Department
for Environment
Food & Rural Affairs

Assessing Current Evidence of Potential Impacts of Plastic on Marine Protected Species & Habitats in England & Wales

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April 2020

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Funded/commissioned by:
This project was funded by the Department for Environment Food and Rural Affairs (Defra), Marine and Fisheries Directorate, and commissioned by the Marine Biodiversity Impacts Evidence Group (MBIEG). The MBIEG was established in March 2014 to co-ordinate evidence collection concerning impacts of human activities. Membership of the MBIEG at the time of publication is Defra, Welsh Government, Natural England, the Centre for Environment, Fisheries and Aquaculture Science (Cefas), Environment Agency, the Inshore Fisheries and Conservation Authority (IFCA), the Joint Nature Conservation Committee (JNCC), Natural Resources Wales (NRW) and the Marine Management Organisation (MMO).

This publication is available at
http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20481&FromSearch=Y&Publisher=1&SearchText=ME6027&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

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This report should be cited as

MBIEWG (2020). Assessing Current Evidence of Potential Impacts of Plastic on Marine Protected Species & Habitats in England & Wales. A report produced by ABPmer for Marine Biodiversity Impacts Evidence Group members: Department for Environment, Food and Rural Affairs, Natural England, Natural Resources Wales, the Marine Management Organisation, the Joint Nature Conservation Committee and Centre of Environment, Fisheries and Aquaculture Science, Project No: ME6027, 77pp

Summary

The statutory nature conservation bodies (SNCBs): Natural England, The Joint Nature Conservation Committee (JNCC) and Natural Resources Wales (NRW), identified an evidence gap regarding the impact of plastic litter on on protected species & habitats in England & Wales. Plastic litter is widespread throughout the marine environment. In recent routine benthic survey work in twenty-two Marine Protected Areas (MPAs) across English inshore waters, Natural England found microplastic particles in all study sites and in 61.2% of the samples collected.

ABPmer was commissioned by the Department for Environment, Food and Rural Affairs' (Defra's) Marine Biodiversity Impact Evidence Group (MBIEG), to synthesise available information to better understand impact of plastic pollution on protected species and habitats. This involved a literature review to identify the potential impacts of marine plastic on the the English and Welsh inshore and offshore protected habitats and species. A prioritisation of habitats and species was also undertaken to highlight those most at risk from plastic litter.

The Marine Protected Area network comprises several types of designated sites (Marine Conservation Zones, European marine sites, SSSIs with marine features and Ramsar sites) which collectively contribute to the conservation or improvement of the marine environment. The features (habitats and species) protected by the sites, represent the range of features present in the UK marine area, so a proportion of their number/area are protected within sites and the remainder are found in the wider seas. This work reviewed current published scientific evidence on the impacts of plastic on these protected habitats and species wherever they occur.

In summary, the aims and objectives of the project were to:

- Complete a comprehensive literature review of the available evidence on the impact of marine plastics on English and Welsh protected habitats and species.
    - Collate key characterising species (habitat sub-features) of biotopes and associated habitat features that occur in England and Wales, as well as species and bird features
    - Using an agreed search methodology, summarise the available evidence on the impact of marine plastics on protected habitats and species
    - Conduct a gap analysis to highlight gaps in the available evidence on the impact of marine plastics on protected habitats and species
- Assess the potential for impact from marine plastics on protected habitat features, habitat sub-features, species features and bird features and assign a confidence to the impact assessment
- Undertake a prioritisation exercise to identify habitat and species features most at risk from marine plastic pollution; and
    - Identify features with the highest potential for impact from marine plastics to indicate the relative priority of each feature for monitoring and conservation efforts.

A spreadsheet accompanying this report provides detailed information on the literature review and assessment of the potential for impact of marine plastics on each habitat feature, habitat sub-feature, species feature and bird feature. The Evidence Spreadsheet is available from the Defra website alongside this report (R3339_Evidence Spreadsheet_Impact Marine Plastics on protected Hab_sp_28Apr2020).

A total of 326 unique references were gathered and reviewed as part of this project. Based on this currently available evidence, the highest potential for impact on any habitat feature, sub-feature, species or bird feature is considered to be 'medium'.
For those habitats and species which are considered to have a 'Medium' potential for impact, this means that generally either:

- Sub-lethal effects on species were found in the environment or at environmental concentrations following exposure to plastic;
- Effects on species from marine plastic have been observed in the environment at the species level (i.e. there is no evidence of population level effects); or
- There is some evidence of altered habitat functioning due to marine plastic.

This suggests that marine plastic pollution is unlikely to pose a high risk to protected species and habitats in England and Wales at concentrations of plastic that can be considered environmentally realistic**.** Future research may uncover greater or lesser impacts from sublethal effects or ingestion, and results are therefore based on best available contemporary knowledge only. Smaller marine organisms (such as fish and invertebrates) are exposed to smaller plastic particles (microplastics and nanoplastics) and have been shown to exhibit biological effects. However, lethal effects are rarely observed, and where they are, the plastic concentrations tested tend to far exceed environmental relevance. Larger marine species (such as birds and marine mammals) are more vulnerable to larger plastic debris that they may ingest or become entangled with. However, no evidence suggests that this physical impact is having population level effects. Similarly, whilst studies suggest some potential effects on habitat functioning, the decline of habitats due to plastic pollution is not evidenced, although it poses an additional cumulative anthropogenic pressure and gradual decline in habitats is difficult to attribute to a particular single pressure.

It is important to note that the issue of marine plastics is a relatively new topic in scientific research, and it can be argued that the impact and effects of plastics in the environment are currently relatively poorly understood. This is exemplified by the gap analysis undertaken as part of this evidence review where the majority of habitats and species had either none, or limited evidence on the impact of marine plastics. Equally, there is generally a low to medium confidence in the assessment of the potential for impact. Furthermore, the assessment of the potential for impact is exclusively based on the evidence available for the species or habitat. As such, it does not account for effects, impact pathways or plastic types, shapes or sizes that are not documented in the available evidence, even if they could be considered feasible or important.

Plastic in the marine environment will also continue to increase (possibly quite rapidly) and degrade into smaller plastic particles, increasing exposure to marine organisms. Long-term risks or sub-lethal impacts of exposure to plastics are also particularly uncertain at the current time, and the persistent nature of plastic means exposure would be continuous throughout all life stages and would not decrease in the environment. Therefore, the findings of this review should be interpreted with an appropriate degree of caution, and it is recommended that this report and the accompanying Evidence Spreadsheet are kept under regular review to keep pace with emerging issues and research.

Contents

Supplementary Spreadsheet (provided separately)

R3339_Evidence Spreadsheet_Impact of Marine Plastics on MPAs_28Apr2020.xlsm

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1 Introduction

The statutory nature conservation bodies (SNCBs), Natural England, The Joint Nature Conservation Committee (JNCC) and Natural Resources Wales (NRW), have identified an evidence gap regarding the impact of plastic litter on protected species & habitats in England & Wales. In recent standard benthic survey work in twenty-two MPAs across English inshore waters, Natural England found microplastic particles in all study sites and in 61.2% of the samples collected, with mean density per study site ranging from 0.2 – 42.7 microplastic particles per 0.1 m² (Green and Johnson, 2020). High densities of plastic were found at remote sites, as well as those closer to urban or industrialised areas. It was noted in this study and across the wider marine evironment

As of June 2019, 25% of UK waters are protected as part of a network of MPAs (JNCC, 2019). There are 355 MPAs across the UK, of these 115 are Special Areas of Conservation (SACs) with marine components, 112 Special Protection Areas (SPAs) for coastal/marine bird species and their supporting habitats and 128 Marine Conservation Zones (MCZs) which includes 31 Nature Conservation MPAs in Scottish waters. The features (habitats and species) protected by the sites, represent the range of features present in the UK marine area, so a proportion of their number/area are protected within sites and the remainder are found in the wider seas. Although the presence of litter in the marine environment is known, there is a lack of information on the impact of plastic litter on protected habitats and species found within and outside of the MPA network.

