 2025a), OSPAR Quality Status Report 2023 (OSPAR, 2023), and scrutiny body outputs. The review was conducted over four phases: evidence gathering and catalogue construction; review of commitments and mechanisms; assessment of delivery potential and regulatory interactions; and reporting.

The core output of the review is a regulatory catalogue recording 81 instruments across a standard set of fields including instrument name, legal basis, responsible authority, source sectors, contaminant groups, pathways addressed, function (preventative, mitigative, or remediation), key mechanisms, entry into force date, and implementation status. Instruments were included if they directly or indirectly govern contaminant emissions, loads, concentrations, or pathways with potential routes to marine waters. The regulatory catalogue is provided as Annex C to this report.

2.2 Limitations and uncertainties

Several limitations apply to both review components, as follows:

- The literature review was bounded by a cap of ten results per search per database; while breadth was deliberately prioritised over depth, some relevant literature may not have been captured, particularly for less-researched contaminant groups such as pharmaceuticals and tyre wear particles in marine environments.
- Evidence quality is uneven across descriptor groups: the evidence base for D8 heavy metals and PCBs is comparatively strong, while evidence for emerging contaminants (particularly mixture toxicity, nano-plastics, and 6PPD-quinone) remains fragmentary.
- Geographic coverage in the monitoring literature is biased towards English waters and the Southern North Sea, with limited data for some Scottish and Welsh coastal areas.
- The regulatory review was completed within a limited time period and the catalogue, while comprehensive, may not be exhaustive. Coverage of guidance documents and agency-level programmes is uneven, particularly for devolved jurisdictions outside England.

- The review did not include primary stakeholder consultation with regulators, industry, or civil society; conclusions on enforcement effectiveness therefore rely on published sources and expert judgement.
- Devolved instruments are treated as consolidated families, which may obscure differences in implementation stringency across the four UK nations.
- Both reviews reflect the state of evidence and regulation as of March 2026. The rapidly evolving context, including the publication of the national PFAS Plan (Defra, 2026a) in February 2026, the enactment of the Water (Special Measures) Act 2025, and ongoing OSPAR review of microplastic assessment criteria, means that some conclusions may require updating as new evidence and regulatory developments emerge.

3 Evidence on Status, Trends and Impacts: Literature Review Findings

Section 3 presents the findings of the semi-systematic literature review, structured around the four research questions agreed with the OEP. Findings are organised by GES descriptor group, with emerging contaminants addressed under LRQ1 and cross-cutting risk drivers addressed under LRQ4.

3.1 LRQ 1: What are the main contaminants affecting the health of UK marine ecosystems as assessed within the GES indicator framework?

Key Finding:	**UK marine waters have not achieved GES for Descriptor 8 (Hazardous Substances), with GES environmental assessment criteria exceedances confirmed for heavy metals and legacy organochlorines across multiple biogeographic regions.** The most recent UKMS assessment confirms persistent failure to meet GES for lead, mercury, copper, zinc, PCB CB118, and PBDE BDE209. GES is partially met for contaminants in seafood (shellfish only) and largely met for eutrophication, but the evidence base for finfish, beach litter, and emerging substances remains insufficient to support a complete assessment. Climate change is exacerbating contaminant status by remobilising legacy pollutants from sediment sinks and altering chemical bioavailability.

This section summarises current evidence on contaminants assessed in the UK GES indicator framework. The UK Marine Strategy Part One (2025 Updated Assessment) provides the most recent comprehensive evaluation of GES achievement, and this, alongside supporting indicator assessments published on the Marine Online Assessment Tool (MOAT)[1] and the OSPAR Quality Status Report 2023[2], forms the primary evidence base for this section.

3.1.1 Descriptor 8: Contaminants

Overall GES status

The UK has not achieved GES for D8. The Cefas MOAT contaminants indicator assessment (Nicolaus, Webster and Charlesworth, 2024) confirms that GES criteria are exceeded for lead, mercury, copper, and zinc in at least one assessed biogeographic region, and that concentrations of PCB CB118 and PBDE BDE209 exceed environmental thresholds in sediments and biota (Barber, 2024a; Barber, 2024b; Webster, 2024). A shift to a more stringent environmental quality standard for mercury has revealed that mercury concentrations may potentially harm marine life across all assessed UK regions. This finding reflects a persistent challenge in which legacy industrial and atmospheric contamination continues to affect sediment and biota quality indicators despite decades of regulatory controls, a conclusion reinforced by the most recent UK Marine Strategy update (Defra, 2025).

[1] Pressures from human activities - Marine online assessment tool

[2] Quality Status Report 2023 - OSPAR-OAP (Prod)

Heavy metals

The main metals of concern in UK marine waters are mercury (Hg), lead (Pb), copper (Cu), and zinc (Zn), with cadmium (Cd) also regionally significant. These metals enter the marine environment via atmospheric deposition, riverine inputs, and industrial and agricultural activities (Axe et al., 2023; Barber, 2024a). OSPAR monitoring highlights that mercury levels in fish and shellfish generally exceed environmental thresholds, with no declining trend in most subregions and a notable annual increase of 2.3% in the Southern North Sea (Barber, 2024a). Lead and copper concentrations in fish and shellfish are above background levels, with copper trending upwards in the Southern North Sea and Irish Sea. Cadmium is also above background in all areas assessed, but lacks an environmental threshold for comparison (Barber, 2024a). While sediment metal concentrations are decreasing, levels in biota are increasing in some UK regions, including increasing trends for mercury and copper in biota in the Southern North Sea, and increasing trends for copper in biota in the Irish Sea (Barber, 2024a). There were no decreasing trends observed for lead, mercury or copper in biota in any UK biogeographic region (Barber, 2024a). These trends are potentially due to ocean acidification increasing metal solubility (Sheahan et al., 2013; Stockdale et al., 2016; Barber, 2024a) and increased storminess remobilising contaminants from sediments (Cave et al., 2003; Sheahan et al., 2013; O'Rourke et al., 2026).

The Humber catchment case study (Cave et al., 2003) illustrates the complexity of heavy metal contamination in major estuarine systems, where a legacy of industrial activity - including direct disposal from tin smelting operations and two titanium dioxide plants through the mid-twentieth century - has resulted in elevated trace metal concentrations in contaminated floodplain sediments. Despite improvements in point source controls, legacy sediment contamination continues to undermine water quality below desired standards. This pattern is representative of heavily industrialised estuaries across the UK.

The European Environment Agency's indicator assessment (EEA, 2025) drawing on ICES (International Council for the Exploration of the Sea) and EMODNET (European Marine Observation and Data Network) data for the Greater North Sea and Celtic Seas confirms exceedances of safe limits for lindane (gamma-HCH) and PCB118 in biota. Available time trends indicate that regions showing improving concentrations are more prevalent than deteriorating ones; however, the exclusion of novel contaminants like PFAS highlights a significant evidence gap.

Persistent organic pollutants

Persistent organic pollutants (POPs), particularly polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs), remain significant contaminants in UK marine biota and sediments. The MOAT assessment confirms that CB118 exceeds GES thresholds in the Irish Sea, Northern North Sea, East Channel, West Channel and Celtic Sea, and that BDE209 exceeds thresholds in the Irish Sea sediment (Webster, 2024; Barber, 2024b). PCBs are a pronounced and ongoing concern: in the past they served many industrial and commercial purposes, and although production was phased out under PARCOM Decision 92/3 (OSPAR, 2006) and subsequently restricted under the Stockholm Convention, these substances persist in the environment through continued leaching from products manufactured before the ban and remobilisation from contaminated sediment sinks (Webster, 2024).

Concentrations of PCBs in UK marine mammal populations, including dolphins and killer whales, have been found at levels sufficient to damage reproductive organs and immune systems (Hutchinson, 2017; Webster, 2024; O'Rourke et al., 2026). PBDEs were progressively banned in the EU from 2004 and restricted under the Stockholm Convention in 2009, but take a long time to degrade and can bioaccumulate, entering the marine environment primarily via riverine transport and atmospheric deposition. Known impacts of PBDEs include effects on the nervous, immune, and endocrine systems of mammals and birds (Barber, 2024b; Nicolaus, Webster and Charlesworth, 2024).

Due to the phase out of PBDEs, there has also been a continuous increase in use of organophosphate esters (OPEs) as replacements for PBDEs in flame retardants, which are highly toxic to marine biota (Wang et al., 2020).

Analysis of PCB concentrations in Eurasian otters in Wales (O'Rourke, 2026) demonstrates the ongoing ecological impact of remobilised legacy PCB contamination. PCBs were found in all liver samples, with 16% of individuals having concentrations above the toxic threshold for dioxin-like PCBs. Remobilisation from riverine and coastal sediments is identified as a major modern source of PCB exposure, a conclusion supported by tissue analysis of North Atlantic marine mammals (Megson et al., 2022), where most samples (16 out of 19 samples) exceeded the lower toxicity threshold for marine mammals (9mg/kg lipid), at which physiological effects begin. Nearly half of the samples also surpassed the upper toxicity threshold (41mg/kg lipid), with two mammals having PCB concentrations more than eight times this level, which is linked to severe effects such as reproductive impairment, immunosuppression, and potentially death. These findings highlight that current environmental standards for water and fish may not adequately protect top predators.

Experimental evidence from Olsvik et al. (2023) demonstrates that exposing Atlantic cod to mixtures of chlorinated (PCBs), brominated (PBDEs), and fluorinated (PFOS) compounds at environmentally realistic concentrations triggers the unfolded protein response (UPR) - a cellular stress pathway associated with liver damage - confirming that mixture exposures at sub-threshold concentrations can still generate biologically meaningful responses.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are monitored in biota and sediments and currently meet GES targets in UK waters. However, they remain important indicators of industrial and petroleum-based pollution. PAHs are of particular concern in the sea-surface microlayer (SML), which can be enriched by up to 1,500 times relative to subsurface water (Wurl and Obbard, 2004). Because the SML functions as a primary habitat for fish eggs and larvae, elevated PAH levels in this compartment can cause significantly elevated rates of embryonic mortality and developmental abnormalities, with implications for future fish recruitment.

Evidence from oil and gas drill cutting accumulations in the North Sea (Breuer et al., 2004) indicates the localised deposition of PAHs and metals within approximately one to two kilometres of platform sites, resulting in decreased benthic diversity and abundance, attributable to a combination of physical smothering, organic enrichment, and chemical contamination. The main contaminants associated with oil and gas activities include heavy metals, radionuclides, and PAHs, which enter the marine environment via drill cutting accumulations, produced water discharges, drill fluids, and accidental spills (Breuer et al., 2004; Tornero and Hanke, 2016; OSPAR, 2026).

Organotin compounds

Tributyltin (TBT), historically used in antifouling paints and now banned internationally, persists in marine sediments and continues to exert ecological effects through its potential for remobilisation. TBT causes imposex - the development of male sex organs in female gastropods - in dogwhelks at behaviour of antifouling paint particles (APPs) in the marine environment, demonstrating that these particles constitute a persistent, interstitial source of biocides in benthic sediments near boat repair facilities, ports, and abandoned structures, with demonstrated uptake by benthic invertebrates and documented phytotoxic effects on marine macroalgae. The review by Tornero and Hanke (2016) further confirms that marine vessels are primary sea-based sources of TBT and 'booster biocides'. 'Booster biocides' are currently used as agents in antifouling paints and can include non-metallic organic compounds and organometallic compounds such as copper pyrithione which to aquatic organisms has toxicity equivalent to TBT compounds, however it is considered to degrade rapidly. In addition to use on boats and marine structures, antifouling compounds such as these are widely used in aquaculture.

Radionuclides

Radionuclides are assessed as part of the UK's GES monitoring programme and are currently recorded as meeting GES targets. Licensed discharges from nuclear facilities, together with residual contamination from historical nuclear weapons testing and global transport from accident events, contribute to background radionuclide levels in UK waters. While current concentrations do not indicate non-compliance, continued monitoring remains important given the long half-lives of certain isotopes and the potential for cumulative exposure in biota.

3.1.2 Descriptor 5: Eutrophication

GES has been met in 95% of UK marine and coastal waters for Descriptor 5. However, around 3% of coastal waterbodies fail, with a further 2% at risk, due to elevated concentrations of dissolved inorganic nitrogen (DIN) entering the marine environment via various point-source and diffuse pathways, primarily agricultural runoff and sewage and wastewater discharges. While, according to Defra (2025), the eutrophication status of UK shelf and oceanic areas has not deteriorated since 2015, these figures mask significant spatial heterogeneity and the persistence of eutrophication problems in intensively farmed catchments and urbanised coastal areas. In many coastal areas and river plumes, nutrient and chlorophyll levels are increasing suggesting deteriorating water quality. Additionally, dissolved oxygen status is worsening overall highlighting a move away from GES over time (Defra, 2025).

The primary sources of nitrogen (N) and phosphorus (P) entering the marine environment include sewage; animal waste and fertilisers associated with agriculture; industrial effluent; atmospheric deposition; and aquaculture (Maier et al., 2009; Axe, Sonesten and Skarbovik, 2022; Groß et al., 2022; Devlin et al., 2023; Devlin et al., 2024; Siems et al., 2024). Inputs of N and P from land-based sources have decreased in the UK since the 1990s (Devlin et al., 2024). Atmospheric deposition accounts for approximately 30–50% of N inputs in OSPAR Regions II–IV, and reduction in atmospheric N deposition alongside reduced fertiliser use have delivered the greatest improvements in N reduction across OSPAR regions; the rate of atmospheric N reduction is more than twice that of waterborne N reduction, highlighting the importance of emissions controls (Axe, Sonesten and Skarbovik, 2022; Devlin et al., 2023).

Regulatory measures under the Nitrates Directive and Nitrate Vulnerable Zone designations have led to some reductions in nitrogen loading; however, agricultural inputs, especially from diffuse runoff and leaching, remain the main pressure. Maier et al. (2009) report longstanding nitrogen and phosphorus enrichment in UK estuaries, with many sites showing high chlorophyll-a levels, shifts in algal communities, and seasonal bottom anoxia. Stable nitrogen isotope analysis ($\delta^{15}N$) was undertaken by Jones, Cullen-Unsworth and Unsworth, 2018 in UK coastal seagrass habitats by analysing seagrass leaf tissue for percentage N by weight and atomic percent (‰) of 15N using a continuous flow isotope ratio mass spectrometer. This revealed high $\delta^{15}N$ values (+10 to +25‰), strongly linked to urban sewage or livestock effluent (Heaton, 1986; Kendall and McDonnell, 2012). Most sites had $\delta^{15}N$ values greater than 6‰, except the Isles of Scilly which was also the only site with 'good' seagrass meadow health status. Lower $\delta^{15}N$ values in the Isles of Scilly may be associated with reduced inputs of urban sewage and/or livestock effluent, likely resulting from a significantly smaller surrounding human population than other sites. Although nutrients from rivers are expected to decrease before reaching the marine environment (Galloway et al., 2004; Craig et al., 2008), the persistently high $\delta^{15}N$ values suggest urban sewage and livestock effluent remain significant in some UK coastal areas, including those not meeting GES. Notably, Southend-on-Sea, where high $\delta^{15}N$ values were found, is at risk of failing GES for eutrophication, underscoring the ongoing impact of these nutrient sources (Devlin et al., 2024).

Actions to tackle eutrophication have been very successful in reducing P inputs, such as through increased removal of P from domestic and industrial wastewater and the heavy regulation of phosphates in laundry detergents (Regulation (EC) No 648/2004). However, there has been less success in reducing waterborne N inputs, potentially due to increased agricultural intensification and use of N-rich fertilisers, such that imbalanced N:P reductions have created offshore gradients from P to N limitation in the North Sea (Burson et al., 2016; Devlin et al., 2023; Devlin et al., 2024; Balkoni et al., 2026). An important finding from recent monitoring research in the German Bight (Balkoni et al., 2026) - a directly comparable North Sea environment - is that disproportionate reduction of P relative to N has resulted in elevated N:P ratios far exceeding the Redfield ratio of 16:1 (the atomic ratio of N:P which reflects the optimal nutrient balance for aquatic primary production). This stoichiometric imbalance can alter phytoplankton community structure, potentially favouring species of lower nutritional quality and contributing to trophic imbalances that cascade through the food web, including a high C:P ratio in phytoplankton that reduces nutritional quality for zooplankton and benthic filter feeders (Burson et al., 2016). Detrimental effects on larval growth of commercially valuable species have also been associated with elevated C:P rations of copepods fed on P-deficient phytoplankton (Malzahn et al., 2007; Schoo et al., 2014). This finding has direct implications for the interpretation of eutrophication trends in UK coastal and estuarine systems.

3.1.3 Descriptor 9: Contaminants in Seafood

GES for D9 has been achieved for shellfish based on surveys conducted between 2016 and 2020 (Izaak Fryer-Kanssen, 2024; Nicolaus and Fryer-Kanssen, 2024). Data from 296 shellfish samples across 99 locations in commercial shellfishery areas (predominantly in Scottish and Northern Irish waters) confirm compliance with regulatory maximum levels for heavy metals (cadmium, lead, and mercury), PAHs, and dioxins and dioxin-like PCBs (Nicolaus and Fryer-Kanssen, 2024). However, GES is considered only partially met overall due to the absence of comparable finfish data, which represents a significant limitation in the current assessment framework. Heavy metals can enter the marine environment and thereby the food chain from both natural sources such as volcanic activity and mineral leaching, and anthropogenic sources including agriculture, industrial processes, and fossil fuel combustion (McKinley and Johnston, 2010; Ferrante et al., 2019; Larsen and Hjermann, 2022; Izaak Fryer-Kanssen, 2024).

An investigation of chemical contaminants in UK marine fish (Fernandes et al., 2015) identified that sea bass, sprats, mackerel, sardines, and herring showed the highest levels of contamination with dioxins, PCBs, and PBDEs. Fish taken from the Southern UK and Northern French coasts, and the Irish Sea, showed higher concentrations of some contaminants than those from other regions. Heavy metal monitoring for the OSPAR region (Larsen and Hjermann, 2022) found that in most areas, lead concentrations in fish and shellfish are above background levels, and mercury is above the environmental threshold, with concerning increasing trends in the Southern North Sea and English Channel.

A meta-analysis of contaminant effects on fish abundance and species richness (McKinley and Johnston, 2010) also found slight but consistent trends toward decreased abundance and species richness near industrial effluent and runoff sources, with sessile invertebrate communities identified as being significantly more responsive to contamination than mobile fish assemblages. This has implications for monitoring strategy design, as fish-based metrics may understate the ecological significance of contaminant pressures.

3.1.4 Descriptor 10: Marine Litter

Marine litter, of which plastics comprise around 90% of monitored materials in UK waters, remains a major and persistent pressure under GES D10. Common items include plastic, metal, glass, processed wood, rubber, clothing, fibreglass, and cigarettes (Pawar, Shirgaonkar and Patil, 2016; Hutchinson, 2017; Russell et al., 2024). Plastics are by far the most prevalent, with typical items being single-use consumer plastics such as bags, caps, bottles, and fishing-related materials like synthetic rope, fishing line, and nets (Derraik, 2002; Gall and Thompson, 2015; Pawar, Shirgaonkar and Patil, 2016; Russell et al., 2024).