ABPmer was commissioned by the Department for Environment, Food and Rural Affairs (Defra) Marine Biodiversity Impact Evidence Group (IEG), to synthesise available information to better understand impacts on protected species and habitatsfrom plastic pollution. This involved a literature review to identify the potential impact of marine plastic on the protected habitats and features found in English and Welsh inshore and offshore waters. A prioritisation of habitats and features was also undertaken to highlight those most at risk from plastic litter based upon the evidence collated in the literature review.

The project steering group (PSG) comprised Natural England, the JNCC, NRW, and the Marine Management Organisation (MMO).

In summary, the aims and objectives of the project were to:

- Complete a comprehensive literature review of the available evidence on the impact of marine plastics on English and Welsh protected habitats and species
  - Collate key characterising species (habitat sub-features) of biotopes and associated habitat features that occur in England and Wales, as well as species and bird features
  - Using an agreed search methodology, find and summarise the available evidence on the impact of marine plastics on protected habitats and species
  - Conduct a gap analysis to highlight gaps in the available evidence on the impact of marine plastics on protected habitats and species
- Assess the potential for impact from marine plastics on habitat features, habitat sub-features, species features and bird features and assign a confidence to the impact assessment
- Undertake a prioritisation exercise to identify habitat and species features most at risk from marine plastic pollution; and
  - Identify features with the highest potential for impact from marine plastics to indicate the sensitivity of important protected habitats and species affected by plastic pollution.

This report is structured as follows:

Section 2: Approach and methodology – explanation of the methods used to review the literature, assess the potential for impact and undertake the prioritisation exercise.
Section 3: Potential for impact – synthesis of the findings of the literature review and results of the impact assessment.
Section 4: Prioritisation exercise –habitat, species and bird features considered most at risk from marine plastic pollution based on the available evidence.
Section 5: Evidence gaps – identification of gaps in evidence and recommendations for further investigation.
Section 6: Conclusion – a summary of the key findings of the review.

A spreadsheet accompanying this report provides detailed information on the literature review and assessment of the potential for impact of marine plastics on each MPA habitat feature, habitat sub-feature, species feature and bird feature. The Evidence Spreadsheet is available from the Defra website alongside this report (R3339_Evidence Spreadsheet_Impact Marine Plastics on protected Hab_sp_28Apr2020).

2 Approach and Methodology

In order to provide information on the potential impact of plastic litter on protected marine habitats and species, a literature review and impact assessment was undertaken. This was focussed on capturing information on each habitat and species in, as well as a review of key characterising species that are found within the selected habitats. (see Section 2.1.1).

The results of the evidence review are presented in an Evidence Spreadsheet that accompanies this report. This Evidence Spreadsheet forms a standardised and searchable evidence base in which information was recorded from the literature review. Based on the available evidence (see Section 2.1.3), the potential for marine plastic pollution to impact each habitat and species was assessed, and this is also presented in the Evidence Spreadsheet.

Details of the information recorded within the Evidence Spreadsheet and the methodology used to search for literature are described in Sections 2.1.1 and 2.1.2, respectively. The approach to the impact assessment is presented in Section 2.1.3.

The key themes found in the literature are discussed in this report, as well as the overarching results from the impact assessment (Section 3). These are structured per species or habitat group (see Section 2.1.1). Following the literature review and impact assessment, the protected habitat and species features were prioritised based on their potential for impact. The approach to this is described in Section 2.2, and the results are presented within this report (Section 4).

The evidence gaps arising from the literature review are also discussed in Section 5 of this report (as well as being documented in the Evidence Spreadsheet), to highlight areas that should be targeted for further investigation. The methodology for the gap analysis is explained in Section 2.1.1

2.1 Literature review and impact assessment

2.1.1 Recorded information

The Evidence Spreadsheet provides a fully searchable and interactive documentation of the evidence that was found during the literature review. Within the Evidence Spreadsheet, key pieces of information gathered from the literature are recorded and categorised alongside the evidence to facilitate interrogation of the spreadsheet and understanding of the literature. A search function is also included in the Evidence Spreadsheet. This allows the user to search the evidence with the use of key words to examine information of particular interest for a specific application (e.g. searching for the key word 'leachate' will return literature that discusses how plastic leachates may impact species or habitats).

The Evidence Spreadsheet is divided between habitat features, species features, bird features, and habitat sub-features. The information included in each worksheet is broadly the same. The habitat sub-features worksheet differs slightly as the key characterising species that are found within biotopes making uphabitats were reviewed. Therefore, additional signposting is provided alongside the evidence and recorded information to indicate the habitats that relate to the key characterising species. Furthermore, there is an additional filtering tool (as well as the search function) which allows the user to separate the habitat sub-features per habitat feature in which they may occur.

Protected geological features in England and Wales were also included in the literature review. However, no evidence relevant to plastic impacts was found. Therefore, geological features were removed from the Evidence Spreadsheet and are not discussed further in this report.

A full description of the information recorded and how it has been categorised is provided in the Evidence Spreadsheet. A description is also summarised below.

Species and habitat groups

Within each worksheet, a '**species group**' or '**habitat group**' was listed against each protected feature (or characterising species within habitat sub-features). These groupings are to facilitate the presentation and understanding of information and are also used in Sections 3 and 4 where a synthesis of the findings is presented. A list of the habitat and species groups is provided in Table 1, and the protected features which are included within them are detailed in the Evidence Spreadsheet accompanying this report.

Table 1. Groupings of habitat features, habitat sub-features, species features and bird features

Habitat features	Habitat sub-features	Species features	Bird features
Dunes Physiographic habitats Reef Rock Saltmarsh Sediment Vegetated sediment	Angiosperm Anthozoan Ascidian Bacteria Brachiopod Bryozoan Cephalochordates Crustacean Echinoderm Foraminifera Hydrozoan Lichen Macroalgae Maerl Microalgae Mollusc Oligochaete Polychaete Sponge	Anthozoan Cnidarian Crustacean Fish Macroalgae Marine mammal Mollusc Plant Polychaete	Accipitriformes Anseriformes Caprimulgiformes Charadriiformes Gaviiformes Passeriformes Pelecaniformes Podicipediformes Procellariiformes Suliformes

Plastic size, shape and type

The '**plastic size**' for which there is evidence was categorised. The definitions used are based on a range of literature, including litter descriptors in the MSFD described by Galgani *et al.* (2013), Gigault *et al.* (2018), and GESAMP (2016). The use of plastic size categories is principally to assist the reporting of impacts, and interrogation of the Evidence Spreadsheet; the specific size ranges of plastics studied within the literature have also been recorded in the evidence. The definitions of each size of plastic are presented in Table 2. It should be noted that 'mesoplastic' and 'megaplastic' are lesser used terms in the general literature, and often 'macroplastic' is defined as sizes above 5 mm.