GES is assessed across three criteria: beach litter, seafloor litter, and floating litter. Decreasing trends have been identified for beach litter and floating litter; however, seafloor litter has shown increasing trends, hindering achievement of GES (Russell et al., 2024). GES for marine litter in the UK was assessed using OSPAR assessments including the indicator 'Abundance, Composition and Trends of Beach Litter' (Camille Lacroix, Silvère André, and Willem van Loon, 2022).

Litter derived from land-based sources enters the marine environment through rivers, drainage and sewerage systems, wind, beach littering, coastal landfills and accidental release from industrial sectors; sea-based pathways include fishing, aquaculture, shipping, and offshore oil and gas activities (Pawar, Shirgaonkar and Patil, 2016; Rummel et al., 2016; Thompson, 2017; Russell et al., 2024). European recycling systems have also been identified as a pathway for plastics, through export to countries where quantities may enter the environment through waste management systems (Bishop, Styles and Lens, 2020). Microplastics, not yet assessed towards GES for marine litter, are prevalent in the environment and derive from vehicle usage (tyre abrasion, brake wear, road markings), degradation of macro-plastics, building and demolition activities, and textiles; atmospheric deposition of plastic dust provides a further pathway (Troost et al., 2018; Thompson, 2017).

Marine litter presents risks to marine life via entanglement and ingestion of macro-plastics, as well as through microplastics, which transfer persistent organic pollutants, plastic additives, and other toxic substances into marine food chains. Plastic litter can disturb benthic organisms by limiting nutrient supply and disrupting gas exchange between sediments and the water column (Corcoran, 2015). Ingestion of microplastics by the European native oyster (Ostrea edulis) restricts food uptake, induces inflammation in the digestive system, and alters respiratory rates and gamete quality (Zapata-Restrepo et al., 2025).

Climate change may intensify the impacts and pathways of marine litter through increased flooding and river flow, heightened storm activity, accelerated degradation and microplastic release, and faster leaching of contaminants from plastics (Russell et al., 2024; Kelly et al., 2025). The chemical complexity of plastic additives, such as bisphenol A (BPA), phthalates, and nonylphenol, is not currently addressed in the GES indicator framework for D10, highlighting a major evidence gap at the intersection of marine litter and hazardous substance assessment.

3.2 LRQ1a: Are there any emerging contaminants not currently considered in the GES framework?

Key Finding:	**A substantial and growing category of emerging contaminants, including PFAS, plastic additives, pharmaceuticals, and tyre-derived chemicals, falls entirely outside the active GES assessment framework, with no established Environmental Quality Standards and inadequate monitoring.** Of the over 4,700 known PFAS variants, only a handful are subject to routine monitoring; an indicator for PFAS in sediments and biota is under development but not yet operational. Nano-plastics, pharmaceutical compounds, and substances such as 6PPD-quinone are detected in the marine environment and have demonstrated biological activity at environmentally relevant concentrations, yet none are formally assessed under current GES descriptors. Bioactivity-based research reveals an 'unknown pool' of chemically active substances in UK waters that existing monitoring is structurally unable to detect.

This section covers LRQ1a, focusing on contaminants found in the evidence base that are not yet part of GES indicator assessments or are only beginning to be integrated without established EQS. The evidence shows a group of substances with clear production, persistence, and biological activity, but lacking adequate regulation and monitoring.

3.2.1 Per- and polyfluoroalkyl substances (PFAS)

PFAS are arguably the most significant group of emerging contaminants highlighted in the review evidence. Widely used since the 1950s in industries and consumer products, such as waterproof clothing, non-stick coatings, carpets, fire-fighting foams (AFFFs), and polymer manufacturing (Ankley et al., 2020; Environment Agency, 2021), PFAS enter the marine environment via atmospheric deposition, wastewater, land run-off, and rivers (Van Den Heuvel-Greve et al., 2024; Wang et al., 2025). Wastewater treatment plants are ineffective at removing PFAS, with industrial effluent and landfill leachate also acting as major sources (Environment Agency, 2021; Ford and Ginley, 2024). While legacy PFAS like perfluorooctane sulfonate (PFOS) are monitored and listed for priority action by OSPAR (OSPAR, 2023c), there are over 4,700 PFAS compounds, the vast majority not currently assessed within the GES framework.

As long-chain legacy PFAS are phased out under regulatory action, they are being replaced by shorter-chain homologues and novel chemical alternatives, including hexafluoropropylene oxide-dimer acid (HFPO-DA, sold commercially as GenX), ADONA, and chlorinated polyfluorinated ether sulfonates (Cl-PFESAs, also known as F-53B) (Joerss, Apel and Ebinghaus, 2019). These substances are widely detected in marine environments but typically lack established EQS, meaning they cannot be formally assessed against GES criteria. The phase-out of legacy PFAS has resulted in an industry transition to replacement substances, some of which are 'emerging PFAS' alongside legacy PFAS not previously subject to significant research or legislation (Joerss, Apel and Ebinghaus, 2019). Ultra-short-chain compounds such as trifluoroacetic acid (TFA) are particularly mobile and persistent in aquatic environments but are generally absent from routine monitoring lists.

Novel PFAS subclasses of concern include perfluoroalkyl phosphinic acids (PFPiAs), used in pesticides and consumer products, and cyclic PFAS such as perfluoroethylcyclohexane sulfonate (PFECHS), used in aircraft hydraulic fluids. These have been detected in North Sea and Baltic Sea sediments and water but are characterised in the literature as “overlooked” or “emerging,” indicating that their spatial distribution and ecological significance remain poorly characterised.

PFAS are found across all trophic levels in the marine environment (Ford and Ginley, 2024). Bioaccumulation and biomagnification in marine biota are well documented (Munoz et al., 2017; Joerss, Apel and Ebinghaus, 2019; Ankley et al., 2020; Wu et al., 2023; Ford and Ginley, 2024; Van Den Heuvel-Greve et al., 2024; Wang et al., 2025). Immunotoxicity in fish, seabirds, and marine mammals has been observed for legacy PFAS, as well as impacts on blood, liver, and kidney function in bottlenose dolphins (Fair and Houde, 2018; Ford and Ginley, 2024). Emerging PFAS have also shown effects on immunity (Ford and Ginley, 2024). Other impacts include disruption of metabolism and the endocrine system, potentially affecting the growth, development, and reproduction of marine organisms (Sun, Xing and Chu, 2023).

Further research is needed on the toxicity and broader effects of emerging PFAS on marine organisms, including cumulative impacts of PFAS mixtures and other contaminants. This is important in order to inform future regulation on emerging PFAS which have been introduced as a consequence of legacy PFAS regulation (Joerss, Apel and Ebinghaus, 2019; Sun, Xing and Chu, 2023; Wang et al., 2025). OSPAR has recently listed PFAS as a priority group and is developing a GES indicator for PFAS in sediments and biota. However, as of the 2024–25 assessment period, this indicator is not yet part of the active framework, leaving a regulatory gap where accumulation and impacts may go unmonitored.

3.2.2 Plastic additives and nano-plastics

The GES framework for D10 addresses marine litter, including microplastics (particles under 5 mm), but does not cover the chemical aspect of plastic pollution, specifically the bioavailability and ecotoxicological effects of leachable additives or the behaviour of nano-plastics. This is a significant gap, given evidence of their ecological impact. Chemicals used in plastics, such as bisphenol A (BPA), phthalates, and nonylphenol (NP), are endocrine disruptors that can leach into seawater and marine organisms' tissues, yet are not included as standard indicators for marine ecosystem health in the GES framework, despite proven biological activity at relevant concentrations. Nano-plastics (typically below 150 µm, sometimes under 1 µm) are increasingly concerning due to their ability to penetrate biological membranes, cross tissue barriers, and enter the food chain. Monitoring protocols for these particles are currently inadequate and not incorporated into GES assessments. The dual risk posed by their physical toxicity and role as chemical vectors means nano-plastics’ full ecological significance remains unaddressed in current frameworks.

3.2.3 Pharmaceuticals and personal care products

Pharmaceuticals and personal care products (PPCPs) constitute a “continuous array” of emerging contaminants released into marine ecosystems via household and industrial wastewater. While pharmaceutical compounds including antibiotics, anti-inflammatory drugs, and antidepressants are increasingly detected in estuarine and coastal waters (Letsinger et al., 2019), they are largely absent from GES monitoring programmes and lack EQS for marine environments. The Drivers and Pressures Affecting the UK Marine Environment Evidence Review (Opergy Group, 2024) identifies these as part of a broader concern about “cocktail effects which are poorly understood and largely uncharacterised in current risk assessment frameworks”.

3.2.4 Tyre-derived compounds

6PPD-quinone, a transformation product of the antiozonant 6PPD used in the manufacture of rubber tyres, has been identified as a potent environmental concern. It has been demonstrated to cause acute mortality in coho salmon at very low concentrations, and several evidence reviews, including the the Drivers and Pressures Affecting the UK Marine Environment Evidence Review (Opergy Group, 2024), have raised it as a major concern. 6PPD-quinone enters the marine environment primarily via road runoff and storm drainage from urban areas, making it a component of the broader "cocktail" of urban contaminants reaching coastal and estuarine waters. It is not yet a standard indicator within the GES framework.

3.2.5 The 'unknown pool' of marine chemicals

OSPAR's integrated biological effects assessment recognizes the marine chemical exposome as a major challenge because only a small fraction of the roughly 140,000 hazardous substances are routinely measured, while pathway-based bioassays are needed to detect effects from unknown or unmonitored contaminants (Ankley, et al., 2021).). This indicates that the fraction of biologically active chemical contamination being directly assessed is substantially less than the total present in the marine environment. Addressing this gap requires investment in non-targeted chemical screening approaches, effect-based monitoring methods, and expanded use of biological effect markers in GES assessments.

3.2.6 Lithium and battery industry chemicals

As the battery industry expands in response to energy transition demands, the potential for new contamination pathways associated with lithium-ion battery production and recycling has been identified in the recent literature (Mrozik et al., 2021). PFAS and other chemicals associated with lithium-ion battery recycling processes may pose novel risks to marine ecosystems as industrial-scale recycling infrastructure develops, though this remains an area of emerging concern rather than confirmed marine impact.

3.3 LRQ2: What are the sources and pathways of the identified contaminants into the marine environment?

Key Finding:	**Contaminants reach UK marine waters through a complex, multi-sector web of land-based, atmospheric, and sea-based pathways, with remobilisation of historically contaminated sediments representing an increasingly significant and climate-sensitive secondary source.** Agriculture is the dominant source of nitrogen and pesticide loading to coastal waters; wastewater and combined sewer overflows (CSOs) introduce diverse chemical mixtures including metals, pharmaceuticals, and microplastics; and shipping, offshore oil and gas operations, and antifouling paint particles contribute directly from sea-based activities. Critically, the remobilisation of legacy contaminants (PCBs, TBT, heavy metals) from historically contaminated estuarine and coastal sediments is an ongoing and poorly regulated source that is being intensified by increased storminess and hydrological change under a changing climate. Nearly one-third of chemicals entering from sea-based sources alone appear to fall outside any regulatory framework (Tornero and Hanke, 2016).

Marine contaminants enter UK and global marine environments through a diverse and often interconnected array of land-based, sea-based, and atmospheric pathways. The ocean functions as the ultimate global sink for many persistent substances, receiving inputs from multiple source sectors over extended spatial and temporal scales. Understanding these pathways is essential for identifying effective intervention points and for evaluating the contribution of different sectors to marine contamination.

3.3.1 Land-based sources

Agricultural runoff

Agriculture is a major source of dissolved nitrogen discharges to the North East Atlantic, and a significant contributor of pesticide contamination to coastal and estuarine waters (OSPAR, 2023). Nutrients enter via surface runoff and subsurface leaching from agricultural land where fertilisers and manures are applied. The diffuse nature of these inputs makes them particularly difficult to regulate compared to point sources. In the UK, reductions in waterborne nitrogen input to coastal waters have been limited since the 1970s, driven by the intensification of farming practices. Despite regulatory interventions through Nitrate Vulnerable Zone designations, agricultural nutrient inputs remain a principal pressure preventing good ecological status for eutrophication in affected coastal waterbodies (Defra, 2016).

Wastewater discharges and combined sewer overflows

Wastewater treatment works (WWTPs) and combined sewer overflows (CSOs) are major pathways for a wide range of contaminants into estuarine and coastal waters, including hazardous substances, nutrients, heavy metals, pharmaceuticals, and microplastics (Cave et al., 2003; Schiedek et al., 2007; Olsvik et al., 2023; Opergy Group, 2024; Defra, 2025). These discharges contain contaminants not only from waste and treatment systems but also from agriculture, urban sources such as road runoff, and industrial sources (Cave et al., 2003; Opergy Group, 2024; Troost et al., 2018). CSOs release untreated or partially treated sewage during heavy rainfall, leading to elevated concentrations of contaminants in receiving waters. In the UK, CSO discharges have attracted significant public and regulatory scrutiny in recent years, with frequent and high-volume events contributing to coastal water quality failures.

The textile industry has historically contributed surfactants, including nonylphenol and its ethoxylates, to UK rivers and coastal waters via wastewater pathways (Sheahan et al., 2002). These endocrine-disrupting compounds have been subject to regulatory controls but continue to be detected in estuarine sediments as legacy contaminants.

Industrial effluent and legacy contamination

Industrial discharges, both current and historical, contribute heavy metals, organic chemicals, and other hazardous substances to UK estuaries and coastal waters. Legacy contamination from historical mining activity (e.g. in the Yorkshire Dales, and from the Humber catchment where direct waste disposal from tin smelting and titanium dioxide manufacturing took place) has left a persistent reservoir of trace metals in contaminated riparian and estuarine sediments. These sediment sinks represent a long-term secondary source of contamination, releasing metals back to the water column through natural and anthropogenic disturbance processes. (Cave et al., 2003; Cave et al., 2005)

Coastal landfills and infrastructure

Coastal and riparian landfills represent a poorly quantified but potentially significant source of legacy and contemporary contaminants to the marine environment, particularly as climate change increases the frequency and intensity of coastal flooding and erosion. The mobilisation of contaminants from landfill sites during storm events introduces both regulated and unregulated chemicals into estuaries and nearshore waters. As sea levels rise and coastal defences are reviewed, managed retreat strategies may expose historically contaminated areas to tidal inundation, with implications for contaminant loading. (Hutchinson, 2017; O'Rourke et al., 2026; Schiedek et al., 2007)

A study by Brand et al. (2018) revealed that in England, 4759 historical landfills are located within flood zone 3, defined by the Environment Agency as having a 1% annual probability of fluvial flooding and/or a 0.5% annual probability of coastal flooding if they are not adequately defended. Of these sites, more than 1,200 are within low-lying coastal zones, many of which are in close proximity to designated environmental sites. The study concluded that without intervention, in the short (by 2025), medium (by 2055) and long term (by 2105), 79, 122 and 144 of England's historical coastal landfill sites respectively, are expected to start eroding into coastal waters. Some sites, such as the Spittles Lane landfill site on a cliff top in Lyme Regis, have already been subject to significant erosion. According to Nicholls et al. (2021), a 400m stretch of the cliff collapsed in 2008, releasing waste to the cliff face and beach below where lead, PAHs and asbestos were subsequently found in sediments. It is highly expected that the whole landfill will eventually erode into the sea because no protection is currently planned at the site, however timescales are uncertain.

3.3.2 Atmospheric deposition

Atmospheric transport and deposition is a major pathway for POPs and certain heavy metals (Wurl and Obbard, 2004; Schiedek et al., 2007; Olsvik et al., 2023). PCBs, PAHs, and some PFAS undergo long-range atmospheric transport (LRAT) via gas-phase partitioning and atmospheric particles, and deposit into the sea through wet and dry deposition; sources include combustion residue and urban dust, deposited both locally and from afar (Wurl and Obbard, 2004; Schiedek et al., 2007). Metals reach the marine environment via atmospheric deposition from industrial and agricultural activities (Axe et al., 2023; Barber, 2024a). Mercury is transported atmospherically as elemental and reactive gaseous forms, making deposition a significant input to open ocean systems. Nitrogen oxides (NOx) and ammonia from fossil fuel combustion and intensive livestock farming also add directly to marine nitrogen loads through atmospheric deposition (Maier et al, 2009).

The OSPAR QSR 2023 identifies fossil fuel combustion and long-range atmospheric transport as among the top three global drivers of D8 contaminant concentrations. This underscores the inherently transboundary nature of marine contamination and the limitations of purely domestic regulatory action in achieving GES.

3.3.3 Sea-based sources

Shipping and maritime activities

Tornero and Hanke (2016) provide a comprehensive review of chemicals entering the marine environment from sea-based sources, identifying 276 substances across 19 metals and metalloids, 10 organometallic compounds, 24 inorganic compounds, 204 organic compounds, and 19 radionuclides. Offshore oil and gas operations were found to contribute the largest number of substances, followed by shipping and mariculture. TBT and biocidal metals,principally copper and zinc, originate primarily from antifouling paints on vessel hulls, entering the water column through leaching and through paint particle shedding during maintenance activities in marinas and boatyards. The review notes that nearly one-third of identified chemicals appear not to be considered under any regulatory framework.

Shipping activities also contribute to hydrocarbon contamination through operational discharges, accidental spills, and the long-term release of contaminants from shipwrecks. Historical dumping sites and sunken ordnance represent additional legacy sources in UK waters. (Tornero and Hanke, 2016)

Offshore oil and gas and renewable energy

Drill cutting accumulations in the Northern and Central North Sea represent localised but significant sources of PAHs, metals, and radionuclides (Breuer et al., 2003). The chemical fate of contaminants in cuttings piles is influenced by particle size, local sedimentation rates, and sediment chemistry, with considerable amounts of contaminants likely to remain within the pile unless disturbed. Disturbances, including trawling, anchor dragging, and storm events, may create pathways for contaminant exposure for benthic organisms. The expanding offshore wind energy sector introduces additional considerations regarding the potential for chemical releases from coatings, sacrificial anodes, and substructure materials over the operational lifetime of installations.

Aquaculture

Marine aquaculture contributes nutrient loads through fish faeces and excess feed, and may introduce veterinary medicines, antifouling compounds, and trace elements into surrounding waters. While evidence reviewed for this study does not suggest that aquaculture is a dominant pathway for the contaminant groups assessed under D8, it is identified as a contributing sector for nutrient enrichment (D5), medicinal products, and as a source of biocidal compounds in localised areas (Tornero and Hanke, 2016). Aquaculture is also cited as a significant local source of excess nutrients in coastal waters which may promote the growth of harmful algal species, with potentially severe consequences for both wild fisheries and the aquaculture industry itself (Brown et al., 2020).

3.3.4 Remobilisation from sediment sinks

A critical and cross-cutting pathway identified consistently across the evidence base is the remobilisation of contaminants previously sequestered in marine and estuarine sediments. Roberts (2012) provides a comprehensive review of the physico-chemical processes involved in contaminant remobilisation from disturbed sediments (resuspended contaminated sediments, (RCS)), the mechanisms that drive disturbance, and the known toxicological and ecological impacts of remobilised contaminants.

Natural disturbance mechanisms include storms, tidal currents, wave action, and bioturbation by benthic organisms. Anthropogenic disturbances comprise vessel movements, bottom trawling, dredging operations (capital and maintenance dredging in ports and channels), and anchoring (Roberts, 2012). Although natural disturbances may occur more frequently, anthropogenic ones can exert greater force and have more prolonged effects. Climate change is expected to accelerate remobilisation by increasing storm frequency and intensity, extending wave disturbance through rising sea levels, and increasing flood-related sediment transport due to heavier rainfall (Nadal et al., 2015; Schiedek et al., 2007).

The O'Rourke (2026) study on PCBs in Eurasian otters and Megson et al. (2022) on marine mammals both indicate that remobilisation from riverine and coastal sediment sinks is a dominant contemporary driver of PCB exposure in top predators in UK waters; a finding with significant implications for the interpretation of GES assessments that focus solely on water column concentrations.

3.3.5 The sea-surface microlayer as a contamination pathway

The sea-surface microlayer (SML) - the uppermost 1 to 1,000 µm (i.e. 1mm) of the ocean - acts simultaneously as a sink and a source of chemical contaminants. Wurl and Obbard (2004) document enrichment factors for POPs, organotin compounds, PAHs, and heavy metals in the SML of up to 1,500 times relative to subsurface water, driven by the hydrophobic nature of many persistent contaminants and the concentration of organic matter at the air-sea interface. Because the SML is a primary habitat for fish eggs and larvae, the elevated concentrations of contaminants in this compartment represent a critical exposure pathway for early life stages and a potential mechanism for recruitment failure in commercially important species.

3.4 LRQ3: What are the impacts of the identified contaminants on the health of marine ecosystems?

Key Finding:	**Marine contaminants are causing documented lethal and sublethal harm across all trophic levels, from molecular cellular stress in fish to reproductive failure and immune suppression in top predators, with impacts compounded by climate change and mixture toxicity**. PCBs are causing immune suppression and reproductive organ damage in UK dolphin and killer whale populations at concentrations above toxic thresholds; TBT-induced imposex persists in dogwhelk populations; hypoxia from eutrophication triggers mass benthic mortality; microplastics transfer persistent organic pollutants and endocrine disruptors into food chains; and contamination of the sea-surface microlayer leads to increased larval mortality and developmental abnormalities in early fish stages. Climate change intensifies these effects by boosting contaminant bioavailability, toxicity, and remobilisation from sediments. The combined impact of multiple chemicals ('cocktail effect') is producing biological harm at concentrations not detected by current single-substance EQS frameworks.

The identified contaminants impact marine ecosystem health through a spectrum of lethal and sublethal effects, operating at the molecular, organism, population, and community levels. These impacts are frequently compounded by the simultaneous presence of multiple stressors, including climate change and habitat loss, making attribution of specific impacts to individual contaminants challenging. The following synthesis draws on evidence spanning laboratory ecotoxicology, field monitoring, modelling studies, and biological effect assessments.

3.4.1 Impacts of marine contaminants

Endocrine disruption and reproductive harm

Endocrine-disrupting chemicals (EDCs), including POPs, PFAS, and organotins, affect reproduction, development, and immune function in marine organisms through interference with hormonal signalling pathways. The most extensively documented marine example is imposex in gastropod molluscs caused by TBT: the development of male sex organs in female dogwhelks (*Nucella lapillus*) has been extensively used as a biological effects indicator in the UK and OSPAR monitoring programmes and represents one of the most clear-cut examples of a marine contaminant-induced endocrine disruption effect (Anderson, 2024).

PCBs and PFAS are linked to suppressed immune function and disrupted thyroid and sex hormone regulation in dolphins, seals, and otters. Hutchinson (2017) reports that PCB concentrations in some UK marine mammal populations, including dolphins and killer whales, reach levels high enough to harm reproductive organs and immune systems. Megson et al. (2022) confirm that most marine mammal tissue samples exceed toxic PCB thresholds. Consequently, reduced reproductive success and higher susceptibility to infectious disease are recognised as long-term risks for species with slow reproductive rates.

Neurotoxicity and mortality in marine mammals

Heavy metals, notably mercury and lead, are established neurotoxins with clear effects in marine mammals. Kakuschke and Prange (2007) summarise evidence from the North and Baltic Seas showing that exposure to cadmium, mercury (including methylmercury), lead, chromium, nickel, and arsenic causes immunosuppression, chronic and acute inflammation, and hypersensitivity reactions. Lead poisoning has been linked to liver damage and deaths in bottlenose dolphins, while mercury inhibits digestive enzyme activity in Atlantic bottlenose dolphins, increasing liver disease risk. Elevated mercury in harbour porpoises is associated with parasitic infections, pneumonia, and is suspected to be carcinogenic. Mercury neurotoxicity in marine mammals results in uremia, lethargy, loss of coordination, and mortality. Due to bioaccumulation and biomagnification, top predators are exposed to much higher methylmercury levels than those lower in the food chain.

Molecular and cellular stress responses

Laboratory experiments by Olsvik et al. (2023) demonstrate that exposure of juvenile Atlantic cod to environmentally realistic concentrations of chlorinated, brominated, and fluorinated compound mixtures activates the unfolded protein response (UPR), a cellular stress pathway indicative of endoplasmic reticulum stress and associated with fatty liver disease and liver damage. Approximately 3% mortality was observed in exposed fish, and the combined mixture treatment showed additive or synergistic effects not predicted from individual compound responses. This evidence supports concern about mixture toxicity at concentrations that individually may not exceed regulatory thresholds.

Climate-contaminant interactions

The interaction between climate change and contaminant toxicity is a cross-cutting theme in the evidence base. Schiedek et al. (2007) review evidence demonstrating that climate-driven changes in temperature, salinity, and pH alter the bioavailability, toxicity, and biological exposure to contaminants in aquatic ecosystems. Increased water temperatures enhance chemical reaction rates and biological uptake: a temperature increase of approximately 2°C is estimated to increase reaction rates by approximately 20%, potentially elevating the bioavailability of priority substances in warmer coastal waters (Nicolaus, Webster and Charlesworth, 2024). Ocean acidification may affect the speciation and toxicity of metals, while changes in salinity affect the partitioning of hydrophobic pollutants between water and biota (Sheahan et al., 2013). Nadal et al. (2015) estimate that climate change will increase degradation rates of POPs in the environment by a factor of two to three for every 10°C increment, with significant implications for GES assessment outcomes based on static environmental thresholds.

3.4.2 Impacts of eutrophication

Hypoxia and benthic community loss

Nutrient enrichment drives elevated primary productivity and consequent hypoxia through the decomposition of accumulated algal biomass. Tett et al. (2007) define such perturbation as an 'undesirable disturbance' where ecosystem health is appreciably degraded. When dissolved oxygen concentrations fall below critical thresholds, sessile benthic organisms including polychaetes, molluscs, and echinoderms, which lack the mobility to escape, suffer mass mortality; alongside potential releases of hydrogen sulfide, this can result in mass death of benthic organisms and fish (Maier et al., 2009; Alldred et al., 2023; Devlin et al., 2023). Mobile species including fish, crustaceans, and cephalopods are forced to migrate, disrupting foraging patterns and concentrating predation pressure in oxygenated areas (Roman et al., 2019).

Higher temperatures from climate change can increase ocean stratification, inhibiting the supply of oxygenated waters to depth and causing greater advection of oxygen-poor waters to new areas, making them vulnerable to hypoxia (Levin et al., 2009; Devlin et al., 2024). The UK Marine Strategy Part

One Draft (Defra, 2025) notes locally persistent near-bottom hypoxia in the Greater North Sea as a documented consequence of eutrophication.

Community composition changes and trophic imbalances

Eutrophication leads to shifts in phytoplankton and macrophyte communities, typically resulting in the loss of slow-growing, light-dependent species such as seagrasses and calcifying algae, replaced by fast-growing macroalgae and opportunistic phytoplankton. Harmful Algal Blooms (HABs) pose a significant acute risk (Maier et al., 2009; Jones, Cullen-Unsworth and Unsworth, 2018; Groß et al., 2022; Devlin et al., 2023; Devlin et al., 2024). These changes reduce habitat quality for invertebrates and juvenile fish. Increased primary production and bloom frequency raise phytoplankton biomass and alter species composition; nutrient-rich river inputs can decrease cell size in phytoplankton communities, favouring small-celled flagellates (Groß et al., 2022). Reduced light availability impacts submerged vegetation like seagrasses, diminishing photosynthesis and causing habitat loss (Jones, Cullen-Unsworth and Unsworth, 2018; Devlin et al., 2023).

N:P ratio imbalances (Balkoni et al., 2026) affect phytoplankton stoichiometry, lowering nutritional quality and potentially favouring jellyfish over larval fish, impacting fisheries productivity (Burson et al., 2016). HAB-derived toxins threaten marine mammals, fish, seabirds, invertebrates, zooplankton, and seagrasses, causing lethal and sub-lethal effects such as paralysis and reduced growth rates. Caged fish and shellfish are particularly susceptible, with HABs linked to mass die-offs in aquaculture (Landsberg, 2002; Griffith and Gobler, 2020). The UK has seen widespread fish deaths from toxic phytoplankton blooms, either from phycotoxins or oxygen depletion; some HAB species also directly harm fish by clogging gills (Brown et al., 2020).

3.4.3 Impacts of marine litter and microplastics

Physical injury and mortality

Large plastic debris causes entanglement-related mortality in turtles, seabirds, and marine mammals, leading to drowning, strangulation, and severe lacerations; one study found that 79% of entanglement interactions with marine biota resulted in direct harm or death (Gall and Thompson, 2015). Ingestion of macro-plastics by seabirds and turtles leads to internal blockages, false satiation, and ultimately starvation; high percentages of studied marine organisms, including sperm whales beached on North Sea coasts and Northern Fulmars, have been found with plastic debris in their digestive tracts (Thompson, 2017). Plastic ingestion impacts the ability to feed adequately, causes internal blockages and lesions in the digestive tract, and has implications for reproduction (Derraik, 2002; Rummel et al., 2016). These impacts are well documented across multiple studies and represent the most visible and publicly recognised consequence of marine plastic pollution.

Chemical vector effects

Microplastics act as vectors for persistent organic pollutants and plastic additives. Hydrophobic contaminants like PCBs can accumulate on microplastic surfaces at concentrations much higher than ambient seawater. When marine organisms, such as fish, seabirds, and invertebrates, ingest microplastics, these chemicals may leach into gut fluids and tissues (Derraik, 2002; Webster, 2024; O'Rourke et al., 2026). Endocrine-disrupting additives, including BPA, phthalates, and nonylphenol, may transfer by this route, contributing to carcinogenesis and reproductive issues.

Plastic litter also affects benthic organisms by limiting nutrient supply through prey reduction or disturbing gas exchange between sediments and water (Corcoran, 2015). In the European native oyster, *Ostrea edulis*, microplastic ingestion reduces food uptake, triggers digestive inflammation, and alters respiration and gamete quality (Zapata-Restrepo et al., 2025). Opergy Group (2024) highlights the chemical vector function of microplastics as a significant, though poorly quantified, contaminant exposure pathway.

3.4.4 Impacts of resuspended contaminated sediments

Roberts (2012) synthesises evidence on the ecological impacts of RCS events, documenting both acute and chronic effects. Disturbance of historically contaminated sediments can cause almost complete inhibition of recruitment by filter-feeding invertebrates for months following the event, representing a significant disruption to benthic community recovery trajectories. Sublethal impacts on fish include chemosensory impairment, narcosis, and significantly reduced feeding rates following brief exposure to elevated suspended contaminant concentrations. Community-level effects can be long-term and widespread, particularly in areas where disturbances are frequent and contaminant concentrations in sediments are high.

3.4.5 Impacts via the sea-surface microlayer

Wurl and Obbard (2004) document high rates of mortality and abnormality in fish larvae and eggs exposed to the elevated contaminant concentrations characteristic of the sea-surface microlayer. Organic pollutants and heavy metals enriched in the SML cause depression of growth rates, prolonged hatch time, and elevated frequencies of developmental abnormalities in fish embryos. Because the SML is a primary habitat for the early life stages of many commercially important species, these impacts have the potential to affect recruitment and ultimately population dynamics in ways that are difficult to attribute to contaminants through standard monitoring approaches.

3.5 LRQ4: What are the primary drivers and risks relating to the achievement of GES for contaminants?

Key Finding:	**GES achievement for contaminants faces four interlocking systemic barriers: the structural pace of chemical innovation outrunning regulation; climate change acting as a pressure multiplier; fundamental monitoring and data gaps; and transboundary contamination dynamics beyond domestic regulatory reach**. Intensive, agriculture, urbanisation, and novel chemical production are the main socioeconomic drivers of contamination. Climate change intensifies contaminant pressures by remobilising legacy pollutants, altering toxicity, and increasing runoff events. Monitoring frameworks fail to capture the full spectrum of chemical stressors or their mixture effects, and roughly one-third of chemicals from sea-based sources lack regulatory oversight. Persistent organic pollutants and PFAS reach UK waters via international transport, so domestic action alone is insufficient. Without coordinated global regulation, improved monitoring, and climate-sensitive GES targets, barriers to achieving GES will persist.

This section synthesises the evidence on the systemic drivers and risks that collectively determine whether GES for contaminants is achievable and maintainable in UK marine waters. The evidence points to a complex, multi-factorial challenge in which socioeconomic activity, climate change, regulatory architecture, and knowledge limitations interact to create conditions in which progress is possible but uncertain and variable across contaminant groups and geographic areas.

3.5.1 Socioeconomic and industrial drivers

Intensive food production

According to the Environment Agency, across England and Wales, agriculture is estimated to account for 50-60% of nitrate losses to the water environment (EA, 2019), and is, therefore, a significant driver of eutrophication-related non-achievement of GES in coastal waters. Agricultural runoff and manure management practices deliver continuous diffuse inputs of dissolved nitrogen to riverine systems, which are then transported to estuaries and coastal waters. Despite existing regulatory frameworks including the Nitrates Directive and cross-compliance under Agriculture Act 2020 instruments, evidence from the 2025 UK Marine Strategy Part One Draft assessment indicates that approximately 3% of coastal waterbodies continue to fail GES for eutrophication, with agricultural inputs as the primary cause. The structural characteristics of intensive arable and livestock farming systems make rapid reductions in nitrogen loading technically and economically challenging, particularly in the absence of targeted agri-environment support (UK Climate Change Committee, 2020).

Urbanisation and wastewater infrastructure

Increasing urbanisation of coastal and catchment areas drives higher volumes of wastewater, stormwater, and CSO discharges into coastal environments. Urban runoff introduces cocktail mixtures of contaminants from household products, road surfaces (including tyre wear particles), building materials, and garden chemicals that have not individually been risk-assessed for their combined effects (Cave et al., 2004; Opergy Group, 2024, OSPAR, 2026). Opergy Group (2024) identified CSO discharges as a priority concern for contaminant loading, particularly in coastal areas serving large urban populations.

Novel chemical production

The rapid pace of industrial chemical innovation represents a structural challenge to the GES assessment framework. With over 4,000 variants of PFAS alone and continuous development of new plastic compounds, flame retardants, and biocides, the rate at which new substances enter the environment consistently outpaces the ability of regulatory bodies to develop monitoring protocols, EQS, and disposal standards. Tornero and Hanke (2016) note that nearly one-third of chemicals identified as entering the marine environment from sea-based sources alone appear not to be considered under any regulatory framework. This systemic gap between chemical innovation and regulatory response represents a fundamental driver of emerging contaminant risk.

Economic prioritisation

Stakeholder recognition of economic prioritisation over ecological sustainability is identified as a fundamental structural driver that inhibits long-term recovery efforts (Opergy Group, 2024). Short-term economic considerations influence decisions on discharge consents, enforcement stringency, and investment in wastewater infrastructure, creating conditions in which regulatory standards are met on paper but environmental targets are not achieved.

3.5.2 Climate change as an overarching pressure multiplier

Climate change is expected to increase waterborne nutrient inputs due to higher annual mean river flow in the Celtic Seas and Greater North Sea (Devlin et al., 2024), as well as rising ground water and coastal inundation from sea level rise and storm surges (Hutchinson, 2017; Richardson et al., 2024). Increased flooding and river flow in the UK may also deliver more marine litter, with climate-induced changes to atmospheric and ocean circulation potentially altering litter movement and retention (Russell et al., 2024; Kelly et al., 2025). Climate change is consistently described as an overarching pressure that exacerbates existing contaminant impacts and complicates the achievement and maintenance of GES. The MOAT Contaminants assessment and MCCIP science review (Sheahan et al., 2013) identify climate change as a major modifier of contaminant behaviour, exposure pathways, and biological effects.

Remobilisation of legacy contaminants from sediment sinks is projected to intensify with more frequent storms, rising sea levels, and increased rainfall, which drive higher sediment transport and flooding of riparian landfills (Hutchinson, 2017; Nadal et al., 2015, Schiedek et al.,2007, Sheahan et al., 2013). Of particular concern is the methylation of inorganic mercury under warming and hypoxic sediment conditions, as methylmercury is more bioavailable and toxic, driving mercury accumulation in marine food webs (Defra, 2025; Nicolaus, Webster and Charlesworth, 2024). Changes in ocean temperature, pH, and salinity alter pollutant partitioning, metal speciation, biological contaminant uptake and detoxification (Sheahan et al., 2013), undermining the predictive value of GES thresholds set under baseline climatic conditions.

The UK Marine Strategy acknowledges that the UKMS assessments have not yet factored in the impact of climate change on assessment outcomes, identifying this as a significant structural limitation of current GES determinations.

3.5.3 Scientific and monitoring risks

Emerging contaminants and mixture effects

The evidence base consistently highlights the inadequacy of current monitoring frameworks in addressing the full range of chemically active substances in the marine environment. Legacy contaminants such as DDT, PCBs, and TBT are well-monitored and have established EQS, but thousands of emerging chemicals (including PFAS substitutes, pharmaceuticals, plastic additives, and novel biocides) lack equivalent standards. The synergistic interactions among co-occurring chemicals ("cocktail effects") are poorly understood and almost entirely absent from current risk assessment methodologies for marine ecosystems. Evidence from molecular ecotoxicology (Olsvik et al., 2023) confirm that mixture exposures at individually sub-threshold concentrations can generate biologically significant responses, undermining the protective adequacy of single-substance EQS-based assessments.