Table 2. Plastic size and definitions

Plastic size	Definition	References
Megaplastic	Greater than 1 m	GESAMP (2016)
Macroplastic	Between 2.5 cm and 1 m	GESAMP (2016)
Mesoplastic	Between 5 mm and 2.5 cm	GESAMP (2016)
Microplastic	Between 1 µm and 5 mm	GESAMP (2016); Galgani *et al.* (2013)
Nanoplastic	Between 1 nm and 1 µm	Gigault *et al.* (2018)
Unknown	Plastic size unknown, not reported, or not studied	n/a
None	No evidence of plastic found in literature	n/a

The '**plastic shape**' studied in the literature, as well as the '**plastic type**', were recorded. The definitions of plastic shape are presented in Table 3, whilst the plastic types examined in the literature are listed in the accompanying Evidence Spreadsheet.

Table 3. Plastic shape and definitions

Plastic shape	Definition
Irregular fragments	Irregularly shaped pieces of mesoplastic, microplastic or nanoplastic generally derived from the breakdown of larger pieces of plastics
Fibrous	Fibrous or filamentous pieces of mesoplastic, microplastic or nanoplastic (e.g. synthetic fibres derived from textiles industry)
Spherical	Spherical pieces of mesoplastic, microplastic or nanoplastic that are characterised by round, smooth surfaces (e.g. beads associated with cosmetic products, or resin pellets used in plastic manufacturing)
Linear	Macroplastic and megaplastic that are elongated in shape (e.g. fishing lines, ropes or nets)
General debris	Macroplastics and megaplastics that are of varying shape (e.g. plastic bags, bottles, packaging)
Various	Mixture of plastic shapes but not explicitly stated in literature
Unknown	Plastic shape unknown, not reported, or not studied
None	No evidence of plastic found in literature

Impact pathways

Whilst searching through the literature, the '**impact pathway**' described was categorised and recorded in the Evidence Spreadsheet, and is also presented in Sections 3.2 to 3.6. This is in order to assist the understanding of the pathways by which impacts may occur for each species or habitat. However, this does not necessarily imply that other impact pathways are not relevant, just that they have not been described or examined in the available literature for that feature. To address this, impact pathways that are 'theoretically possible but with no direct evidence available' in the literature reviewed for a particular MPA feature are differentiated from those that are 'unlikely to be relevant and with no direct evidence available' in this report. Further discussion on impact pathways is provided in Section 3.2. The impact pathway categories and their definitions are shown in Table 4.

Table 4. Impact pathways and definitions

Impact pathways	Definition
Ingestion	Ingestion of plastic that may lead to suffocation, satiation, starvation, or mechanical damage to digestive system
Toxicity	Toxic effects caused by chemicals released from or adhered to plastic
Entanglement	Entanglement of species in plastic that may result in drowning, injuries, or compromised movement and feeding
Smothering, abrasion, or dislodgement	Blanketing effects and damage to species/habitats caused by the rubbing of plastics over its surface
Substrate change	Change to habitat functioning due to presence of plastic in sediments, or on the shore or seabed
Habitat provision[1]	Settling of (mainly) sessile organisms on plastic debris that may result in increased distributions of species, or use of plastic material in habitat building (e.g. nests)
Unknown	Impact pathways are not examined in the evidence
None	No evidence of any impact pathway found in literature

Evidence and impact assessment

Information on the '**study type**' provided in the Evidence Spreadsheet identifies whether research was undertaken in a laboratory or field environment, whether it is a review of literature, or if it is evidence presented as an aside to another piece of research.

Where it is noted in the literature, information on '**environmental concentrations**' of plastic in the marine environment was recorded. This helped with the impact assessment as definitions include reference to environmental concentrations (see Section 2.1.3) and may also be useful for future applications of this work. Key references found are presented in Table 8 in Section 3.1.1.

A synthesis of the '**evidence**' is provided in the Evidence Spreadsheet, which provides the basis on which to assess the potential for impact on MPA features. This is also summarised in Section 3 of this report.

A '**gap analysis**' was also incorporated into the Evidence Spreadsheet, and highlights where gaps in the evidence exist based on the searches undertaken. The use of the definitions 'No evidence', 'Limited evidence' and 'Multiple evidence' describe the quantity of evidence and are mutually exclusive, whereas 'Proxy evidence', 'No UK evidence' and 'Conflicting evidence' are used to describe the type and quality of evidence and are compatible with any definition except 'No evidence'.

The definitions of the categories used in the gap analysis are presented in Table 5. The outcomes of the gap analysis are also discussed in Section 5 of this report.

'**Proxy information**' in the Evidence Spreadsheet signposts where relevant information exists on other species included in the literature review. This was used, where appropriate, to inform the impact assessment (see Section 2.1.3).

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[1] This impact pathway relates only to the impact on the protected feature; it does not account for the potential for impact on the wider marine ecosystem associated with the potential transfer of invasive non-native species (though this is noted where relevant in Section 3 and the accompanying Evidence Spreadsheet).

The '**potential for impact**' and '**confidence**' associated with the impact assessment was also documented in the Evidence Spreadsheet (see Section 2.1.3), as well as '**references**' and '**search terms**' (see Section 2.1.2).

In Section 3, a broad synthesis of the information gathered from the literature review is presented, along with the results of the impact assessment. This has been structured by habitat and species group and discussed in the context of key factors that may influence potential impacts from plastics (e.g. feeding strategies, size of plastic, location of plastic in the environment).

Table 5. Gap analysis definitions

Gap analysis	Definition
Mutually exclusive definitions	
No evidence	No evidence was found for habitats or species and interactions with, or effects of, marine plastic (i.e. no literature)
Limited evidence[2]	There is a limited amount of evidence on the interactions with, and/or effects of, marine plastic on a species or habitat
Multiple evidence	There are multiple pieces of evidence on the interactions with, and/or effects of, marine plastic on a species or habitat (this does not imply that impacts/effects are well-known and should not be studied further)
Compatible definitions	
Proxy evidence	No evidence on specific habitats or species and interactions with, or effects of, marine plastic, but evidence is available for similar habitats or species that can be used as proxies
No UK evidence	The available evidence is not based on studies in the field in UK waters
Conflicting evidence	There is conflicting evidence on the interactions with, or effects of, marine plastic on a species or habitat

2.1.2 Literature search

The methodology used to search for literature was loosely based on MMO (2018). Google Scholar was used to search for both peer-reviewed and 'grey' literature, and the search was conducted using compound search terms designed to capture plastic-related literature on a certain species, species group or habitat.

The structure of the search terms is shown below, and the exact search terms used are presented in the Evidence Spreadsheet. Each set of search terms comprised four parts. The first part related to the species or genus, and the second part related to the size of plastic. Part three included 'impact' or 'effect', and part four, 'marine' or 'freshwater'.

The last three parts of the search terms remained identical for each search (shown in italics below). Each part of the search terms was separated by the Boolean operator 'AND', and within each part, terms were separated by the Boolean operator 'OR'.

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[2] Limited evidence was generally applied to MPA features with four or less research studies on plastics, however, it also accounts for how much information is provided in each study (i.e. whether there was extensive research on the impact/effect, or whether just presence of, or interactions with, plastic was examined).

("species/genus" OR "common name") AND *(plastic OR microplastic OR macroplastic OR nanoplastic*[3]*)* AND *(impact OR effect)* AND *(marine OR freshwater)*

For habitat sub-features, species features and bird features, once an initial search at the species level was undertaken, a genus level search was also completed. This was to ensure any relevant information on proxy species was captured.

When searching for habitat features, the above structure of search terms returned mainly irrelevant results. Therefore, the terms 'litter', 'pollution' or 'debris' were also included, to focus the search results further (as shown below).

("habitats") AND *(plastic OR* microplastic OR *macroplastic OR nanoplastic)* AND *(impact OR effect)* AND *(marine OR freshwater)* AND *(litter OR pollution OR debris)*

Returns from each search were examined to determine their relevance for inclusion in the review. Where a high number of spurious results were returned from the search, the search terms were tailored or revised to increase their relevance.