While it is neither technically or economically feasible to monitor all chemically active substances individually, research increasingly supports the use of 'sentinel compounds', chemical groupings and effects-based indicators as proxies for broader contaminant classes. Compounds such as PFOS and PFOA are often used to indicate wider PFAS contamination (Hepburn et al., 2019), selected pharmaceuticals (e.g. carbamazepine) serve as markers of chronic wastewater inputs (Dvory et al., 2018; Zhang and Geißen, 2010), and sum parameters are increasingly applied to prioritise mixture-relevant exposures (Hepburn et al., 2019). In parallel, effects-based bioassays and molecular biomarkers offer integrative tools that capture the cumulative biological impacts of complex chemical mixtures without requiring full chemical characterisation. However, while these proxy approaches improve coverage, they are not yet systematically embedded within marine monitoring frameworks or EQS-based risk assessments, and they do not fully resolve uncertainties related to mixture toxicity and emerging substance substitution.

Monitoring gaps and data limitations

The current GES assessment for D9 is limited to shellfish, with no comparable finfish data available (Fryer-Kanssen, 2024). Additionally, the survey sites for shellfish are significantly skewed towards North-West Scotland, making the overall assessment of this descriptor uncertain. Marine litter monitoring is acknowledged to be conducted at low spatial and temporal resolution, particularly for beach litter and nano-plastic fractions (Russell et al., 2024). PFAS indicators are under development but not yet operational in UK GES assessments (Nicolaus, Webster and Charlesworth, 2024). Long-term chemical monitoring beyond flagship species is limited, reducing the ability to track trends across the broader marine ecosystem.

The absence of reliable, standardised historical data further complicates the establishment of natural baselines against which anthropogenic contamination can be measured. Without robust baselines, defining what "acceptable" GES looks like for a specific contaminant in a specific region is inherently uncertain, and the risk that GES criteria are set at levels that already incorporate significant anthropogenic contamination cannot be discounted.

3.5.4 Regulatory and governance risks

Transboundary contamination

The transboundary nature of persistent contaminants is a fundamental constraint on the UK's ability to achieve GES through domestic regulatory action alone. PFAS, POPs, and mercury undergo long-range atmospheric and oceanic transport, meaning that UK marine quality is partly determined by the chemical management practices and emission controls of other nations. OSPAR provides a regional governance framework for coordinated action on hazardous substances in the North East Atlantic, but its effectiveness depends on the commitment and capacity of contracting parties. Post-Brexit changes in the UK's relationship with EU chemical regulation - including the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation - have introduced uncertainty about the extent to which the UK will maintain alignment with EU chemical hazard assessments, restrictions, and monitoring obligations.

It is worth noting that the UK government now views selective alignment with the EU as an economic strategy, especially to ease trade friction through SPS agreements and regulatory standards. For chemicals, this suggests that UK policies will increasingly mirror EU hazard assessments and controls for areas like pesticides and biocides, relying more on EU processes even while maintaining formal independence. Though alignment will stay sector-specific, it may limit divergence in chemical regulation and require the UK to uphold monitoring systems comparable to the EU to maintain market access.

Spatial competition and cumulative pressure

The rapid expansion of offshore industries (such as offshore wind energy, carbon capture and storage infrastructure, and aquaculture) creates increasing competition for marine space and potential for cumulative disturbance of benthic habitats. Bottom trawling, dredging, and the physical footprint of offshore installations represent pathways for the remobilisation of contaminated sediments, and the combined effect of multiple disturbance activities on historically contaminated sites may exceed the capacity of benthic communities to recover (Roberts, 2012). The 'spatial squeeze' on marine ecosystems is identified as a significant factor complicating the achievement of GES across multiple descriptors (Opergy Group, 2024).

Policy gaps and enforcement

Ineffective management, insufficient funding for long-term surveillance programmes, and limited enforcement capacity are identified in the Opergy evidence review (2024) as structural impediments to the implementation of the UK Marine Strategy. Broader regulatory and policy risks are addressed separately in Section 4 below.

4 Regulatory and Policy Landscape

This section presents the findings of the regulatory review, structured around the five research questions agreed with the OEP. Findings are organised by GES descriptor group, with emerging contaminants addressed under RRQ5.

4.1 RRQ1: What are the key regulatory and policy levers used to control contaminants affecting UK marine waters?

Key Finding:	**The UK's regulatory framework for marine contaminants comprises 81 instruments at different levels, but coverage is systematically weighted towards source control and prevention rather than remediation of established contamination.** The catalogue reveals a framework that is densest (in terms of the number of instruments) at the level of retained EU secondary legislation and international commitments, with the bulk of operative instruments targeting chemical restriction, discharge control, and product regulation. Coverage is comprehensive for well-characterised, point-source contaminant groups but thins sharply for diffuse pathways (including agricultural), emerging substances, and the marine environment itself, as only a small number of instruments operate directly on the sea rather than on upstream sources. The framework's breadth conceals significant unevenness: some contaminant groups and pathways are governed by multiple overlapping instruments while others, including legacy contaminated sediments and microplastics in wastewater effluent, are covered by none.

The regulatory framework for marine contaminants in the UK is structured across five tiers:

1. International treaty obligations;
2. UK primary legislation;
3. Secondary legislation and regulations (including retained EU law);
4. Policy commitments and strategies; and
5. Public body programmes and monitoring schemes.

The review identified 81 instruments across all five tiers and involving at least seven UK government departments and agencies, with equivalent bodies across the four devolved administrations. This section identifies the principal regulatory and policy levers for each GES descriptor group.

4.1.1 Descriptor 8: Contaminants

The principal regulatory levers relevant to D8 operate across both international and domestic scales. At the international level, OSPAR provides the overarching strategic framework for hazardous substance management in the North-East Atlantic, with its Hazardous Substances Strategy, the Lists of Chemicals for Priority Action (LCPA), and the List of Substances of Possible Concern (LSPC) providing the basis for priority-setting. The Stockholm Convention on Persistent Organic Pollutants, and the Minamata Convention on Mercury, add binding international restrictions on the most persistent and toxic legacy substances.

At the domestic level, the primary levers are:

1. The UK REACH regulations,[3] which provide the framework for chemical restriction, authorisation, and registration;

2. The Environmental Permitting Regulations (EPR) (England and Wales), with parallel systems in Scotland (CAR/PPC) and Northern Ireland (PPC), which control industrial and waste discharges through individual permits containing emission limit values;

3. The Industrial Emissions Directive (IED) as retained in UK law, which sets technology-based standards for large industrial installations;

4. The Environmental Quality Standards for priority substances under the Water Framework Directive, which define numerical concentration thresholds for approximately 45 priority substances in surface waters; and,

5. The Control of Mercury Regulations and the Persistent Organic Pollutants Regulation (UK POPs), which provide substance-specific restriction regimes for the most concerning legacy contaminants.

For offshore operations, the Offshore Chemicals Regulations 2002 constitute a dedicated and internationally regarded regulatory system, operationalising the OSPAR Harmonised Mandatory Control System (HMCS) for the UK Continental Shelf. The RIFE (Radioactivity in Food and the Environment) programme serves as the principal monitoring lever for radionuclide contamination from nuclear installations.

4.1.2 Descriptor 5: Eutrophication

The principal regulatory levers relevant to D5 are concentrated in the agricultural and wastewater sectors, which together represent the dominant sources of nitrogen and phosphorus inputs to UK coastal and estuarine waters. In the agricultural sector, the key levers are:

1. The Farming Rules for Water (England);

2. Nitrate Vulnerable Zone designations under the Nitrate Pollution Prevention Regulations (and devolved equivalents in Scotland, Wales, and Northern Ireland); and

3. The Control of Agricultural Pollution (Wales) Regulations.

The National Emission Ceilings Regulations 2018 sets emission reduction commitments, which aim to reduce atmospheric nitrogen deposition, which OSPAR estimates is responsible for approximately 40% of total nitrogen entering the North-East Atlantic Convention area. However there are no specific nitrogen deposition targets within the regulations.

For the wastewater sector, the Urban Wastewater Treatment Regulations 1994 (and devolved equivalents) constitute the principal lever, requiring secondary treatment for discharges above specified population-equivalent thresholds. The Storm Overflows Discharge Reduction Plan sets milestones for reducing combined sewer overflow spill frequencies, with direct relevance to nutrient loading in estua-

3 Northern Ireland is still subject to the EU REACH due to Northern Ireland protocols and the Windsor framework.

rine and coastal waters. River Basin Management Plans (RBMPs), produced under the Water Framework Directive (WFD) transpositions across all three jurisdictions, constitute the principal integrated planning instrument, identifying pressures and required measures at the river basin district level.

4.1.3 Descriptor 9: Contaminants in Seafood

For D9, the principal regulatory levers are:

1. The Contaminants in Food Regulations (setting statutory maximum levels for heavy metals, PAHs, dioxins, and dioxin-like PCBs in shellfish and finfish for human consumption);
2. the Official Controls for shellfish classification (area-based microbiological and chemical assessment); and,
3. The food safety monitoring functions of the Food Standards Agency and Cefas.

The WFD environmental quality standards for priority substances form an indirect but important lever, as chemical quality in spawning and nursery habitats influences contaminant accumulation in the food chain. Marine licensing under the Marine and Coastal Access Act 2009 and equivalent devolved legislation provides a site-specific consenting lever relevant to activities that could affect shellfish production areas.

4.1.4 Descriptor 10: Marine Litter

For D10, the principal regulatory levers are upstream product controls: the Environmental Protection (Microbeads) (England) Regulations 2017 and equivalent instruments across the devolved nations; and the single-use plastics restrictions introduced across all four UK nations between 2021 and 2023.

The UK Marine Strategy Programme of Measures (PoM) 2021 includes marine litter measures in its framework, and the OSPAR Regional Action Plan for Marine Litter provides the international coordination mechanism. The Producer Responsibility (Packaging Waste) Regulations create obligations on producers and importers, providing an indirect lever on the plastic waste stream that represents the primary source of marine litter. Notably, no dedicated instrument addresses the management of marine litter already in the environment, the coastal litter-to-microplastic fragmentation pathway, or the wastewater pathway for microplastics. These represent structural absences in the lever set for D10.

4.2 RRQ2: How do these levers operate across different contaminant sources and pathways?

Key Finding:	**Regulatory levers operate primarily through source restriction, discharge permitting, and environment quality standards. However, systemic pathway gaps leave major drivers of GES failure unaddressed, and fragmentation in the regulatory landscape weakens the management of contaminant pathways.** The levers identified under RR-RQ1 operate through three principal mechanisms: upstream restriction of substances before they enter the environment; point-of-discharge control for permitted installations; and receiving environment quality standards against which ambient monitoring is assessed. A fourth mechanism applies in the offshore sector: pre-use hazard assessment of chemicals before discharge is permitted under the OSPAR HMCS. A recurring structural problem is the fragmentation between the WFD, which governs inland and coastal waters to one nautical mile, and the UKMS, which covers

	the wider marine environment: instruments acting on catchment sources operate under different metrics, objectives, and institutional leads than those governing marine outcomes, weakening the coherence of pathway management from source to sea. Similarly, other major instruments, such as the Environmental Impact Assessment (EIA) regime, and NEC Regulations, do not include consideration of the GES framework, meaning that consenting and emissions decisions with direct implications for marine contaminant pressures are made without formal reference to GES objectives. Further, certain pathways, such as the spread of microplastics from wastewater and the presence of legacy contaminants in sediment, persist without regulation.

This section examines how the regulatory levers identified under RRQ1 operate in practice across the principal contaminant source sectors and pathways relevant to each GES descriptor. For each descriptor, the analysis considers pathway coverage, the mechanisms of effect, and the degree of integration between instruments.

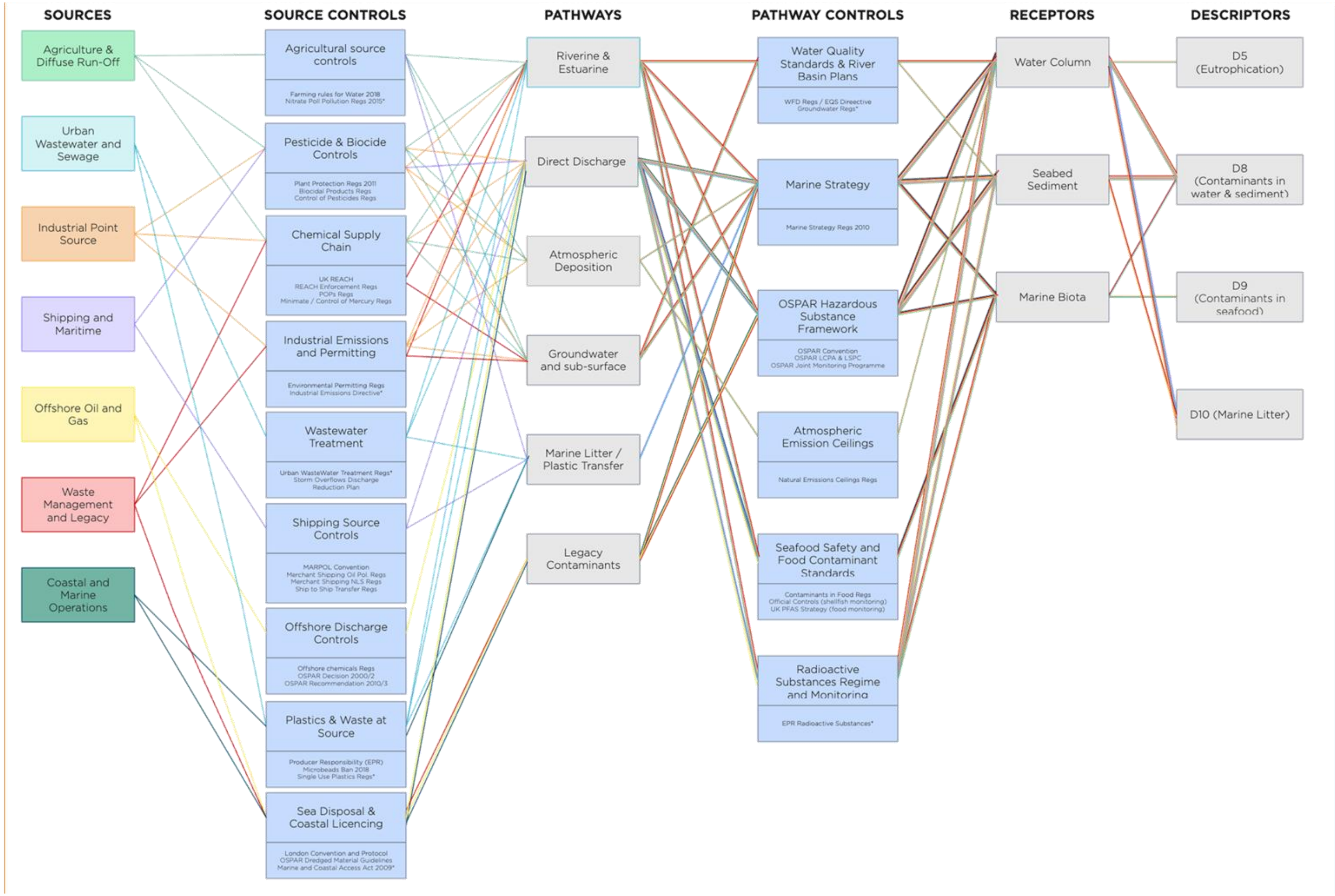
The source sectors covered in the regulatory catalogue are: agriculture and land use; urban wastewater; industrial point sources; shipping and ports; offshore energy; coastal and marine operations; and cross-cutting or overarching instruments.

Figure 2 shows the number of instruments that cover each source sector and contaminant group, and Figure 3 shows how the regulatory instruments interact with the causal pathways from source sector to GES descriptor

Figure 2 Regulatory coverage heatmap: Count of consolidated instrument families by source sector and contaminant group. Darker shading indicates higher instrument density; cells in orange indicate zero coverage.

	Nutrients (N, P)	Heavy Metals (Cd, Hg, Pb etc.)	Persistant Organics (POPs, PCBs)	Hydrocarbons	Pesticides and Biocides	Radionuclides	Emerging contaminants
Agriculture and Diffuse Runoff	6	3	4	0	6	0	1
Urban Watewater and Sewage	4	4	2	0	2	0	2
Industrial Point Source	4	10	11	5	5	0	1
Shipping and Maritime	1	0	3	4	2	1	0
Offshore Oil and Gas	0	3	4	4	0	0	0
Waste Management	0	4	3	1	0	2	0
Coastal / Marine operations	0	3	3	2	0	0	0
Cross-sector / overarching	8	19	20	13	13	9	11

Figure 3 Position of groups of instruments from the regulatory catalogue on the causal pathway from source sector to GES descriptors



4.2.1 Descriptor 8: Contaminants

For D8, the regulatory framework operates primarily through three pathway mechanisms:

1. Source restriction (preventing substances from being manufactured, used, or placed on the market);
2. Discharge control (setting limits on what can be released from permitted installations); and
3. Environmental quality standard enforcement (defining thresholds in receiving water bodies that trigger compliance action).

UK REACH and the UK POPs Regulation operate at the source restriction level. The EPR and IED permit systems operate at the discharge control level, setting installation-specific emission limit values based on Best Available Technique conclusions. The WFD EQS system operates at the receiving environment level, with EA, SEPA, NRW, and NIEA responsible for monitoring ambient concentrations and taking enforcement action where thresholds are exceeded.

The offshore sector pathway is addressed through a distinct, internationally regarded system. The OSPAR HMCS, operationalised domestically through the Offshore Chemicals Regulations 2002, requires risk assessment of all chemicals used offshore before discharge is permitted, applying the CHARM (Chemical Hazard and Risk Management) model. This risk-based approach means that high-hazard substances are restricted before entering the marine environment, rather than being managed through post-discharge monitoring. In addition, the biocidal products regulations control the antifouling agents used on vessels and aquaculture netting, thereby addressing a well-documented, though largely localised, contaminant pathway around ports, marinas, and aquaculture sites.

A structural weakness in pathway coverage applies to the legacy sediment pathway. Contaminated marine and estuarine sediments, particularly in historically industrialised estuaries such as the Tees, Clyde, Thames, and Humber, continue to emit hazardous substances to the water column through remobilisation driven by tidal action, dredging, and storms. No domestic regulatory instrument creates an obligation or mechanism to assess, manage, or remediate this pathway at a national scale. Marine licensing for dredging operations provides a site-specific consenting function, but does not address the background legacy sediment burden as a management objective.

4.2.2 Descriptor 5: Eutrophication

For D5, the regulatory framework operates primarily through two source sector mechanisms. In the agricultural sector, Nitrate Vulnerable Zone (NVZ) designations and action programmes create geographically targeted controls on nitrogen application rates, storage, and timing, operating at the farm level through Environment Agency compliance monitoring. The Farming Rules for Water (FRfW) apply additional source controls across England, including restrictions on applications near watercourses and in wet conditions. In the wastewater sector, the Urban Wastewater Treatment Regulations set technology standards at the treatment works level, with the EA and equivalent regulators overseeing permit compliance.

It should be noted that the Environmental Impact Assessment (EIA) regime, while applicable to certain activities that may affect nutrient loading (such as intensive agricultural developments, new Wastewater Treatment Works (WwTW), or coastal infrastructure), does not require applicants to assess impacts against GES Descriptors or targets. This means that consenting decisions for activities with potential eutrophication implications are made without formal consideration of their implications for D5 GES achievement. This is a generic governance gap identified across multiple GES descriptors: the absence of a formal GES assessment step in the EIA and marine licensing processes represents a missed opportunity to embed GES objectives into the decisions of greatest relevance to their delivery.

The pathway from catchment nutrient inputs to marine eutrophication is mediated by complex lag times and estuarine processing, which limits the responsiveness of the marine environment to upstream source controls. RBMPs provide the mechanism for identifying these source-to-marine pathway connections. However, the connection between freshwater WFD objectives and marine GES assessments is not always clear in planning and reporting. Atmospheric nitrogen deposition is addressed through the NEC Regulations, but this pathway is not systematically integrated into the GES framework for D5.

4.2.3 Descriptor 9: Contaminants in Seafood

For D9, the regulatory framework operates primarily through the food safety pathway: controlling concentrations of contaminants in harvested seafood that reaches human consumption. The Official Controls shellfish classification system provides area-level monitoring of production waters, with sites classified A, B, or C based on faecal indicator bacteria concentrations, and with parallel chemical monitoring determining suitability for harvesting. This system is well-integrated with EU-derived maximum level standards for metals, PAHs, and dioxins in the Contaminants in Food Regulations.

The pathway connection between upstream chemical contamination (e.g. from industrial discharges, agricultural diffuse sources, or shipping activities) and contaminant accumulation in shellfish and finfish is addressed indirectly through the permit and quality standard systems, which reduce contaminant concentrations in the water column and sediment that contribute to bioaccumulation. However, there is no dedicated instrument directly linking WFD chemical status at the catchment level to shellfish production area management decisions, representing a potential integration gap.

4.2.4 Descriptor 10: Marine Litter

For D10, the regulatory framework operates almost exclusively through upstream plastic production and waste management pathways. The microbeads ban (through the Environmental Protection (Microbeads) (England) Regulations 2017, and devolved equivalents) restricts microplastics in rinse-off personal care products at the point of manufacture and sale. The single-use plastics restrictions and producer responsibility regulations reduce plastic waste entering waste management systems. These instruments operate on the principle that reducing plastic entering the waste stream will ultimately reduce plastic entering the sea, primarily via stormwater drainage, river transport, and coastal littering pathways.

The wastewater pathway for microplastics is a major vector by which plastic particles from washing synthetic textiles and other domestic sources reach the sea via WwTW effluent. However, this is not currently addressed by any regulatory instrument. No discharge standard, permit condition, or monitoring requirement specifically addresses microplastic concentrations in WwTW discharges. Similarly, the fragmentation of macroplastic litter already on beaches and coastlines into secondary microplastics, driven by UV exposure, wave action, and abrasion, represents an unregulated source pathway for which no coastal management obligation exists. Beach cleaning is largely voluntary, with no regulatory duty equivalent to the urban litter obligations under the Environmental Protection Act 1990.

4.3 RRQ3: To what extent do existing regulations and policies support the achievement or maintenance of GES?

Key Finding:	**The regulatory framework broadly supports GES maintenance for D5 and D9 (for regulated substances and shellfish), but is structurally insufficient to achieve or maintain GES for D8 and D10.** Overall, the regulatory framework's adequacy is closely tied to the nature of the problem each descriptor presents. Where GES failures are driven by ongoing, permitted inputs from identifiable sources, the framework performs reasonably well. However, where failures are driven by legacy contamination already present in the environment, the framework is structurally insufficient regardless of how well individual instruments are implemented. The 2015 PoM's maintenance premise and the unresolved Article 14 exception for D8 legacy contamination are symptomatic of this deeper mismatch between regulatory design and the actual drivers of GES non-achievement.

This section assesses the extent to which the existing regulatory framework supports the achievement or maintenance of GES for each descriptor. The assessment draws on the UK Marine Strategy Part One (2025 updated assessment), the OSPAR Quality Status Report 2023, and the OEP's Annual Progress Report (2024-25) as the principal evaluative evidence bases, alongside the analysis of instrument coverage and enforcement delivered through the regulatory review.

4.3.1 Descriptor 8: Contaminants

For D8, the existing regulatory framework is insufficient to achieve or maintain GES within UKMS timescales under a business-as-usual scenario. The 2024 draft UKMS part one assessment indicates that GES has not been achieved for D8, with exceedances of assessment criteria for metals (mercury, lead, copper, zinc) across at least one biogeographic region, and for CB118 and BDE209 in sediments and biota.

The framework is broadly well-designed for the source control function, restricting production and discharge of hazardous substances. REACH restriction processes, EPR permit limits, IED BAT standards, and POPs-class bans represent a comprehensive source control architecture for the substances it covers. The primary structural inadequacy is the mismatch between the preventative design of the framework and the nature of the D8 GES failures. The principal drivers of current GES non-achievement are not ongoing permitted discharges, but rather legacy contamination in marine sediments. Mercury concentrations in fish and shellfish show no decreasing trend in most UK regions despite decades of source controls (Barber, 2024a), which may be influenced by the continued supply from factors including the resuspension of contaminated sediment (Environment Agency, 2019b). The regulatory framework has no instrument directed at this pathway beyond marine licencing for dredge and disposal operations (which will not address the resuspension through factors such as storm events or fish trawling activities).

This inadequacy was embedded in the UKMS Programme of Measures from its initial conception. The 2015 PoM for Contaminants was built on the premise that GES had largely been achieved and adopted a maintenance-focused approach, leaning on existing instruments rather than identifying new actions. Legacy contaminated sediments were acknowledged as an exception case, but the justification for applying the MSFD Article 14(4) exception, citing disproportionate remediation costs, was found by the EU Commission to be only partially substantiated, due to the absence of a cost-benefit analysis and an evaluation of alternative remediation options (EU Commission, 2018). The 2025 PoM exception for Contaminants has not substantially strengthened this evidence base. The persistent reliance on exception provisions without an evidence-based remediation pathway constitutes a systemic regulatory gap that source control instruments cannot close.

A secondary limitation is the coverage gap for emerging chemical contaminants, particularly PFAS. These substances are not included in the WFD EQS regime for surface waters and have no agreed marine quality standards under the UKMS framework. UK REACH has initiated a restriction process for PFAS in firefighting foams, but a UK-wide restriction on non-essential PFAS uses will not be in plact before 2027 at the earliest. The Cefas MOAT indicator assessment does not include PFAS, meaning that accumulation in UK marine biota is occurring outside the GES assessment framework.

4.3.2 Descriptor 5: Eutrophication

For D5, the existing regulatory framework broadly supports the maintenance of GES at national scale, though its adequacy for the subset of failing waterbodies and for future climate change conditions is less assured. Approximately 95% of UK marine and coastal waters meet GES for D5, which represents a genuine regulatory achievement attributable in significant part to the Nitrates Directive, NVZ designations, and UWWT standards introduced from the 1990s onwards.

However, the 5% failure rate is not evenly distributed: failures are concentrated in intensively farmed catchments and urbanised estuaries where agricultural diffuse inputs and WwTW discharges combine with high residence times and restricted tidal exchange. In these systems, the regulatory framework is in place but its effectiveness is constrained by three factors:

1. Enforcement resourcing limiting inspection frequencies and compliance monitoring (OEP, 2026);
2. The long lag times between catchment management interventions and measurable marine outcomes, which can be a decade or more for large estuarine systems; and
3. The N:P imbalance arising from greater success in phosphorus reduction relative to nitrogen, which risks structural changes to phytoplankton community composition in the North Sea.

The NEC Regulations address atmospheric nitrogen deposition, but this pathway remains poorly integrated into GES assessment and RBMPs.

4.3.3 Descriptor 9: Contaminants in Seafood

For D9, GES has been achieved for shellfish based on the 2016-2020 survey evidence, and the Official Controls classification system and Contaminants in Food Regulations together constitute an effective regulatory backstop for the contaminants currently assessed. The framework broadly supports maintenance of GES for D9 for the regulated contaminants in shellfish.

However, the GES descriptor is considered only partially met, primarily due to the absence of comparable finfish monitoring data. This represents both an evidence gap and a potential regulatory blind spot: the contaminant profile for finfish (particularly for PCBs, PBDEs, and dioxins in fatty fish) may differ from that for shellfish, and the combination of bioaccumulation at higher trophic levels and the documented PCB concentrations in top marine predators suggests that contaminant levels in commercially important finfish species may warrant more systematic regulatory attention. Additionally, novel emerging contaminants including PFAS are not subject to maximum levels in seafood, meaning that accumulation in shellfish and finfish represents an unmonitored and unregulated pathway to human dietary exposure.

4.3.4 Descriptor 10: Marine Litter

For D10, GES has not been achieved, and the existing regulatory framework appears unlikely to deliver GES within UKMS timescales. The UKMS PoM 2021 acknowledges that the trajectory of improvement is insufficient given the scale of accumulated marine litter and the limitations of upstream product controls in driving measurable environmental improvement at the pace required. Seafloor litter is increasing despite modest improvements in beach and floating litter, which may reflect the long residence times of plastics deposited in deeper waters and on the seafloor.

A key constraint on progress is the design of the GES targets themselves for this descriptor. For seafloor litter and floating litter, the UKMS targets are surveillance indicators, monitoring whether trends are moving in the right direction, rather than quantitative reduction targets requiring measurable improvement by a set date. A surveillance-only target cannot be failed in the same way as a quantitative threshold, but it also provides no minimum ambition against which regulatory adequacy can be assessed. This design reflects the data limitations present when targets were set in 2012 but has not been updated to reflect the decade of monitoring data since accumulated. The continued use of surveillance framing for seafloor and floating litter insulates the regulatory framework from accountability for continued environmental deterioration.

The upstream product controls (microbeads ban, SUP restrictions, and producer responsibility obligations) represent a positive contribution to reducing future plastic inputs to the sea but do not and cannot address the stock of plastic already present in the marine environment. They also do not address the principal diffuse pathways through which plastic currently reaches the sea: WwTW effluent (microplastics); surface water drainage (fragments and fibres); river transport; and in-situ coastal fragmentation of stranded macroplastic. The GES target for D10 remains framed primarily in terms of macrolitter rather than microplastics, meaning that the fastest-growing component of the marine plastic burden is assessed against a less stringent standard than the science warrants.

4.4 RRQ4: Where are there gaps, overlaps, exemptions, or enforcement challenges that may undermine effectiveness?

Key Finding:	**The most significant structural gaps in the regulatory framework are: the absence of any instrument for legacy marine sediment remediation; an enforcement deficit undermining well-designed agricultural and discharge controls; the misalignment of the EIA and marine licensing with GES objectives; and the lack of any pathway-specific controls for microplastics in WwTW effluent.** The gaps in the regulatory framework for contaminants share a common character: they are not failures of legislative design but of coverage, enforcement, and institutional coherence. The FRfW and EPR permit systems are appropriately designed but under-enforced due to EA inspection capacity constraints. The EIA and marine licensing regimes are widely referenced as delivery mechanisms within the UKMS PoM but neither requires formal assessment against GES Descriptors, creating a structural accountability gap. PFAS maximum levels in seafood, adopted by the EU in January 2023, have no UK equivalent. The wastewater microplastics pathway and coastal litter fragmentation pathway remain entirely unregulated, and the 2025 PoM exception for Marine Litter was applied without quantitative recovery modelling or evaluation of removal-based alternatives.

This section identifies the principal gaps, overlaps, exemptions, and enforcement challenges in the regulatory framework for each descriptor. It draws on the findings of the regulatory catalogue analysis, various scrutiny reports, and expert knowledge of the regulatory landscape.

4.4.1 Descriptor 8: Contaminants

For D8, four categories of gap and enforcement challenge are identified. First, coverage gaps exist in relation to legacy contaminated sediments (no instrument addresses assessment or remediation at national scale in the marine environment), PFAS (no binding marine EQS, no agreed GES assessment criteria, no timely restriction process), and to the chemical complexity of plastic additives, pharmaceutical compounds, and tyre wear particles, which are present in UK marine waters but outside both the WFD EQS regime and the GES assessment framework.

Second, implementation and enforcement limitations affect even well-designed instruments. The Farming Rules for Water create appropriate obligations on the agricultural sector but rely on Environment Agency (EA) inspection and enforcement. However, EA capacity constraints mean that inspection frequencies are likely insufficient to deter non-compliance across the full range of agricultural operators (OEP, 2025; National Audit Office, 2022). Similar constraints apply to EPR permit monitoring, where self-monitoring data from permitted operators is the primary compliance evidence.

Third, jurisdictional fragmentation creates coordination gaps for contaminants crossing regulatory boundaries. A single contaminant group such as PFAS may pass through the regulatory domains of the EA (industrial discharges, or WwTW effluent), the FSA and Cefas (seafood monitoring), and the HSE (UK REACH restriction decisions) without any single authority holding a mandate to assess the end-to-end pathway or coordinate action across regulators. Whilst it is likely not be appropriate to establish regulation according to chemical group, the absence of a cross-regulator PFAS coordination mechanism, similar to that established for pharmaceuticals under the cross-government Pharmaceuticals in the Environment Group, is an identified gap.

Fourth, there is an observed inconsistency in assessments under marine licensing, specifically the treatment of contaminated sediment remobilisation as illustrated by the recent Tees Estuary dredging case (Gibbon v MMO, 2025/2026), in which the Marine Management Organisation (MMO) conceded a judicial review challenge over the adequacy of sediment sampling underpinning a disposal licence for historically contaminated material (Matrix Chambers, 2026). The primary basis for determining the suitability of sediment for disposal at sea (including the disturbance of material through methods such as water injection dredging) through the marine licencing system involves sediment sampling and analysis. Such sampling for marine licencing follows the OSPAR Guidelines for Dredged Materials, with analysis results compared to Cefas Action Levels. However, these Action Levels were reviewed in 2021, with revised levels suggested to reduce contaminant disposal in the marine environment, and improve transparency in decision-making, but the Government have yet to implement any change to the action levels, and therefore they have not been updated since their implementation in 1995 (Mason et al., 2022). The non-binding character of the OSPAR Guidelines for Dredged Materials, alongside the discretionary nature of the weight-of-evidence approach within which the Cefas Action Levels sit, means that the MMO and devolved equivalent bodies have wide discretion in how they assess dredging proposals involving historically contaminated material, leading to inconsistent outcomes.

4.4.2 Descriptor 5: Eutrophication

For D5, the primary gaps and challenges relate to enforcement rather than legislative design. The Farming Rules for Water (FRfW), introduced in 2018, represent a potentially powerful instrument for reducing diffuse agricultural nitrogen losses. However, the OEP has found that FRfW enforcement has been limited: the EA issued approximately 750 advisory visits in the first three years of operation but very few formal enforcement actions, reflecting a compliance-led rather than enforcement-led approach that may be insufficient to drive the behaviour change needed in high-pressure catchments. NVZ action programmes have similar enforcement limitations, with non-compliance rates documented in agricultural pollution incidents data.

An overlap challenge exists between the WFD RBMPs and GES assessment for D5: the river basin management system and the marine strategy system use different geographic boundaries, different assessment metrics, and different institutional lead bodies, making integrated pathway management from agricultural source to marine endpoint difficult to coordinate. A specific and consequential loophole arises from the WFD classification of many UK transitional and estuarine water bodies as 'heavily modified', a designation that permits lower ecological objectives than 'good ecological status'. Because estuaries are the primary interface between catchment nutrient inputs and coastal marine systems, the acceptance of lower ecological ambitions in this transitional zone may directly undermine the D5 GES target in adjacent coastal waters. This creates a structural inconsistency in which upstream WFD management objectives may be insufficiently stringent to support downstream UKMS objectives, yet the two frameworks have no formal mechanism for reconciling this divergence. For example, the Marine Strategy Regulations 2010 adopt the WFD definitions of coastal and transitional waters to define the inner boundary of the marine strategy area, with transitional waters (including estuaries) sitting outside that boundary. The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 govern these transitional water bodies with different assessment metrics, objectives and institutional leads. No formal coordination mechanism exists between the two regimes to ensure that WFD management objectives in transitional waters are consistent with UKMS GES objectives in the adjacent coastal marine environment.

Atmospheric nitrogen deposition has been reported to contribute approximately 35-40% of nitrogen inputs to the North-East Atlantic, but sits outside the WFD and RBMP frameworks (OSPAR Commission, 2023). It is instead addressed only at the national emissions level through the NEC Regulations, with no mechanism linking NEC compliance trajectories to localised estuarine eutrophication outcomes.

Finally, the EIA framework, while applicable to activities that may affect nutrient loading, does not require assessment against GES Descriptors, meaning that development decisions relevant to eutrophication pressures are not formally evaluated for their GES implications.

4.4.3 Descriptor 9: Contaminants in Seafood

For D9, the principal gap is the absence of monitoring and maximum levels for emerging contaminants in seafood. PFAS are not subject to any statutory maximum level in shellfish or finfish for human consumption in the UK, despite being detected in marine organisms and in some seafood products commercially available in European markets. The EU has introduced a maximum level for the sum of four PFAS in seafood, effective from January 2023. However, the UK has not introduced an equivalent standard, representing a post-EU divergence with direct relevance to GES for D9.

The finfish data gap identified under RRQ3 also constitutes a monitoring gap with enforcement implications: shellfish contamination is systematically assessed through the Official Controls classification system, but no equivalent systematic monitoring exists for contaminants in commercially important finfish species. This means that GES D9 compliance is assessed on an incomplete evidence base, and that potential exceedances in finfish would not necessarily be detected by the current framework.

4.4.4 Descriptor 10: Marine Litter

For D10, gaps are identified at the level of pathway coverage and at the level of GES standard design. The wastewater microplastics pathway is the most significant unaddressed source pathway, with no permit condition, monitoring standard, or GES criterion specific to microplastics in WwTW effluent. The coastal litter-to-microplastic pathway is similarly unaddressed: no instrument places a duty on any public body to manage, clear, or monitor stranded plastic litter on coastlines and beaches as a microplastic source pathway. This is a structural gap distinguishing the D10 framework from other environmental domains where a continuous legacy pollution source would attract a formal management obligation.