For example, when searching for literature on habitats, overly complex habitat feature search terms that were not returning relevant search results were simplified (e.g. mudflats OR sandflats was also searched alongside '"Mudflats and sandflats not covered by seawater at low tide"').

Where literature on specific species or habitats was found in general high-level searches (e.g. searches to obtain information on the issue of marine plastics in general) or from other resources (e.g. sharing of knowledge within professional network), these were included in the review so as not to omit potentially useful information. Furthermore, useful papers or studies cited within the literature that was found in the search were also included in the review.

In order to prevent Google Scholar tailoring searches based on user information or search history, Google accounts were logged out before conducting searches, and search settings (such as dates) were left as default (i.e. not specified). The searches were mainly conducted in November and December 2019, with some additional searching in January and February 2020.

2.1.3 Potential for impact and confidence score

Potential for impact

A high-level assessment was carried out to indicate the potential for a receptor (i.e. species/habitat feature, or characterising species of habitat feature) to be impacted by marine plastic, based on the available evidence. This is referred to here as the 'potential for impact' and the definitions of each impact level are provided in Table 6.

The definitions were formulated based on the general scale of impacts and effects found from the literature review. The results of the impact assessment are captured within the Evidence Spreadsheet and are also summarised in Section 3.

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[3] Google uses stemming algorithms and so a search for 'plastic' will also return similar results to 'microplastic', for example. However, the inclusion of plastic size categories in the search terms improved the ordering of the most relevant literature. Generally, 'mesoplastic' and 'megaplastic' are lesser used terms in the literature (but are used in this study for reporting purposes) and made little difference to the order of search results and so were not included in the search terms.

Table 6. Impact assessment definitions

Potential for impact	Definition
High (H)	Significant effects to species at a population level OR lethal effects observed at environmentally relevant concentrations OR a significant change in habitat extent/functioning/characterising species observed in the environment
Medium (M)	Significant effects to species at an individual level OR sub-lethal effects observed at environmentally relevant concentrations or lethal effects observed at unrealistic environmental concentrations OR some change in habitat extent/functioning/characterising species observed in the environment
Low (L)	Negligible effects to species OR sub-lethal effects observed at unrealistic environmental concentrations OR negligible change in habitat extent/functioning/characterising species observed in the environment
No effect	No effects to species and possibly a beneficial effect (relating to the impact pathway on 'habitat provision')
Undetermined	Effects are undetermined based on the available evidence

It is important to note that the assessment of the potential for impact was exclusively based on the evidence available for the habitat or species. As such, it does not account for effects, impact pathways or plastic types, shapes or sizes that are not documented in the available evidence, even if they could be considered feasible or important. The associated confidence score (see below and accompanying Evidence Spreadsheet) accounts for this to some degree, but all results should be interpreted with an appropriate degree of caution. Where evidence is not available on a particular impact pathway for a feature (or habitat or species group), this is detailed as either 'theoretically possible but with no direct evidence available', or 'unlikely to be relevant and with no direct evidence available' in Table 10 to Table 36 in Section 3 (see Section 2.1.1).

In some instances, the same impact pathway was studied but with conflicting magnitudes or directions of effect, which fell under differing definitions of 'potential for impact'. In these cases, the assessment adopts the overall consensus of the literature if there was sufficient evidence to allow this. If this was not possible (due to lack of evidence to adopt a consensus), the worst-case outcome was adopted (i.e. a higher potential for impact), adhering to a precautionary approach to address uncertainty. There were also multiple impact pathways on species or habitats that are reported in the literature. The worst-case potential for impact was also adopted as the overall potential for impact in these cases and is documented in the Evidence Spreadsheet (though Sections 3.3 to 3.6 provide extra information per impact pathway). The uncertainty in this assessment was then accounted for in the confidence score (see below).

For habitat features, information was sourced on habitat features themselves as well as the multiple key characterising species of sub-feature biotopes. In these cases, the potential for impact for each component of the habitat feature was reviewed, and the maximum potential for impact score of any individual species or habitat was applied as the overriding potential for impact score for the associated habitat feature (i.e. adopting a precautionary approach). This information can be obtained by using the filtering tool in the accompanying Evidence Spreadsheet, and a summary per habitat feature group is presented in Section 3.4.8.

The impact assessment incorporates the principles of the Marine Evidence-based Sensitivity Assessment (MarESA; Tyler-Walters *et al*., 2018). Sensitivity assessments are a standardised approach to determine how easily a species or biotope is affected by a pressure. The assessment of 'sensitivity' is defined as 'the likelihood of change when a pressure is applied to a feature (receptor) and is a function of the ability of the feature to tolerate or resist change (resistance) and its ability to recover from impact (resilience)'. However, a full sensitivity assessment following the MarESA methodology is outwith the scope of this project, and indeed requires a specified level of pressure to be set (termed the pressure benchmark), which is currently lacking for marine plastics. Therefore, use of the term 'sensitivity' has been avoided in the impact assessment, and instead 'potential for impact' is used. Nevertheless, information on the 'resistance' and 'resilience' of species and habitats has been gleaned from the literature where available and used to inform the potential for impact. It should be noted, however, that the concept of resilience or recoverability may be difficult to establish for marine plastics, as most of the literature focusses on acute impacts over short time periods.

Consideration was also given to the use of other potentially useful information on species/habitats that could be used as proxies in the impact assessment. This is recorded in the Evidence Spreadsheet under 'proxy information', where relevant information on other species included in the literature review is signposted. This was then taken into account in the impact assessment where possible.

Confidence score

A '**confidence**' score was assigned to each potential for impact assessment to provide a measure of the quality of the evidence used and its applicability to the assessment. These are detailed in the accompanying Evidence Spreadsheet. The scores are based on those used as part of ME5218 (validating an activity-pressure matrix). They have been tailored to include key aspects of the confidence assessment used as part of MarESA, specifically the quality of evidence (information sources), applicability of evidence, and degree of concordance (agreement between studies). Table 7 presents the confidence scores used within this review. The definitions, in part, take account of the gap analysis.

Table 7. Confidence score methodology

Confidence score	Definition
High (H)	There is a good understanding of the impact on the same species/habitats in the UK marine environment and it is well supported by peer reviewed papers (observational or experimental) or grey literature reports by established agencies. There is consensus amongst the experts on the impact (direction and magnitude).
Medium (M)	Whilst there is an understanding of the impact on species/habitats, the evidence is based on proxy information outside of the UK or in the laboratory and/or the assessment is based on limited peer-reviewed papers and relies heavily on grey literature or expert judgement. There is a majority agreement between experts on the direction of the change; but conflicting evidence/opposing views exist on the magnitude of impact.
Low (L)	There is limited or no understanding of the impact on species/habitats and the assessment is not well supported by evidence, or only by expert judgement. There is no clear agreement amongst experts on the direction or magnitude of the impact.
Note: Evidence is defined as expert opinion or advice, data, methodology, results from data analysis, interpretation of data analysis, and collations and interpretations of scientific information (meta-analysis), peer-reviewed papers, grey literature, industry knowledge and anecdotal evidence (adapted from JNCC, 2015).	

2.2 Prioritisation exercise

The outputs of the literature review and impact assessment were used to inform a simple prioritisation exercise in order to identify which protected habitats and species have the highest potential for impact, and thus are most at risk from marine plastic impacts.

The prioritisation exercise has taken into account the relative potential for impact to different types of plastic pollution on features. This is presented alongside the confidence associated with each assessment.

3 Potential for Impact

The results of the literature review and impact assessment are presented and discussed in this section of the report. An overarching discussion on controlling factors that may influence the potential for impact from marine plastics on habitats and species is presented in Section 3.1. The impact pathways for habitats and species that are documented in the literature, as well as theoretically possible impact pathways that are not documented in the literature, are also summarised in Section 3.2.

Habitat sub-features (Section 3.3), habitat features (Section 3.4), species features (Section 3.5), and bird features (Section 3.6) have all been reviewed separately. Where it aids understanding, some features have been grouped together (but are still reported individually in the Evidence Spreadsheet).

3.1 Controlling factors

Prior to discussing the potential for impact on the protected habitats and species, it is pertinent to consider some key controlling factors that may influence the potential for impact from marine plastics on habitats and species.

These factors include (but are not limited to):

- The concentrations of plastic and other stressors in the marine environment;
- Plastic size, shape and type; and
- Functional groups and feeding strategies.

3.1.1 Environmental concentrations and conditions

Much of the literature on the effects of plastics to marine organisms is based on experiments carried out in laboratories, particularly for invertebrates exposed to microplastics and nanoplastics. It can be challenging to conduct these experiments in an environmentally realistic way, and the results of these experiments cannot always be directly applied to natural conditions (Lehtiniemi *et al.,* 2018). In particular, plastic concentrations used in studies tend to be higher than those commonly found in the environment; often, studied concentrations are orders of magnitude higher (Lenz *et al*., 2016). Even where authors cite environmentally relevant concentrations, these tend towards pollution hotspots and may not be representative of wider environmental concentrations (Green, 2016; Lenz *et al*., 2016). Whilst assessing high concentrations can be important in an emerging field of science as a ‘proof of principle’ regarding mechanisms by which organisms may be affected by plastics (Von Moos *et al*., 2012; Van Cauwenberghe *et al.,* 2015), there remains uncertainty over the potential for impact in conditions reflective of the natural environment. Real-world situations, in which long-term chronic exposures at low concentrations of plastics would be prevalent, are important to understand (Von Moos *et al*., 2012).

Notwithstanding the above, it is difficult to determine the concentration of plastics in the environment. Reported concentrations can exhibit large spatial variability. For example, Van Cauwenberghe and Janssen (2014) note seawater concentrations ranging from less than one microfibre per m^3 to several hundreds of particles and fibres per m^3. Setälä *et al.* (2016) suggest estimates of microplastic abundances vary from low concentrations of three particles per m^3 to very high, hot-spot concentrations of 102,000 particles per m^3. Studies which note the concentration of plastics found in the environment are presented in Table 8.

Further research is needed to establish environmental concentrations of plastic (of different sizes, shapes and types) in the marine environment, which is particularly important as the scale and magnitude of plastic pollution is likely to continue to increase.

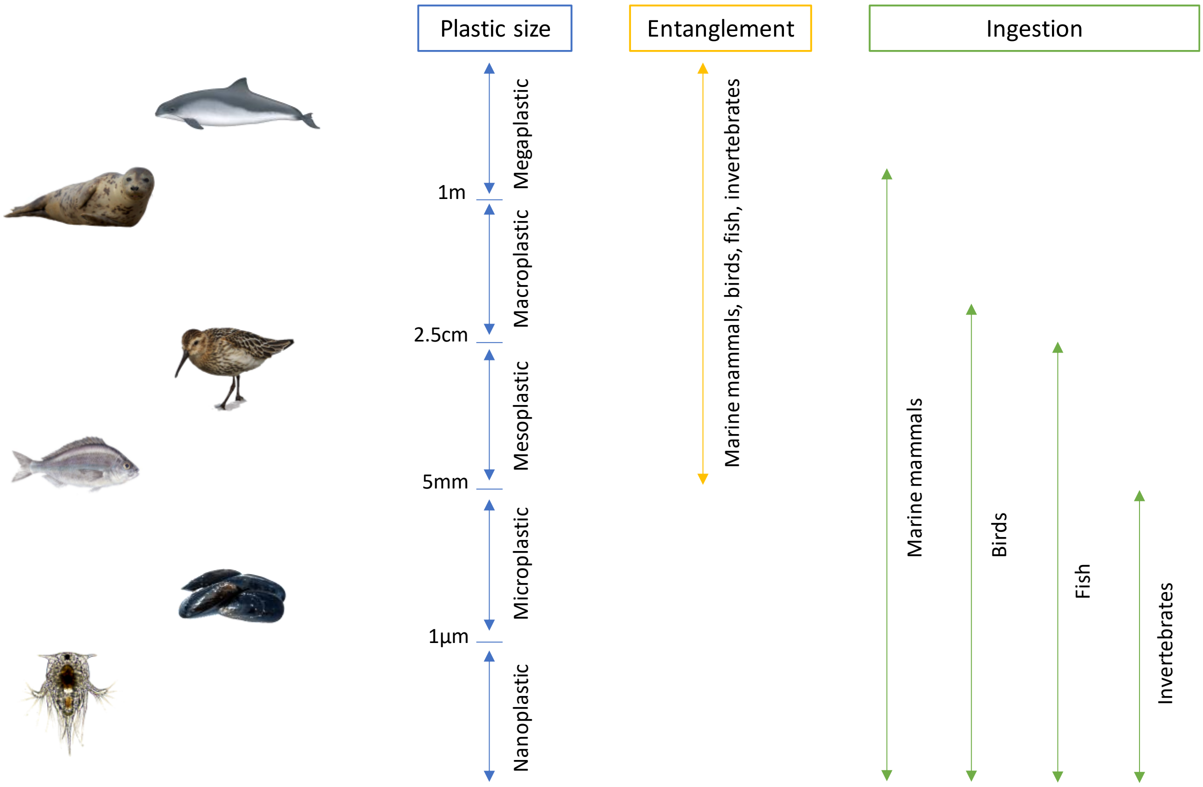
Table 8. Reported environmentally realistic concentrations of plastics in the marine environment

Medium	Plastic size	Concentration/density	Location	Reference
Seawater	Microplastic	500 µg/l	Estimated	Koelmans *et al.* (2015)
	Microplastic	10 – 100 µg/l	Northwest Mediterranean; North Pacific Subtropical Gyre	Revel *et al.* (2018)
	Microplastic	80 µg/l, up to 250 µg/l	North Pacific Subtropical Gyre	Green (2016)
	Microplastic	0.2 – 320 µg/l (median 4.7 µg/l)	Estimated	Beiras *et al.* (2018).
	Microplastic	32 µg/l	Estimated	Paul-Pont *et al.* (2016)
	Microplastic	10 microplastic beads/ml	Not specified	Lo and Chan (2018)
	Microplastic	0.1 microplastic/ml	Sweden	Kaposi *et al.* (2014)
	Microplastic	0.5 microplastic/ml	South Korea	Ribeiro *et al.* (2017).
Sediment	Microplastic	1, 10 and 25 mg/kg dry weight sediment	Not specified	Bour *et al.* (2018)
	Microplastic	10 – 50 mg/kg	Belgium; India	Revel *et al.* (2018)
	Microplastic	0 – 1% dry weight sediment	Not specified	Redondo-Hasselerharm *et al.* (2018)
	Microplastic	3% dry weight sediment	Hawaii	Carson *et al.* (2011)
	Microplastic	<1300 microplastic/kg dry sediment	No specified	Näkki *et al.* (2019)
	Microplastic	137 – 703 microplastic items/kg dry weight sediment	Northern Adriatic	Renzi *et al.* (2018)
	Microplastic	1 – 8 particles per 50 ml sediment	UK	Browne *et al.* (2011); Kershaw (2015)
Surface coverage	Microplastic	0.2 – 42.7 per 0.1 m²	UK	Green and Johnson (2020)
	Macroplastic	234.24 items of macro-debris per km²	Marshall Islands	Richard and Beger (2011)
	Mesoplastic Macroplastic Megaplastic	30 – 100 items per km (100 m width)	Svalbard	Węsławski and Kotwicki (2018)
	Various	1288 plastic items per km	UK	Nelms *et al.* (2017)

Experiments are also commonly done with virgin particles of uniform type, size and shape that do not represent those found in the environment (Lehtiniemi *et al.,* 2018). In the environment, there is likely to be a mix of different plastic types and co-exposures with other pollutants in the environment. This has the potential to cause additive and synergistic effects on marine organisms which may be different to the effects encountered in experiments where plastics are studied in isolation. Environmental stressors such as temperature, pH and salinity may also compromise and alter an organism's resistance and resilience to plastic pollution. This adds to the uncertainty around the impact of plastics in the marine environment.