A further and distinct gap lies in the design of the PoM itself. All three UKMS cycles have structured marine litter measures around preventing new inputs (i.e. through product controls, waste management legislation, and behaviour change) but have not included removal of litter already in the marine environment. This oversight is significant because the UKMS GES target for beach litter requires a reduction in total amounts present, rather than slowing the rate of increase. A prevention-only strategy is insufficient to meet a target of that form: without removal measures operating alongside source controls, the accumulated stock of marine litter will continue to maintain GES exceedance even if all new inputs were eliminated. The Part Three Update (2025) applied a Regulation 15(2)(e) exception for Marine Litter on the grounds that time is needed for measures to take effect. This rationale has been assessed as only weakly evidenced, with no quantitative modelling, clear recovery timeline, or evaluation of alternative removal-based measures provided in support.

The current D10 GES criteria are framed primarily around macrolitter counts and are not yet designed to assess microplastic concentrations in water, sediment, or biota against environmental quality thresholds. The UK Marine Strategy PoM 2021 acknowledges this limitation. Until GES criteria for microplastics are established, the regulatory framework cannot be formally evaluated for adequacy against the fastest-growing component of the marine plastic burden. Achieving GES for D10 under any realistic assessment framework will require both further upstream source controls and active measures to address the accumulated stock of marine plastic, a trajectory that the current framework does not chart.

4.5 RRQ5: Are emerging contaminants adequately addressed within current regulatory frameworks?

Key Finding:	**Emerging contaminants are inadequately addressed by current regulatory frameworks, with no binding marine quality standards, no agreed GES assessment criteria, and a governance structure that cannot respond to new evidence at the pace required.** The regulatory framework has no established mechanism for incorporating emerging contaminants into binding marine management standards within a timeframe suitable for the pace of environmental accumulation. PFAS, microplastics, and pharmaceuticals are all present in UK marine waters at ecologically significant concentrations, yet none is subject to a marine quality standard, a GES assessment criterion, or an operational monitoring requirement under the UKMS. The UKMS review cycle, subject to repeated delays, systematically produces regulatory lags of a decade or more between first detection and binding management response.

This section addresses the adequacy of current regulatory frameworks for emerging contaminants (defined for this purpose as substances not currently assessed within the GES indicator framework but for which evidence of presence and potential ecological or human health effects in UK marine waters is available). Three groups are addressed:

1. PFAS (per- and polyfluoroalkyl substances);
2. microplastics (and plastic additives); and,
3. pharmaceuticals.

The cross-cutting nature of emerging contaminants means that findings here also apply to specific descriptors as noted.

4.5.1 Descriptor 8: Contaminants

PFAS represent the most acute emerging contaminant challenge for D8 and for the regulatory framework as a whole. Despite detection in UK coastal waters, sediments, and marine biota at concentrations documented to cause immunotoxic, endocrine-disrupting, and reproductive effects in marine mammals and seabirds, PFAS are not included in the WFD Environmental Quality Standards regime, have no agreed GES assessment criteria under the UKMS, and are not subject to any binding marine management standard in the UK.

The UK PFAS Plan, published in February 2026, adopts a monitoring and evidence-gathering approach rather than binding source controls, committing to a multi-year assessment of PFAS contamination in English estuarine and coastal environments by 2028 as a precondition for 'considering future regulatory action' (Defra, 2026). The HSE is consulting on a potential restriction of PFAS in firefighting foams, but a final decision is not expected before 2027 and would address only one source sector. In contrast, the EU is progressing a comprehensive cross-class restriction on non-essential PFAS uses under EU REACH, with restrictions already adopted for some applications (EU Regulation 2024/2462). This divergence creates a risk of differential levels of protection in shared sea areas and a widening gap between UK and EU marine contaminant management for this substance class.

The PFAS regulatory trajectory illustrates a structural feature of the UKMS governance framework: the six-year review cycle is the primary mechanism for adaptive management, but review cycles have been subject to significant delays and the cycle itself does not provide a mechanism for responding to emerging scientific evidence between updates. This means that new contaminants detected and shown to cause ecological harm during one cycle may not receive binding management responses until the following cycle: A lag that can extend beyond a decade from first detection to operational standard. The same structural constraint applies to microplastics, pharmaceuticals, and any other contaminants not yet identified. Addressing this requires not only faster PFAS-specific action, but reform of the adaptive management mechanism within the UKMS to permit between-cycle review and intervention for rapidly accumulating emerging contaminants.

For heavy metals assessed under D8, the framework is broadly adequate for established contaminants, but emerging evidence on contaminant mixtures, including the documented unfolded protein response in Atlantic cod at environmentally realistic mixture concentrations (Olsvik et al., 2023), suggests that the current single-substance EQS approach may not capture biologically significant effects of co-occurring contaminants at individually sub-threshold concentrations.

4.5.2 Descriptor 5: Eutrophication

Emerging contaminant concerns for D5 are relatively limited compared to D8 and D10, as the eutrophication framework is primarily concerned with macro-nutrient loading rather than novel chemical substances. However, two emerging dimensions are relevant. First, the nutrient contribution from sediment remobilisation (specifically the release of bioavailable nitrogen (as ammonium) and phosphorus from organic-rich estuarine sediments under anoxic or disturbed conditions) is not currently addressed within the eutrophication regulatory framework. This internal loading pathway can sustain eutrophic conditions in estuaries and semi-enclosed coastal areas even after significant reductions in surface catchment nutrient inputs, and there is no instrument in the catalogue directed at its management.

Second, the stoichiometric consequences of differential nutrient reduction (specifically the elevated N:P ratios arising from more successful phosphorus reduction) represent an emerging risk for phytoplankton community composition and trophic function in North Sea-connected waters (Balkoni et al., 2025). Regulatory frameworks for eutrophication management do not currently include provisions for monitoring or managing N:P ratios as a management target, despite the evidence from comparable North Sea environments reviewed in the literature review.

4.5.3 Descriptor 9: Contaminants in Seafood

For D9, the most significant emerging concern is the absence of regulatory coverage for PFAS, pharmaceuticals, and plastic additive chemicals in seafood. PFAS have been detected in shellfish and fish in UK and European waters, and the EU has moved ahead of the UK in establishing maximum levels for PFAS in food (including seafood). No equivalent UK standard has been introduced, meaning that shellfish and finfish harvested from UK waters are not assessed against any PFAS standard, and accumulation in the food chain continues outside the GES assessment and food safety frameworks.

Pharmaceutical compounds present in WwTW effluent (including synthetic oestrogens, antibiotics, and anti-inflammatory drugs) are detected in UK estuarine and coastal waters and are taken up by marine organisms, but are not subject to any maximum level under D9. The environmental risk assessment requirements in the Human Medicines Regulations and Veterinary Medicines Regulations provide a pre-market pathway assessment for new pharmaceuticals, but do not address the cumulative load of legacy pharmaceutical compounds already cycling through UK marine waters. This represents a structural gap that is expected to grow in significance as pharmaceutical use and WwTW throughput increase.

4.5.4 Descriptor 10: Marine Litter

For D10, the most significant emerging regulatory gap is the absence of any framework for managing microplastics as an environmental quality issue, as opposed to a litter management issue. The current D10 GES framework addresses marine litter in terms of macrolitter counts and the absence of visible plastic at reference sites. However, microplastics require a different assessment approach (e.g. quantitative concentration standards in water, sediment, and biota) which the current framework does not yet provide.

No instrument in the UK regulatory catalogue sets a standard for microplastic concentrations in coastal or marine waters, establishes a monitoring protocol equivalent to the EQS system for chemicals, or creates an obligation to reduce microplastic inputs from the WwTW pathway. The OSPAR Regional Action Plan on Marine Litter includes microplastics as a priority concern and provides a coordination framework, but national-level regulatory instruments translating this into operational standards are absent.

Plastic additive chemicals, including phthalates, bisphenol A, nonylphenol, and brominated flame retardants leaching from marine plastic debris, represent an emerging intersection between D8 and D10 that is not addressed within either descriptor's GES framework. These substances are regulated at source through REACH restrictions, but their release from plastic material already present in the marine environment is not addressed by any instrument.

In addition, the effectiveness of source controls for marine litter is not necessarily sufficient to address pressures on the marine environment. The Resources and Waste Strategy (2018) and the Litter Strategy for England (2017) provide the overarching policy framework for addressing terrestrial litter, and both identify the marine environment as a downstream recipient of land-based litter. However, the available evidence does not support a conclusion that these strategies are driving measurable improvement in land-based litter outcomes. Defra's Environmental Indicator Framework records a deteriorating trend in fly-tipping in England, with the total number of incidents increasing by 20.4% in the five years to 2023/24 to reach 1.15 million incidents (Defra, 2025b). Where these land-based litter policies (which are the primary mechanism for managing litter entering the marine environment) are proving ineffective, it is likely to have related impacts on the prevalence of marine litter.

5 Synthesis Across Evidence and Regulation

This section draws together the findings of the literature and regulatory reviews to provide an integrated assessment of the challenges to achieving and maintaining GES for contaminants in UK marine waters. It is structured around four themes: (i) an integrated view by contaminant group; (ii) the relative significance of sectors and pathways; (iii) the effectiveness, gaps and interactions in the regulatory framework; and (iv) the key systemic challenges to GES achievement.

5.1 Integrated view by contaminant group

For legacy heavy metals and organochlorines assessed under D8, the literature review highlights the implications of GES not being met, with the primary driver for this failure being the persistence of legacy contamination in marine sediments, a problem that source control regulation alone cannot resolve. The regulatory review confirms that the framework has no national remediation programme capable of addressing this legacy. The combination of increasing biota concentrations for mercury and copper in the Southern North Sea and Irish Sea, the projected amplification of sediment remobilisation by climate change, and the complete absence of remediation-oriented instruments creates a strong probability that GES for D8 metals will not be achieved within current UKMS timescales under business-as-usual.

For PCBs, the literature documents population-level impacts on UK cetacean populations at concentrations exceeding mammalian toxicity thresholds, driven by sediment remobilisation and continued leaching from products manufactured before the ban. The regulatory review confirms that these pathways are not adequately controlled by source restriction alone. A downward trend in PCB concentrations in biota in some regions provides some evidence of regulatory effectiveness over the very long term,[4] but the pace of decline is insufficient to achieve GES within UKMS timescales.

For eutrophication (D5), the literature and regulatory reviews are broadly consistent: the framework is sufficient at national scale, but persistent localised failures reflect long lag times between agricultural source controls and marine outcomes. The unresolved N:P imbalance, reflecting greater success in reducing phosphorus than nitrogen, creates ongoing risks for phytoplankton community composition and trophic structure, particularly in the North Sea. Climate change represents the most significant future risk, through projected increases in river flows and associated nutrient loading.

For marine litter (D10), the literature review documents increasing seafloor litter despite improving trends for beach and floating litter, with significant ecological impacts including entanglement, ingestion, and contaminant transport via the chemical vector role of microplastics. The regulatory review confirms that the existing framework of upstream product controls, while making a positive contribution to specific litter categories, does not address the dominant diffuse pathways through which microplastics enter the sea (principally via WwTW effluent, surface water drainage, and coastal fragmentation of stranded macroplastic), and does not include microplastics within the GES assessment framework for D10. The design of GES targets as surveillance indicators rather than quantitative reduction thresholds for seafloor and floating litter further insulates the framework from accountability for continued environmental deterioration.

[4] According to MOAT, PCB concentrations are measured in sediment, fish and shellfish, collected between 1999 and 2021 from monitoring sites throughout UK biogeographic regions, at frequencies ranging from annually to every six years.

For PFAS and other emerging contaminants, the literature documents widespread presence across all trophic levels and documented immunotoxic, endocrine-disrupting, and reproductive impacts in marine mammals, seabirds, and fish. The regulatory review confirms that these substances are almost entirely outside the operational regulatory framework: no binding marine quality standards, no agreed GES assessment criteria, and a UK policy approach (the 2026 PFAS Plan) that defers binding action by several further years. The UK-EU divergence in PFAS management, with the EU already advancing restrictions on non-essential PFAS uses, creates a risk of differential environmental protection in shared sea areas. A possible implication of this is that ongoing PFAS use and emissions in the UK could contribute to regional, transboundary contamination, potentially offsetting reductions achieved through stricter EU controls. This is particularly pertinent for PFAS which are highly persistent in the marine environment and are difficult to remediate once released. Further possible implications relate to migratory species, particularly those at higher trophic levels which are subject to PFAS bioaccumulation. Divergent ecological protection for transboundary species complicates both conservation outcomes and assessment of regulatory success. The combination of accumulation in the marine environment, documented ecological effects, and UK regulatory inaction represents the most acute emerging challenge for GES achievement.

5.2 Relative significance of sectors and pathways

Taking the literature and regulatory evidence together, the relative significance of key sectors and pathways can be summarised as follows.

5.2.1 Legacy contaminated sediments

The legacy sediment pathway is the single most important driver of ongoing GES failure for D8, and the pathway most conspicuously absent from the operational regulatory framework. Contaminated estuarine and coastal sediments, particularly in the Tees, Clyde, Thames, and Humber catchments, continue to emit hazardous substances to the water column through remobilisation driven by tidal action, storms, and dredging. No current instrument can compel or fund the assessment, management, or remediation of historically contaminated marine sediments at scale. The justification applied for the MSFD Article 14(4) exception in successive UKMS Programmes of Measures, citing disproportionate remediation costs, has been found only partially substantiated, and the 2025 PoM does not resolve this weakness.

5.2.2 Wastewater and combined sewer overflows

The wastewater pathway is critical for both traditional contaminants (nutrients, metals, organics) and emerging contaminants (PFAS, microplastics, pharmaceuticals). While traditional contaminant pathways via WwTW are regulated through permits, emerging contaminants in effluent remain entirely unaddressed. The Storm Overflows Discharge Reduction Plan (SODRP) sets milestones for reducing CSO spill frequencies, but these extend to 2035 and beyond. No permit condition, discharge standard, or monitoring requirement specifically addresses microplastic concentrations in WwTW discharges, a significant structural absence given that washing of synthetic textiles represents a major pathway for plastic fibres and particles to reach coastal waters.

5.2.3 Agricultural diffuse pathways

Agricultural diffuse pathways remain the primary driver of eutrophication GES failures, with instruments in place (the FRfW, NVZ action programmes, and RBMPs) but effective implementation constrained by EA enforcement resourcing and long lag times between catchment management interventions and measurable marine outcomes. The OEP has found that early implementation of the FRfW was shaped by statutory guidance that discouraged robust enforcement, encouraging an advice-led approach and weakening the Environment Agency's use of formal enforcement powers.[5]

5.2.4 Offshore energy sector

The offshore energy sector represents a relative regulatory success story. The OSPAR Harmonised Mandatory Control System (HMCS), operationalised domestically through the Offshore Chemicals Regulations 2002 and the Chemical Hazard and Risk Management (CHARM) model, has demonstrated measurable reductions in dispersed oil discharges and provides systematic environmental hazard assessment for offshore chemical use. However, the rapid expansion of offshore wind, carbon capture and storage (CCS) infrastructure, and aquaculture creates increasing potential for cumulative disturbance of benthic habitats and remobilisation of contaminated sediments.

5.2.5 Industrial point sources

The industrial point source pathway is the most comprehensively regulated contaminant pathway in the catalogue, with EPR permit conditions, IED Best Available Technique (BAT) standards, WFD EQS, and REACH chemical restrictions operating in combination. The principal limitation is enforcement resourcing: self-monitoring data from permitted operators is the primary compliance evidence, and EA inspection capacity limits independent verification.

5.2.6 Atmospheric deposition

Atmospheric deposition contributes approximately 30–50% of nitrogen inputs to OSPAR Regions II–IV, making it a major pathway for eutrophication, and also delivers metals, PAHs, and PFAS to marine waters. It is addressed at the national emissions level through the National Emission Ceilings (NEC) Regulations but is not systematically integrated into either the marine GES assessment framework or River Basin Management Plans.

5.3 Effectiveness, gaps and interactions in the framework

The framework's coverage of contaminant pressures and pathways is systematically biased towards established, well-characterised contaminant groups and point source industrial pathways, reflecting the historical development of environmental regulation. Diffuse agricultural pathways, legacy sediment, and emerging contaminants are underserved relative to their current and projected contribution to GES failures.

5.3.1 Coverage strengths

The source control architecture for established contaminants is comprehensive: REACH restriction processes, EPR permit limits, IED BAT standards, and POPs-class bans together constitute a mature system. The Official Controls shellfish classification system and the Contaminants in Food Regulations provide an effective regulatory backstop for the contaminants currently assessed under D9. The UKMS and OSPAR Convention provide a coherent strategic framework integrating international commitments with domestic regulatory obligations.

5.3.2 Structural gaps in regulatory coverage

Four structural gaps stand out across the descriptors. First, the absence of any national instrument for legacy marine sediment remediation means that the dominant driver of D8 GES non-achievement

[5] Investigation into lawfulness of government guidance on water pollution from agriculture | Office for Environmental Protection.

is entirely unaddressed. Second, PFAS - present across all trophic levels, causing documented ecological harm, and accumulating in UK marine waters - remain absent from the WFD EQS regime, the UKMS GES assessment framework, and any binding marine management standard. Third, no instrument addresses microplastic concentrations in WwTW effluent or the coastal litter-to-microplastic fragmentation pathway, together representing the fastest-growing component of the marine plastic burden. Fourth, neither the EIA framework nor marine licensing under the Marine and Coastal Access Act 2009 requires formal assessment against GES Descriptors, creating a structural accountability gap across all descriptors, particularly relevant for activities involving contaminated sediment disturbance. The legacy sediment pathway is the key driver of ongoing GES failure for D8 and the pathway most conspicuously absent from the operational regulatory framework. The wastewater microplastics pathway is similarly absent from operational regulation: no discharge standard, permit condition, or monitoring requirement specifically addresses microplastic concentrations in WwTW discharges, despite the wastewater pathway being a major vector by which plastic particles reach the sea. With respect to the fourth gap, consenting decisions for activities with significant potential eutrophication or contamination implications are made without formal consideration of their implications for GES achievement, constituting a missed opportunity to embed GES objectives into the decisions of greatest relevance to their delivery. This is a governance gap identified across multiple GES descriptors.

5.3.3 Enforcement and implementation gaps

Even the well-designed instruments are not delivering their intended environmental outcomes. For example, EA inspection capacity constraints limit FRfW and EPR compliance rates. The Farming Rules for Water have been applied in a predominantly advisory manner. Monitoring coverage is insufficient for emerging contaminants, for finfish under D9, and for beach litter and nano-plastics under D10. Part 1 of the UKMS also acknowledges that GES assessments have not yet factored in the impact of climate change on assessment outcomes, a significant structural limitation.

5.3.4 Jurisdictional fragmentation

No single authority holds an end-to-end mandate for any major contaminant pathways. A contaminant such as PFAS may pass through the regulatory domains of the EA (industrial discharges, WwTW effluent), the FSA and Cefas (seafood monitoring), and the HSE (UK REACH restriction decisions) without any authority holding a mandate to assess the end-to-end pathway or coordinate action. The WFD river basin management system and the UKMS GES assessment framework use different geographic boundaries, different assessment metrics, and different institutional leads, making integrated pathway management from agricultural source to marine endpoint structurally difficult.