3.1.2 Plastic size, shape and type

The size of plastic, in some instances, can influence the likely impact to different marine organisms (GESAMP, 2014; Figure 1). Taking entanglement as an example, larger plastic items (megaplastic and macroplastic) have the potential to entangle marine mammals, birds, fish, and some larger crustacean invertebrates, whereas smaller plastic items (mesoplastic, microplastic, and nanoplastic) are unlikely to pose a risk of entanglement to larger marine species. In terms of ingestion, macroplastic items mainly pose a risk to marine mammals and birds, and mesoplastics pose more of an ingestion risk to birds and fish. However, whilst ingestion of smaller plastic items (microplastics and nanoplastics) by larger marine species will occur, they are unlikely to cause any impacts through choking or starvation. Microplastic and nanoplastic likely pose a larger ingestion risk to smaller species such as fish and invertebrate species.



Adapted from GESAMP, 2014

Figure 1. Likely impact pathways of differently sized plastics to marine organisms

The anatomy and physiology of organisms also influences the impact of different sized plastics. The marine isopod *Idotea emarginata* has a fine-meshed filter structure in the stomach that separates the midgut gland tubules, as studied by Hämer (2014). This was found to be an effective tool to prevent the passage of indigestible particles >1 µm into the relevant digestive organs. Faeces contained similar concentrations of microplastics to that in the food that was fed to the isopods suggesting that microplastic accumulation greater than 1 µm did not occur. No distinct effects on health were found and therefore microplastics of >1 µm in size were concluded not to pose a mechanical threat to marine isopods (Hämer, 2014). Similar results were found in common periwinkle *Littorina littorea*, where plastic particles of 1 – 100 µm also did not reach the midgut gland and were excreted along with particles of sand and frustules (Gutow *et al*., 2016). Separately, studies on the mussel *Mytilus edulis* indicate that this species seems to have a size limit for particle retention between 10 – 30 µm with larger particles rejected as pseudofaeces (Van Cauwenberghe *et al.,* 2015). However, smaller nanoplastic particles have been shown to traverse biological compartments. For example, 0.5 µm plastic microspheres have been detected in the midgut gland and haemolymph of shore crabs *Carcinus maenas* following feeding on plastic contaminated *M. edulis* (Farrell and Nelson, 2013) suggesting that nanoplastics may affect a much wider spectrum of organisms (Koelmans *et al.,* 2015).

Certain types of plastics have also been shown to be more toxic than others. Della Torre *et al.* (2014) found higher larval malformations in purple sea urchin *Paracentrotus lividus* embryos when exposed to amino-modified polystyrene compared with carboxylated polystyrene. Malformations included incomplete or absent skeletal rods, fractured ectoderm, reduced length of the arms, and a high percentage of blocked embryo development at early stages. While both variants are able to enter cells via endocytosis and become internalized in cellular compartments (based on their small sizes), this study demonstrates that amino-modified polystyrene can cause disruption of the cell membrane and generate oxidative stress in urchins. Amino-modified plastics are cationic and therefore can be especially toxic as they can more easily interact with cell membranes (Canesi *et al*., 2015). However, Della Torre *et al.* (2014) note that amino-modified polystyrene is less common in the environment.

As well as size and type, plastic shape is important when considering potential biological effects. Au *et al.* (2015) found polypropylene fibres (20 – 75 µm in length, with a diameter of 20 µm) were more toxic than polyethylene spherical particles (10 – 27 µm in diameter) in the freshwater amphipod *Hyalella azteca*. Over 10-days, the lethal concentration 50% (LC_{50}) for spherical particles and fibres was 46,400 microplastics/ml and 71.43 microplastics/ml, respectively (likely higher than environmental concentrations). Acute exposure to fibres also resulted in significantly less growth in the amphipods (this was not observed for the spherical particles), and egestion times for the fibres were slower than for the spherical particles which did not differ from normal food materials.

Blarer and Burkhardt-Holm (2016) found similar results for freshwater amphipod *Gammarus fossarum* where polyamide fibres (500 x 20 µm) significantly reduced assimilation efficiency after two weeks (though effect concentrations, 2680 fibres per cm^2 base area of glass beakers, were above that expected to be found in the environment), whereas polystyrene beads (1.6 µm in diameter) showed no changes in examined end points. It was suggested that, as feeding rates were not affected, the presence of fibres interfered with food processing and the sharp edges of the fibres could have caused more pronounced mechanical injuries to the gut epithelium resulting in reduced energy acquisition (Blarer and Burkhardt-Holm, 2016). Au *et al.* (2015) suggested that the greater toxicity of microplastic fibres corresponded with longer residence times for the fibres in the gut. The difference in residence time might have affected the ability to process food, resulting in an energetic effect reflected in sub-lethal endpoints.

3.1.3 Functional groups and feeding strategies

There is evidence to suggest that organisms with different feeding strategies and guilds will have different plastic exposure pathways, and thus have a different potential for impact. For example, the differences in plastic shape, quantity and colour consumed by two species of fish, European smelt

Osmerus eperlanus and European flounder *Platichthys flesus*, may be due to feeding strategy (McGoran *et al*., 2017). European flounder are benthic feeders, ingesting large quantities of sediment, whereas European smelt are more selective pelagic predators. The larger amounts of microplastic ingested by flounder may have therefore been consumed with sediment when feeding on benthic invertebrates, as benthic environments retain microplastics that sink to the ocean floor or riverbed (Katsnelson, 2015; McGoran *et al*., 2017).

The feeding guild of birds can also be seen to influence the potential for impact from different impact pathways. For example, tubenoses (Procellariiformes: albatross, fulmar, petrel, shearwaters) obtain food from surface seizing or shallow diving and have higher incidences of ingested plastic. Therefore, tubenoses are at greater risk from ingestion of plastic in comparison to auk species which predominantly obtain their food through pursuit diving. However, the deeper diving strategies of the auks mean that they are more vulnerable to entanglement with ghost fishing nets as they spend longer periods of time within the water column. Furthermore, unlike other bird species (e.g. gulls), fulmarine petrels do not usually regurgitate indigestible hard items, as explained by Van Franeker *et al.* (2015). They only spit out stomach contents in fear, in fights, or when feeding their chicks, and in these cases only materials from the glandular first stomach (proventriculus) are lost as the narrow passage to the second muscular stomach (gizzard) prevents materials in the gizzard from returning to the proventriculus. Therefore, most plastic particles accumulate in the muscular gizzard and are ground up until they are small enough to pass into the intestines (along with other hard food or debris items). However, Van Franeker *et* al. (2011) suggest it reasonable to assume that fulmars lose or accumulate characteristic local pollution levels within time frames of at most a very few weeks or even a number of days.