This fragmentation between the WFD and the UKMS, is a recurring issue. Instruments acting on catchment sources operate under different metrics, objectives, and institutional leads than those governing marine outcomes, weakening the coherence of pathway management from source to sea. The connection between freshwater WFD objectives and marine GES assessments is not always clear in planning and reporting. While River Basin Management Plans (RBMPs) provide a mechanism for identifying source-to-marine pathway connections, this linkage is not consistently applied.

Atmospheric nitrogen deposition is addressed through the National Emission Ceilings (NEC) Regulations, but this pathway is not systematically integrated into the GES framework for D5, despite accounting for a significant proportion of nitrogen inputs to OSPAR Regions II to IV.

5.3.5 Post-Brexit dynamics and future resilience

UK chemicals regulation appears to be diverging from the more precautionary EU trajectory, particularly for PFAS and endocrine-disrupting compounds (EDCs). It should, however, be noted that Northern

Ireland remains subject to EU REACH under the Windsor Framework.[6] In shared sea areas, this risks differential environmental protection and complicates transboundary contamination management. The OSPAR Convention provides a partial buffer but does not resolve operational divergence. Future resilience is threatened by: the emergence of new contaminant classes (PFAS successors, microplastics, pharmaceuticals, tyre wear derivatives) accumulating faster than the regulatory lifecycle can adapt; the amplification of legacy contamination pathways by climate change; and the potential for further post-Brexit divergence. The UKMS's six-year review cycle cannot respond to rapidly accumulating emerging contaminants between cycles, creating a structural lag that, for PFAS, has already extended beyond a decade from first detection to any prospect of operational standards.

5.4 Key challenges to achieving and maintaining GES

Drawing together the evidence from both review components, the following constitute the primary systemic challenges to achieving and maintaining GES for marine contaminants in UK waters.

1. Legacy sediment contamination as a self-sustaining source of GES failure

Legacy substances continue to drive exceedances of GES thresholds through remobilisation from historically contaminated marine sediments. No regulatory instrument currently addresses this pathway at national scale. Climate change will amplify it through increased storminess, ocean acidification, and mercury methylation under warming and hypoxic conditions. Resolution requires a national remediation programme for legacy contaminated marine sediments, which neither the current regulatory framework nor the 2025 UKMS Programme of Measures establishes.

2. An enforcement gap that undermines well-designed instruments

The regulatory framework contains instruments appropriately designed for most major contaminant pathways, although there is a notable gap regarding the lack of coherence between the WFD and Marine Strategy Regulations. The primary constraint is operational, not legislative: enforcement resourcing has not kept pace with regulatory ambition. The Farming Rules for Water, EPR permits, and WFD quality standards are potentially effective mechanisms that are delivering below their designed potential due to EA inspection capacity constraints, predominantly advisory approaches to agricultural compliance, and jurisdictional fragmentation in estuaries. The EIA and marine licensing regimes are widely referenced as delivery mechanisms within the UKMS PoM, but neither requires formal assessment against GES Descriptors. As a result, consenting decisions for activities with significant contamination or eutrophication implications do not consider the implications for GES achievement, a governance gap that is identified across multiple GES descriptors and that the 2025 PoM does not resolve. The OEP has consistently found that government is not on course to meet most marine environment commitments (OEP, 2026).

3. A regulatory lifecycle that cannot keep pace with emerging contaminant accumulation

The time from evidence generation to agreed quality standard to binding enforcement action for a new contaminant can be measured in decades. PFAS have been detected in UK marine waters, documented to cause ecological harm, and subjected to voluntary phase-outs for more than 25 years, yet remain outside all binding marine quality standards. The 2026 PFAS Plan's monitoring-first approach adds further years to this timeline. The same dynamic applies to microplastics and pharmaceuticals, and will apply to successor contaminants as yet unidentified. The UKMS governance framework's six-

[6] The Windsor Framework seeks to address challenges arising from the Northern Ireland Protocol as a result of the UK's departure from the EU, with the practical effect that Northern Ireland maintains alignment with a number of the EU single market rules, while the rest of the UK diverged.

year review cycle does not permit between-cycle intervention for rapidly accumulating contaminants, creating a structural feature that systematically disadvantages the most rapidly emerging problems. For PFAs, this structural lag has already extended beyond a decade from first detection to any prospect of operational standards, and the six-year review cycle cannot respond to rapidly accumulating emerging contaminants between cycles. Addressing this systemic challenge requires not only faster contaminant-specific action but reforms to the adaptive management mechanism within the UKMS to permit between-cycle review and intervention.

4. Unresolved N:P imbalance and catchment lag times for eutrophication

Greater regulatory success in reducing phosphorus than nitrogen has created long-term structural changes to North Sea nutrient ratios with potential for altered phytoplankton community composition and trophic cascades that may reduce the nutritional quality of primary producers and shift community structure towards gelatinous predators. Even where nitrogen reduction targets are now being met at source, the lag between catchment management interventions and coastal marine outcomes, which can be a decade or more for large estuarine systems, means that eutrophication pressures will persist for years to decades beyond the point of regulatory intervention.

5. Post-Brexit divergence and the weakening of the precautionary approach

UK chemicals regulation is diverging from the more precautionary EU trajectory, particularly for PFAS and EDCs , although Northern Ireland remains subject to EU REACH under the Windsor Framework and is therefore not subject to the same divergence. In shared sea areas, this risks different levels of environmental protection on either side of the same water body and complicates transboundary contamination management. The OSPAR Convention provides a partial buffer but does not resolve divergence at the operational standards level. As the EU raises protection standards for emerging contaminants, the relative contamination burden in UK marine waters from Great Britain's sources risks increasing compared to what would occur under maintained regulatory alignment.

5.5 Uncertainties and confidence assessment

The confidence in the principal findings of this review is high for established contaminant groups (metals, PCBs, PBDEs, nutrients) where a substantial and consistent body of peer-reviewed evidence and OSPAR Quality Status assessments is available. Confidence is moderate for marine litter and eutrophication, where GES assessment frameworks exist but monitoring coverage is variable and climate change projections add uncertainty to future trajectories. Confidence is lower for emerging contaminants, reflecting the genuinely early state of evidence on marine-specific toxicity, mixture effects, and marine fate for PFAS, pharmaceuticals, and novel plastic additives.

The regulatory conclusions are grounded in primary legislative and policy analysis and are considered robust, with the principal area of uncertainty being enforcement effectiveness, where published data may not fully reflect operational practice. The rapidly evolving regulatory context, including the publication of the national PFAS Plan (February 2026), enactment of the Water (Special Measures) Act 2025, and ongoing OSPAR review of microplastic assessment criteria, means that some conclusions may require updating as new evidence and regulatory developments emerge.

6 References

Alldred, F.C., Gröcke, D.R., Leung, C.Y., Wright, L.P. and Banfield, N., 2023. Diffuse and concentrated nitrogen sewage pollution in island environments with differing treatment systems. *Scientific Reports*, 13(1), p.4838. https://doi.org/10.1038/s41598-023-32105-6.

Hannah Anderson, 2024. *Status and trends in the levels of imposex in marine gastropods indicator assessment for the UK Marine Strategy*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/imposex/> [Accessed 2 April 2026].

Ankley, G.T., Berninger, J.P., Blackwell, B.R., Cavallin, J.E., Collette, T.W., Ekman, D.R., Fay, K.A., Feifarek, D.J., Jensen, K.M., Kahl, M.D., Mosley, J.D., Poole, S.T., Randolph, E.C., Rearick, D., Schroeder, A.L., Swintek, J. and Villeneuve, D.L., 2021. Pathway-Based Approaches for Assessing Biological Hazards of Complex Mixtures of Contaminants: A Case Study in the Maumee River. *Environ Toxicol Chem*, 40(4), pp 1098-1122. doi: 10.1002/etc.4949.

Ankley, G.T., Cureton, P., Hoke, R.A., Houde, M., Kumar, A., Kurias, J., Lanno, R., McCarthy, C., Newsted, J., Salice, C.J., Sample, B.E., Sepúlveda, M.S., Steevens, J. and Valsecchi, S., 2020. Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. *Environmental Toxicology and Chemistry*, 40(3), pp.564–605. https://doi.org/10.1002/etc.4869.

Axe, P., Sonesten, L. and Skarbovik, E., 2022. *Inputs of Nutrients to the OSPAR Maritime Area*. [online] The 2023 Quality Status Report for the North-East Atlantic. Available at: <https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/inputs-nutrients/> [Accessed 16 February 2026].

Axe, P., Sonesten, L., Skarbovik, E., Pirntke, U., Berbee, E. and Christensen, A.M., 2023. *Inputs of Mercury, Cadmium and Lead via Water and Air to the OSPAR Maritime Area In: Quality Status Report 2023*. OSPAR.

Balkoni, A., Boersma, M., Sidorenko, V., De Amorim, F.D.L.L., Sarker, S., Spence-Jones, H.C., Rick, J.J., Van Beusekom, J.E.E. and Wiltshire, K.H., 2026. Long-Term Effects of Nutrient Shifts and Warming on Chlorophyll-a in a Temperate Coastal Environment. *Estuaries and Coasts*, 49(1), p.13. https://doi.org/10.1007/s12237-025-01620-2.

Barber, J., 2024a. *Status and trends of Metals (cadmium, lead and mercury) in biota and sediment*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/metals-in-sediment-and-biota/> [Accessed 12 February 2026].

Barber, J., 2024b. *Status and Trends of Polybrominated diphenylethers (PBDEs) in Biota and Sediment*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/pbdes-in-sediment-and-biota/> [Accessed 12 February 2026].

Bishop, G., Styles, D. and Lens, P.N.L., 2020. Recycling of European plastic is a pathway for plastic debris in the ocean. *Environment International*, 142, p.105893. https://doi.org/10.1016/j.envint.2020.105893.

Brand, J.H., Spencer, K.L., O'shea, F.T. and Lindsay, J.E., 2018. Potential pollution risks of historic landfills on low-lying coasts and estuaries. *WIREs Water*, 5(1), p.e1264. https://doi.org/10.1002/wat2.1264.

Breuer, E., Stevenson, A.G., Howe, J.A., Carroll, J. and Shimmield, G.B., 2004. Drill cutting accumulations in the Northern and Central North Sea: a review of environmental interactions and chemical fate. *Marine Pollution Bulletin*, 48(1–2), pp.12–25. https://doi.org/10.1016/j.marpolbul.2003.08.009.

Brown, A.R., Lilley, M., Shutler, J., Lowe, C., Artioli, Y., Torres, R., Berdalet, E. and Tyler, C.R., 2020. Assessing risks and mitigating impacts of harmful algal blooms on mariculture and marine fisheries. *Reviews in Aquaculture*, 12(3), pp.1663–1688. https://doi.org/10.1111/raq.12403.

Burson, A., Stomp, M., Akil, L., Brussaard, C.P.D. and Huisman, J., 2016. Unbalanced reduction of nutrient loads has created an offshore gradient from phosphorus to nitrogen limitation in the North Sea. *Limnology and Oceanography*, 61(3), pp.869–888. https://doi.org/10.1002/lno.10257.

Camille Lacroix, Silvère André, and Willem van Loon, 2022. *Abundance, Composition and Trends of Beach Litter: Common Indicator Assessment*. [online] London: OSPAR Comission. Available at: <https://www.researchgate.net/profile/Willem-Mgm-Loon/publication/365433764_Abundance_Composition_and_Trends_of_Beach_Litter_In_OSPAR_2023_The_2023_Quality_Status_Report_for_the_North-East_Atlantic_OSPAR_Commission_London/links/6374e2b02f4bca7fd06675ee/Abundance-Composition-and-Trends-of-Beach-Litter-In-OSPAR-2023-The-2023-Quality-Status-Report-for-the-North-East-Atlantic-OSPAR-Commission-London.pdf>.

Cave, R., Ledoux, L., Turner, K., Jickells, T., Andrews, J. and Davies, H., 2003. The Humber catchment and its coastal area: from UK to European perspectives. *The Science of The Total Environment*, 314–316, pp.31–52. https://doi.org/10.1016/S0048-9697(03)00093-7.

Cave, R.R., Andrews, J.E., Jickells, T. and Coombes, E.G., 2005. A review of sediment contamination by trace metals in the Humber catchment and estuary, and the implications for future estuary water quality. *Estuarine, Coastal and Shelf Science*, 62(3), pp.547–557. https://doi.org/10.1016/j.ecss.2004.09.017.

Corcoran, P.L., 2015. Benthic plastic debris in marine and fresh water environments. *Environmental Science: Processes & Impacts*, 17(8), pp.1363–1369. https://doi.org/10.1039/C5EM00188A.

Craig, L.S., Palmer, M.A., Richardson, D.C., Filoso, S., Bernhardt, E.S., Bledsoe, B.P., Doyle, M.W., Groffman, P.M., Hassett, B.A., Kaushal, S.S., Mayer, P.M., Smith, S.M. and Wilcock, P.R., 2008. Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment*, 6(10), pp.529–538. https://doi.org/10.1890/070080.

Defra, 2025. *UKMS Part One Update Consultation Document 2025 (FINAL)*. [Consultation document] Available at: <https://consult.defra.gov.uk/uk-marine-strategy-1/uk-marine-strategy-part-one-update-2025/supporting_documents/UK%20Marine%20Strategy%20Part%20One%20Update%20consultation%20June%202025.pdf> [Accessed 12 February 2026].

Defra, 2025b, *Environmental Indicator Framework Theme J (Resource Use and Waste).* [online] Defra. Available at: Available at: https://www.gov.uk/government/publications/environmental-indicator-framework-theme-j-resource-use-and-waste/environmental-indicator-framework-theme-j-resource-use-and-waste#j6-waste-crime

Defra (2016). *Implementation of the Nitrate Pollution Regulations 2015 in England: Method for designating Nitrate Vulnerable Zones for waters affected by eutrophication*. (December 2016). [online] Marine Online Assessment Tool. Available at: Method for designating Nitrate Vulnerable Zones for waters affected by eutrophication. [Accessed 8 April 2026].

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin*, 44(9), pp.842–852. https://doi.org/10.1016/S0025-326X(02)00220-5.

Devlin, M., Graves, C., Greenwood, N., Brooks, R., Best, M., Napier, F., Harrison, T. and Charlesworth, M., 2024. *Eutrophication*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/eutrophication/> [Accessed 26 January 2026].

Devlin, M.J., Prins, T.C., Enserink, L., Leujak, W., Heyden, B., Axe, P.G., Ruiter, H., Blauw, A., Bresnan, E., Collingridge, K., Devreker, D., Fernand, L., Gómez Jakobsen, F.J., Graves, C., Lefebvre, A., Lenhart, H., Markager, S., Nogueira, M., O'Donnell, G., Parner, H., Skarbøvik, E., Skogen, M.D., Sonesten, L., Van Leeuwen, S.M., Wilkes, R., Dening, E. and Iglesias-Campos, A., 2023. A first ecological coherent assessment of eutrophication across the North-East Atlantic waters (2015–2020). *Frontiers in Ocean Sustainability*, 1, p.1253923. https://doi.org/10.3389/focsu.2023.1253923.

Dvory, N.Z., Livshitz, Y., Kuznetsov, M., Adar, E., Gasser, G., Pankratov, I., Lev, O. and Yakirevich, A., 2018. Caffeine vs. carbamazepine as indicators of wastewater pollution in a karst aquifer. *Hydrology and Earth System Sciences*, 22(12), pp.6371–6381. https://doi.org/10.5194/hess-22-6371-2018.

Environment Agency, 2021. *Poly- and perfluoroalkyl substances (PFAS): sources, pathways and environmental data*.

Environment Agency, 2019. *River Basin Management Plan 2021*. UK Government / Environment Agency.

Environment Agency, 2019b *Mercury: sources, pathways, and environmental data.* Available at: https://consult.environment-agency.gov.uk/environment-and-business/challenges-and-choices/user_uploads/mercury-pressure-rbmp-2021.pdf

European Environment Agency, 2025. *Hazardous substances in marine organisms in Europe's seas*. [online] Available at: <https://www.eea.europa.eu/en/analysis/indicators/hazardous-substances-in-marine-organisms> [Accessed 16 February 2026].

Fair, P.A. and Houde, M., 2018. Poly-and perfluoroalkyl substances in marine mammals. *Marine Mammal Ecotoxicology*, pp.117–145. https://doi.org/%2010.1016/B978-0-12-812144-3.00005-X.

Ferrante, M., Napoli, S., Grasso, A., Zuccarello, P., Cristaldi, A. and Copat, C., 2019. Systematic review of arsenic in fresh seafood from the Mediterranean Sea and European Atlantic coasts: A health risk assessment. *Food and Chemical Toxicology*, 126, pp.322–331. https://doi.org/10.1016/j.fct.2019.01.010.

Ford, A.T. and Ginley, F., 2024. Insights into PFAS contaminants before and after sewage discharges into a marine protected harbour. *Chemosphere*, 366, p.143526. https://doi.org/10.1016/j.chemosphere.2024.143526.

Gall, S.C. and Thompson, R.C., 2015. The impact of debris on marine life. *Marine Pollution Bulletin*, 92(1–2), pp.170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041.

Galloway, J.N., Dentener, F.J., Capone, D.G., Boyer, E.W., Howarth, R.W., Seitzinger, S.P., Asner, G.P., Cleveland, C.C., Green, P.A., Holland, E.A., Karl, D.M., Michaels, A.F., Porter, J.H., Townsend, A.R. and Vöosmarty, C.J., 2004. Nitrogen Cycles: Past, Present, and Future. *Biogeochemistry*, 70(2), pp.153–226. https://doi.org/10.1007/s10533-004-0370-0.

Griffith, A.W. and Gobler, C.J., 2020. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. *Harmful Algae*, 91, p.101590. https://doi.org/10.1016/j.hal.2019.03.008.

Groß, E., Di Pane, J., Boersma, M. and Meunier, C.L., 2022. River discharge-related nutrient effects on North Sea coastal and offshore phytoplankton communities. *Journal of Plankton Research*, 44(6), pp.947–960. https://doi.org/10.1093/plankt/fbac049.

Heaton, T.H.E., 1986. Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: A review. *Chemical Geology: Isotope Geoscience section*, 59, pp.87–102. https://doi.org/10.1016/0168-9622(86)90059-X.

Hepburn, E., Madden, C., Szabo, D., Coggan, T.L., Clarke, B. and Currell, M., 2019. Contamination of groundwater with per- and polyfluoroalkyl substances (PFAS) from legacy landfills in an urban redevelopment precinct. *Environmental Pollution*, 248, pp.101–113. https://doi.org/10.1016/j.envpol.2019.02.018.

Hutchinson, P.T.H., 2017. *Future of the Sea: Hazardous chemicals and physical contaminants in the marine environment*. UK Government Office for Science.

Izaak Fryer-Kanssen, 2024. *Contaminant concentrations in seafood - Marine online assessment tool*. [online] Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants-in-seafood/contaminant-concentrations-in-seafood/> [Accessed 11 February 2026].

Joerss, H., Apel, C. and Ebinghaus, R., 2019. Emerging per- and polyfluoroalkyl substances (PFASs) in surface water and sediment of the North and Baltic Seas. *Science of The Total Environment*, 686, pp.360–369. https://doi.org/10.1016/j.scitotenv.2019.05.363.

Jones, B.L., Cullen-Unsworth, L.C. and Unsworth, R.K.F., 2018. Tracking Nitrogen Source Using δ15N Reveals Human and Agricultural Drivers of Seagrass Degradation across the British Isles. *Frontiers in Plant Science*, 9, p.133. https://doi.org/10.3389/fpls.2018.00133.

Kakuschke, A. and Prange, A., 2007. The Influence of Metal Pollution on the Immune System A Potential Stressor for Marine Mammals in the North Sea. *International Journal of Comparative Psychology*, [online] 20(2). https://doi.org/10.46867/IJCP.2007.20.02.07.

Kelly, F.J., Wright, S.L., Woodward, G. and Fussell, J.C., 2025. Plastic pollution under the influence of climate change: implications for the abundance, distribution, and hazards in terrestrial and aquatic ecosystems. *Frontiers in Science*, 3, p.1636665. https://doi.org/10.3389/fsci.2025.1636665.

Kendall, C. and McDonnell, J.J., 2012. *Isotope Tracers in Catchment Hydrology*. Elsevier.

Landsberg, J.H., 2002. The Effects of Harmful Algal Blooms on Aquatic Organisms. *Reviews in Fisheries Science*, 10(2), pp.113–390. https://doi.org/10.1080/20026491051695.

Larsen, M. and Hjermann, D., 2022. *Status and Trends for Heavy Metals (Mercury, Cadmium and Lead) in Fish, Shellfish and Sediment*. [online] Available at: <https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/heavy-metals-biota-sediment/> [Accessed 11 February 2026].

Letsinger, S., Kay, P., Rodríguez-Mozaz, S., Villagrassa, M., Barceló, D. and Rotchell, J.M., 2019. Spatial and temporal occurrence of pharmaceuticals in UK estuaries. *Science of The Total Environment*, 678, pp.74–84. https://doi.org/10.1016/j.scitotenv.2019.04.182.

Levin, L.A., Ekau, W., Gooday, A.J., Jorissen, F., Middelburg, J.J., Naqvi, S.W.A., Neira, C., Rabalais, N.N. and Zhang, J., 2009. Effects of natural and human-induced hypoxia on coastal benthos.

Maier, G., Nimmo-Smith, R.J., Glegg, G.A., Tappin, A.D. and Worsfold, P.J., 2009. Estuarine eutrophication in the UK: current incidence and future trends. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19(1), pp.43–56. https://doi.org/10.1002/aqc.982.

Malzahn, A.M., Aberle, N., Clemmesen, C. and Boersma, M., 2007. Nutrient limitation of primary producers affects planktivorous fish condition. *Limnology and Oceanography*, 52(5), pp.2062–2071. https://doi.org/10.4319/lo.2007.52.5.2062.

Mason et al., 2022. *Reviewing the UK's Action Levels for the Management of Dredged Material.* Geosciences, 12(1), 3. https://doi.org/10.3390/geosciences12010003

Matrix Chambers, 2026, *High court quashes licence for disposal of River Tees dredging.* Available at: https://www.matrixlaw.co.uk/news/high-court-quashes-marine-licence-for-disposal-of-river-tees-dredging/

McKinley, A. and Johnston, E., 2010. Impacts of contaminant sources on marine fish abundance and species richness: a review and meta-analysis of evidence from the field. *Marine Ecology Progress Series*, 420, pp.175–191. https://doi.org/10.3354/meps08856.

Megson, D., Brown, T., Jones, G.R., Robson, M., Johnson, G.W., Tiktak, G.P., Sandau, C.D. and Reiner, E.J., 2022. Polychlorinated biphenyl (PCB) concentrations and profiles in marine mammals from the North Atlantic Ocean. *Chemosphere*, 288, p.132639. https://doi.org/10.1016/j.chemosphere.2021.132639.

Mrozik, W., Rajaeifar, M.A., Heidrich, O. and Christensen, P., 2021. Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. *Energy & Environmental Science,* 14(10), pp 6099-6121. https://doi.org/10.1039/D1EE00691F

Munoz, G., Budzinski, H., Babut, M., Drouineau, H., Lauzent, M., Menach, K.L., Lobry, J., Selleslagh, J., Simonnet-Laprade, C. and Labadie, P., 2017. Evidence for the Trophic Transfer of Perfluoroalkylated Substances in a Temperate Macrotidal Estuary. *Environmental Science & Technology*, 51(15), pp.8450–8459. https://doi.org/10.1021/acs.est.7b02399.

Nadal, M., Marquès, M., Mari, M. and Domingo, J.L., 2015. Climate change and environmental concentrations of POPs: A review. *Environmental Research*, 143, pp.177–185. https://doi.org/10.1016/j.envres.2015.10.012.

National Audit Office, 2022. *Environmental compliance and enforcement*. (National Audit Office, May 2022. HC 243). [online] NOA. Available at: https://www.nao.org.uk/wp-content/uploads/2022/05/Environmental-compliance-and-enforcement.pdf. [Accessed 8 April 2026].

Nicholls, R.J., Beaven, R.P., Stringfellow, A., Monfort, D., Le Cozannet, G., Wahl, T., Gebert, J., Wadey, M., Arns, A., Spencer, K.L., Reinhart, D., Heimovaara, T., Santos, V.M., Enríquez, A.R. and Cope, S., 2021. Coastal Landfills and Rising Sea Levels: A Challenge for the 21st Century. *Frontiers in Marine Science*, [online] 8. https://doi.org/10.3389/fmars.2021.710342.

Nicolaus, E.E.M. and Fryer-Kanssen, I., 2024. *Contaminants in seafood*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants-in-seafood/> [Accessed 26 January 2026].

Nicolaus, E.E.M., Webster, L. and Charlesworth, M., 2024. *Contaminants*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/> [Accessed 26 January 2026].

OEP, 2026. *Progress in improving the natural environment in England 2024/2025*. [online] OEP. Available at: https://www.theoep.org.uk/report/progress-improving-natural-environment-england-20242025. [Accessed 8 April 2026].

OEP, 2025. *Progress in improving the natural environment in England 2023/2024*. [online] OEP. Available at: https://www.theoep.org.uk/report/government-has-chance-get-track-meet-legal-environmental-commitments-window-opportunity. [Accessed 8 April 2026].

Olsvik, P.A., Meier, S., Zhang, X., Goksøyr, A., Karlsen, O.A. and Yadetie, F., 2023. Environmentally realistic concentrations of chlorinated, brominated, and fluorinated persistent organic pollutants induce the unfolded protein response as a shared stress pathway in the liver of Atlantic cod. *Journal of Applied Toxicology*, 43(12), pp.1859–1871. https://doi.org/10.1002/jat.4519.

Opergy Group, 2024. *Evidence Review Report - Drivers and Pressures Affecting the UK Marine Environment*.

O'Rourke, E., Schumacher, M., Charlesworth, M., Andrade, T., Pereira, M.G., Hailer, F. and Chadwick, E., 2026. Increasing concentrations of polychlorinated biphenyls (PCBs) in Eurasian otters (Lutra lutra) from Wales suggest remobilisation from sediment sinks. *Environmental Pollution*, 388, p.127354. https://doi.org/10.1016/j.envpol.2025.127354.

OSPAR, 2006. *Overview Assessment: Implementation of PARCOM Decision 92/3 on the Phasing out of Pcbs and Hazardous PCB Substitutes*. [online] Available at: <https://docslib.org/doc/3476859/implementation-of-parcom-decision-92-3-on-the-phasing-out-of-pcbs-and-hazardous-pcb-substitutes> [Accessed 16 March 2026].

OSPAR, 2023. *Eutrophication Thematic Assessment: QSR 3*. [online] Available at: <https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/thematic-assessments/eutrophication/> [Accessed 2 April 2026].

OSPAR, 2023a. *Eutrophication*. [online] OSPAR Commission. Available at: <https://www.ospar.org/work-areas/hasec/eutrophication> [Accessed 17 February 2026].

OSPAR, 2023b. *Eutrophication: OSPAR's quality status report 2023 briefing note series*.

OSPAR, 2023c. *OSPAR List of Chemicals for Priority Action*. [online] Available at: <https://ospar-archive.s3.eu-west-1.amazonaws.com/DECRECS/AGREEMENTS/04-12e_agreement_list_of_chemicals_for_priority_action_update_2023-24.pdf?X-Amz-Content-Sha256=UNSIGNED-PAYLOAD&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAJIACMW2T5USCSU5A%2F20260316%2Feu-west-1%2Fs3%2Faws4_request&X-Amz-Date=20260316T094449Z&X-Amz-SignedHeaders=host&X-Amz-Expires=900&X-Amz-Signature=4ddce608e58d6b3e8f2be925f6fcc0f58bb843035c7f52730f1d0bc626525442> [Accessed 16 March 2026].

OSPAR, 2026. *Quality Status Report 2023. Synthesis Report. Chapter 7: Preventing pollution to achieve clean seas.* [online] Available at: <https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/synthesis-report/achieving-clean-seas/> [Accessed 15 February 2026]. *PARCOM*. Decision 92/3 on the Phasing out of PCBs and Hazardous PCB Substitutes.

Pawar, P.R., Shirgaonkar, S.S. and Patil, R.B., 2016. Plastic marine debris: Sources, distribution and impacts on coastal and ocean biodiversity.

Rawson, A., Patton, J., Hofmann, W., Pietra, G.G. and Johns, L., 1993. Liver abnormalities associated with chronic mercury accumulation in stranded Atlantic bottle nosed dolphins. *Ecotoxicology and Environmental Safety*, 25, pp.41–47.

Richardson, C.M., Davis, K.L., Ruiz-González, C., Guimond, J.A., Michael, H.A., Paldor, A., Moosdorf, N. and Paytan, A., 2024. The impacts of climate change on coastal groundwater. *Nature Reviews Earth & Environment*, 5(2), pp.100–119. https://doi.org/10.1038/s43017-023-00500-2.

Roberts, D.A., 2012. Causes and ecological effects of resuspended contaminated sediments (RCS) in marine environments. *Environment International*, 40, pp.230–243. https://doi.org/10.1016/j.envint.2011.11.013.

Roman, M.R., Brandt, S.B., Houde, E.D. and Pierson, J.J., 2019. Interactive Effects of Hypoxia and Temperature on Coastal Pelagic Zooplankton and Fish. *Frontiers in Marine Science*, [online] 6. https://doi.org/10.3389/fmars.2019.00139.

Rummel, C.D., Löder, M.G.J., Fricke, N.F., Lang, T., Griebeler, E.-M., Janke, M. and Gerdts, G., 2016. Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine Pollution Bulletin*, 102(1), pp.134–141. https://doi.org/10.1016/j.marpolbul.2015.11.043.

Russell, J., Masani, H., Shears, I., Nicolaus, M. and Clarke, S., 2024. *Marine litter*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/marine-litter/> [Accessed 26 January 2026].

Schiedek, D., Sundelin, B., Readman, J.W. and Macdonald, R.W., 2007. Interactions between climate change and contaminants. *Marine Pollution Bulletin*, 54(12), pp.1845–1856. https://doi.org/10.1016/j.marpolbul.2007.09.020.

Schoo, K.L., Aberle, N., Malzahn, A.M., Schmalenbach, I. and Boersma, M., 2014. The reaction of European lobster larvae (Homarus gammarus) to different quality food: effects of ontogenetic shifts and pre-feeding history. Oecologia, 174(2), pp.581–594. https://doi.org/10.1007/s00442-013-2786-5.

Sheahan, D.A., Brighty, G.C., Daniel, M., Jobling, S., Harries, J.E., Hurst, M.R., Kennedy, J., Kirby, S.J., Morris, S., Routledge, E.J., Sumpter, J.P. and Waldock, M.J., 2002. Reduction in the estrogenic activity of a treated sewage effluent discharge to an english river as a result of a decrease in the concentration of industrially derived surfactants. Environmental Toxicology and Chemistry, 21(3), pp.515–519. https://doi.org/10.1002/etc.5620210307.

Sheahan, D., Maud, J., Wither, A., Moffat, C. and Engelke, C., 2013. Impacts of climate change on pollution (estuarine and coastal). *MCCIP Science Review 2013*, p.8 pages. https://doi.org/10.14465/2013.ARC25.244-251.

Shlosberg, A., Bellaiche, M., Regev, S., Gal, R., Brizzi, M., Hanji, V., Zaidel, L. and Nyska, A., 1997. Lead toxicosis in a captive bottlenose dolphin (Tursiops truncatus) consequent to ingestion of air gun pellets. *Journal of Wildlife Diseases*.

Siebert, U., Joiris, C., Holsbeek, L., Benke, H., Failing, K. and Petzinger, E., 1999. Potential relation between mercury concentrations and necropsy findings in cetaceans from German waters of the North and Baltic Seas. *Marine Pollution Bulletin*, 38, pp.285–295.

Siems, A., Zimmermann, T., Sanders, T. and Pröfrock, D., 2024. Dissolved trace elements and nutrients in the North Sea—a current baseline. *Environmental Monitoring and Assessment*, 196(6), p.539. https://doi.org/10.1007/s10661-024-12675-2.

Stockdale, A., Tipping, E., Lofts, S. and Mortimer, R.J.G., 2016. Effect of Ocean Acidification on Organic and Inorganic Speciation of Trace Metals. *Environmental Science & Technology*, 50(4), pp.1906–1913. https://doi.org/10.1021/acs.est.5b05624.

Sun, J., Xing, L. and Chu, J., 2023. Global ocean contamination of per- and polyfluoroalkyl substances: A review of seabird exposure. *Chemosphere*, 330, p.138721. https://doi.org/10.1016/j.chemosphere.2023.138721.

Tett, P., Gowen, R., Mills, D., Fernandes, T., Gilpin, L., Huxham, M., Kennington, K., Read, P., Service, M., Wilkinson, M. and Malcolm, S., 2007. Defining and detecting undesirable disturbance in the context of marine eutrophication. *Marine Pollution Bulletin*, 55(1–6), pp.282–297. https://doi.org/10.1016/j.marpolbul.2006.08.028.

Thompson, P.R.C., 2017. *Future of the Sea: Plastic Pollution*. UK Government Office for Science.

Tornero, V. and Hanke, G., 2016. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. *Marine Pollution Bulletin*, 112(1–2), pp.17–38. https://doi.org/10.1016/j.marpolbul.2016.06.091.

Troost, T.A., Desclaux, T., Leslie, H.A., Van Der Meulen, M.D. and Vethaak, A.D., 2018. Do microplastics affect marine ecosystem productivity? *Marine Pollution Bulletin*, 135, pp.17–29. https://doi.org/10.1016/j.marpolbul.2018.05.067.

UK Climate Change Committee, 2020. *Policy framework for deep emissions reductions and carbon removals in agriculture and land use in the UK*. https://www.theccc.org.uk/wp-content/uploads/2020/01/Vivid-Economics-and-ADAS-2020-Policy-framework-for-deep-emissions-reductions-and-carbon-removals-in-agriculture-and-land-use-in-the-UK.pdf

Van Den Heuvel-Greve, M.J., Schotanus, J., Kotterman, M.J., Kwadijk, C.J.A.F., Brasseur, S.M.J.M., Leopold, M., Van Zwol, J., Van Den Ende, D., Cornelisse, S.A., De Froe, E. and Foekema, E., 2024. *Exposure and Magnification of Pfas in a Temperate Estuarine Food Web, Including Top Predators*. https://doi.org/10.2139/ssrn.5073708.

Wang, Q., Shao, Y., Leung, K.M.Y., Lam, P.K.S. and Ruan, Y., 2025. Per- and polyfluoroalkyl substances (PFAS) in the marine environment: An overview and prospects. *Marine Pollution Bulletin*, 216, p.117993. https://doi.org/10.1016/j.marpolbul.2025.117993.

Webster, L., 2024. *Status and trends of Polychlorinated Biphenyls (PCBs) in biota and sediment*. [online] Marine Online Assessment Tool. Available at: <https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/pcbs-in-sediment-and-biota/> [Accessed 12 February 2026].

Wang, X., Zhu, Q., Yan, X., Wang, Y., Liao, C. and Jiang, G., 2020. A review of organophosphate flame retardants and plasticizers in the environment: Analysis, occurrence and risk assessment. *Science of The Total Environment*, 731, p.139071. https://doi.org/10.1016/j.scitotenv.2020.139071.

Wu, Y., Jin, R., Chen, Q., Du, X., Yang, J. and Liu, M., 2023. Organic contaminants of emerging concern in global estuaries: Environmental occurrence, fate, and bioavailability. *Critical Reviews in Environmental Science and Technology*, 53(4), pp.550–575. https://doi.org/10.1080/10643389.2022.2077062.

Wurl, O. and Obbard, J.P., 2004. A review of pollutants in the sea-surface microlayer (SML): a unique habitat for marine organisms. *Marine Pollution Bulletin*, 48(11–12), pp.1016–1030. https://doi.org/10.1016/j.marpolbul.2004.03.016.

Zapata-Restrepo, L.M., Bawden, K., Sidaoui-Haddad, G., Spencer, E., Williams, I.D. and Hudson, M., 2025. Microplastics in the European native oyster, Ostrea edulis, to monitoring pollution-related patterns in the Solent region (United Kingdom). *Environmental Monitoring and Assessment*, 197(5), p.544. https://doi.org/10.1007/s10661-025-13975-x.

Zhang, Y. and Geißen, S.-U., 2010. Prediction of carbamazepine in sewage treatment plant effluents and its implications for control strategies of pharmaceutical aquatic contamination. *Chemosphere*, 80(11), pp.1345–1352. https://doi.org/10.1016/j.chemosphere.2010.06.030.

Annex 1 List of attachments

Attachment 1: Literature synthesis matrix (Excel)

Attachment 2: Regulatory Catalogue (Excel)

icf.com

twitter.com/ICF
linkedin.com/company/icf-international
facebook.com/ThisIsICF
#thisisicf

About ICF

ICF (NASDAQ:ICFI) is a global consulting and digital services company with over 9,000 full- and part-time employees, but we are not your typical consultants. At ICF, business analysts and policy specialists work together with digital strategists, data scientists and creatives. We combine un-matched industry expertise with cutting-edge engagement capabilities to help organisations solve their most complex challenges. Since 1969, public and private sector clients have worked with ICF to navigate change and shape the future. Learn more at icf.com.