Setälä *et al*. (2016) undertook a mesocosm study to look at differences in plastic ingestion in a range of coastal invertebrates with different feeding types. They found filter feeding bivalves (*Mytilus trossulus* and *Limecola balthica,* though this can also deposit feed) to ingest the highest amount of plastic compared with free-swimming crustaceans (*Gammarus* spp. and littoral mysids) and benthic polychaetes/amphipods that were feeding only on the sediment surface (*Marenzelleria* spp. and *Monoporeia affinis*). This suggests plastics are taken up more effectively by filter-feeding animals or animals at least partly using the water column while feeding. This is supported by Karlsson *et al*. (2017) and Messinetti *et al*. (2018). However, other studies show contradictory results. Bour *et al*. (2018) found filter-feeders were less exposed to microplastics than deposit-feeders or predators (both in terms of frequency and number of particles found per organism) sampled from the Baltic Sea. It was suggested that some filter-feeders could be more efficient at selecting or excreting ingested particles, but another explanation could have been the lower availability of microplastics in the water column above the sediment surface.

Whilst differences in plastic exposure between feeding strategies have been found, La Beur *et al*. (2019) found no statistically significant effect of feeding guild on ingestion rates at a cold-water coral reef in Scotland. This might be due to rapid tidal cycling currents at the study site; species may not have a chance to ingest microparticles as frequently as species at other sites with different hydrographical conditions. Equally, some bird species with similar feeding guilds show different rates of plastic ingestion. For example, the rates of plastic ingestion in black guillemot was found to be 0%, compared to 17.8% in puffin (although both results are generally lower than other feeding guilds) (O'Hanlon *et al*., 2017). This is despite both species being part of the group of water column feeders (and both being auks).

The key point is that whilst there are similarities in the interaction with and exposure to plastics between species within the same functional group, they may not always be consistent. Furthermore, plastics in different locales within the environment (i.e. water surface, water column, sediment surface and subsurface) may not be uniform and thus generalisations based on the behaviour of species may not always be useful. Similarly, different life stages of organisms are likely to affect exposures and sensitivities to plastic, but this is not readily compared in the literature (see Section 5.2).

3.2 Impact pathways

Prior to presenting the potential for impact assessment, this section summarises the impact pathways (see Section 2.1.1 for definitions) that were encountered during the literature review process, and the habitat and species groups that have documented evidence of these impact pathways occurring[4]. Impact pathways that are considered 'theoretically possible but with no direct evidence available' in the literature reviewed for a particular Protected species or habitat group are also detailed. This information is summarised in Table 9. The habitat features, habitat sub-features, and species and bird features included in each grouping are detailed in Evidence Spreadsheet accompanying this report.

Examples of plastic impact pathways that are theoretically possible but not documented in the literature reviewed include toxicity in most protected birds (with the exception of Manx shearwater), and smothering, abrasion or dislodgement of polychaete reef. These are impact pathways that are possibly occurring in the environment, but evidence of the scale of the impacts or effects is not available. There are also instances where impact pathways are considered unlikely to be relevant and with no direct evidence available in the current literature. Examples include habitat provision for marine mammals, and ingestion by macroalgae.

Table 10 to Table 36 (Sections 3.3 to 3.6) also present information on documented impact pathways for protected features, alongside potential for impact scores. Impact pathways that have no evidence available but are either theoretically possible or unlikely to be relevant are also noted.

Table 9. Potential impact pathways for species and habitat groups identified in the literature review (those marked with * are judged to be theoretically possible but with no direct evidence available)

Impact pathway	Habitat feature	Habitat sub-feature	Species feature	Bird feature
Ingestion	Reef	Anthozoan Ascidian Crustacean Echinoderm Mollusc Oligochaete Polychaete *Bryozoan *Foraminifera *Hydrozoan *Sponge	Crustacean Fish Marine mammal Mollusc *Anthozoan *Cnidarian *Polychaete	Anseriformes Charadriiformes Gaviiformes Pelecaniformes Procellariiformes Suliformes *Accipitriformes *Caprimulgiformes *Passeriformes *Podicipediformes

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[4] It is important to reiterate that the impact pathways documented for each species or habitat is based on the available evidence. This does not mean that other impact pathways are not relevant to other species or habitats, only that other potential impact pathways may not have been examined for those species or habitats and detailed in the literature. When determining the potential for impact (Section 3.3 to 3.6), the assessment is based on the available evidence, and should be interpreted as such (see Section 2.1.3 also).

Impact pathway	Habitat feature	Habitat sub-feature	Species feature	Bird feature
Toxicity	*Reef *Saltmarsh *Vegetated sediment	Crustacean Echinoderm Mollusc Polychaete *Angiosperm *Anthozoan *Ascidian *Bryozoan *Foraminifera *Hydrozoan *Macroalgae *Microalgae *Oligochaete *Sponge	Fish Marine mammal *Anthozoan *Cnidarian *Crustacean *Macroalgae *Mollusc *Polychaete	Procellariiformes *Accipitriformes *Anseriformes *Caprimulgiformes *Gaviiformes *Passeriformes *Pelecaniformes *Podicipediformes *Suliformes
Entanglement	Reef *Rock	Anthozoan *Crustacean *Echinoderm	Anthozoan Marine mammal *Cnidarian *Crustacean *Fish	Anseriformes Caprimulgiformes Charadriiformes Gaviiformes Pelecaniformes Podicipediformes Suliformes *Accipitriformes *Anseriformes *Caprimulgiformes *Passeriformes
Smothering, abrasion or dislodgement	Dunes Reef Rock Saltmarsh Sediment Vegetated sediment *Physiographic habitats	Angiosperm Anthozoan Macroalgae Microalgae Polychaete *Ascidian *Bryozoan *Echinoderm *Hydrozoan *Mollusc *Oligochaete *Sponge	Anthozoan *Cnidarian *Polychaete	n/a
Substrate change	Reef Rock Sediment Vegetated sediment *Dunes *Physiographic habitats *Saltmarsh	Angiosperm Polychaete *Echinoderm *Oligochaete	*Polychaete	n/a

Impact pathway	Habitat feature	Habitat sub-feature	Species feature	Bird feature
Habitat provision	n/a	Anthozoan Ascidian Bryozoan Crustacean Echinoderm Foraminifera Hydrozoan Macroalgae Microalgae Polychaete *Sponge	*Anthozoan *Crustacean *Macroalgae	Charadriiformes Pelecaniformes Suliformes *Accipitriformes *Anseriformes *Caprimulgiformes *Gaviiformes *Passeriformes *Podicipediformes *Procellariiformes

3.3 Habitat sub-features

This section focusses on the impact of plastics to habitat sub-features. A summary of the potential for impact on the sub-features is described (either individually or grouped to aid the synthesis of information) and is presented in Table 10 to Table 19. The definition of the potential for impact is provided in Table 6, and further detail on the evidence is provided in the accompanying Evidence Spreadsheet.

3.3.1 Anthozoans

Anthozoans included in the review included various species of anemones and corals. The evidence suggests a similar potential for impact for both of these groups.

The potential impact pathways documented in the literature on **anemones** include:

- Ingestion; and
- Habitat provision.

For ingestion, Okubo *et al*. (2018) found that spherical microplastics (3, 6, and 11 µm) fed to anemones *Aiptasia* sp. with forceps (therefore likely higher than concentrations in the environment) suppressed infectivity of symbiotic algae into bleached individuals. This is a sub-lethal effect at unrealistic environmental concentrations. Therefore, the potential for impact to anemones is considered **Low** for ingestion (Table 10). de Orte *et al*. (2019) also found *Aiptasia pallida* to ingest plastic fibres (30 µm in diameter, 50 – 1000 µm in length), but effects were not studied.

For habitat provision, there is evidence of attachment to larger pieces of plastic debris (macroplastic and megaplastic). The potential for impact is **No effect** (Table 10), as whilst there is evidence of the settlement of species on plastic surfaces, the effects of this on the health of organisms or populations are unlikely to be detrimental and may be beneficial (though this is not determined in the literature).

For **coral** species, potential impact pathways documented in the literature include:

- Ingestion;
- Entanglement;
- Smothering, abrasion and dislodgement; and

- Habitat provision.

Experiments conducted in the laboratory show ingested microspheres (3, 6, and 11 µm) trapped in the gut (wrapped in mesenterial tissue) of the stony coral *Favites chinensis*, and a consequent suppression of infectivity by symbiotic algae (Okubo *et al.,* 2018). As well as this, reduced calcification resulted from exposure to polythene beads (500 µm) in the cold water coral *Lophelia pertusa* (Chapron *et al*., 2018). The microplastic concentrations tested in these studies (direct feeding with forceps, 350 beads/ml, respectively) were higher than those reported in the marine environment, and as such can be considered to have a **Low** potential for impact for ingestion (Table 10).

Entanglement and damage to coral structures from macroplastic and megaplastics (linear, general debris) have been found in the environment, particularly in the Mediterranean Sea and the Indian Ocean. Whilst the densities of plastic found in these environments were relatively low, effects were evident and included soft plastics entangled in *L. pertusa* causing necrosis (Fabri *et al*., 2014), damage and epibiosis to sea fans such as the pink sea fan *Eunicella verrucosa* (Angiolillo *et al*., 2015; Consoli *et al*., 2019), and increases in the likelihood of diseases in Indian Ocean coral reefs as a result of contact with macroplastic (Lamb *et al.,* 2018). Reduced skeletal growth rates have also been found in the aquaria-based experiments after smothering *L. pertusa* with polythene sheets (Chapron *et al.,* 2018). Plastic sheets were thought to act as a physical barrier to food supply. As such, the potential for impact to anthozoan corals and sea fan species from entanglement and smothering, abrasion or dislodgement is considered **Medium** (Table 10).

Studies also show evidence of plastic providing habitat and shelter for benthic marine organisms. Colonisation of snagged long lines by scleractinian corals was also recorded by Fabri *et al*. (2014). This is corroborated by Tubau *et al.* (2015) who found the stony coral *Madrepora oculata* colonising plastic and litter in the North-western Mediterranean Sea. The potential for impact associated with habitat provision for corals is **No effect** (Table 10), as whilst there is some evidence of attachment, this is unlikely to effect the health of the organisms or populations and may be beneficial (though this is not determined in the literature).

Table 10. Potential for impact from marine plastics on anthozoan habitat sub-features

Impact pathway	Anemones	Corals
Ingestion	Low	Low
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Medium
Smothering, abrasion and dislodgement	Theoretically possible but with no direct evidence available	Medium
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	No effect	No effect
Overall impact	**Low**	**Medium**

3.3.2 Crustaceans

From the literature review, amphipods were the most widely studied crustaceans. There was also evidence on the impact of plastics on barnacle species, the isopod *Eurydice pulchra*, crab and lobster species (reviewed in the Evidence Spreadsheet under 'crustaceans') and opossum shrimp *Neomysis integer*.

Potential impact pathways that were documented in the literature for **amphipods** include:

- Ingestion;
- Toxicity; and
- Habitat provision.

Generally, high concentrations of microplastics (up to three orders of magnitude higher than concentrations encountered in the natural environment) caused sub-lethal effects to freshwater amphipod species. The potential for impact is therefore considered **Low** (Table 11). Effects included reduced growth (Redondo-Hasselerharm *et al*., 2018), reduced reproduction rates (Au *et al*., 2015), and reduced assimilation efficiency (Blarer and Burkhardt *et al*., 2016). Most authors associated negative effects with a reduced ability to intake and process food. Fibrous plastics were considered more toxic due to their sharp edges, mechanical damage to the gut and consequent increased residence times in amphipods, though effects were still sub-lethal and occurred at unrealistic environmental concentrations (Au *et al*., 2015; Blarer and Burkhardt *et al*., 2016).

Chua *et al*. (2014) found that microplastics have the potential to act as a vector for the transfer of persistent organic pollutants into the marine amphipod *Allorchestes compressa,* though toxicity was not studied, and the potential for impact is **Undetermined** (Table 11).

For habitat provision, *Corophium* sp. were the most common invertebrates to bio-foul nylon, polypropylene, polyethylene rope in the sublittoral around the Firth of Clyde, Scotland (Weldon and Cowie, 2017). The potential for impact due to habitat provision is **No effect** (Table 11), as effects on the health of the amphipod are unlikely to be detrimental and may be beneficial (though this is not determined in the literature).

The documented literature on **barnacles** relates to:

- Ingestion;
- Toxicity; and
- Habitat provision.

Ingestion was considered to have a **Medium** potential for impact (Table 11). This is based on sub-lethal effects (alteration of enzyme activates) on *Amphibalanus amphitrite* larvae at concentrations of polystyrene nanoplastic beads (0.1 µm; 0.001 – 10 mg/l) considered representative of environmental concentrations (Gambardella *et al.,* 2017).

Leachates from a range of recyclable plastics were also found to affect mortality rates of barnacle nauplii (Li *et al.,* 2016). Tested concentrations were high (0.10 and 0.50 m^2/l), and probably unlikely in most environmental conditions (it may be possible in very warm, shallow and stagnant tidal pools). Polyvinyl chloride, polyethylene and polycarbonate released the most toxic leachates, increasing mortality up to around 30%, while leachates from polypropylene and polystyrene were the least toxic. For toxicity, the potential for impact is considered **Medium** (Table 11).

Most of the evidence relates to barnacle settlement on plastic surfaces. Some studies also implicate plastic debris in the dispersal of barnacle species (Barnes and Milner, 2005; Rees and Southward, 2009;

Whitehead *et al*., 2011). The potential for impact due to habitat provision is **No effect** (Table 11), as effects on the health of barnacles are unlikely to be detrimental and may be beneficial (though this is not determined in the literature).

Documented impact pathways for ***Neomysis integer*** included ingestion only.

N. integer was found to ingest microplastic, and in comparatively higher amounts compared with other species; they are omnivorous feeding on detritus, phytoplankton and zooplankton (both sediment surface and water column) (Setälä *et al.,* 2016). The effect of high concentrations of microplastic polystyrene beads (5 µm) were studied by Wang *et al*. (2017); no effect on mortality was found at concentrations that are probably higher than found in the environment (500 µg/l), and short-term mortality rates of 30% were found at higher concentrations (1000 µg/l). Therefore, the potential for impact is considered **Low** for ingestion (Table 11).

For ***Eurydice pulchra***, impact pathways that were documented in the literature included ingestion only.

Ingestion of microplastics (polystyrene microbeads and fragments of 1 – 100 µm, polyacrylic fibres of 20 – 2,500 µm) by *I. emarginata* (another isopod) was studied by Hämer *et al.* (2014). Microplastics were only present in the gut and stomach; *I. emarginata* are seemingly able to prevent intrusion of particles smaller than 1 µm into the midgut gland which is facilitated by the complex structure of the stomach including a fine filter system. Long-term bioassays (6 weeks) showed no distinct effects on health, and as such the potential for impact is considered **Low** for ingestion (Table 11).

Literature on other **crustaceans** was included in the Evidence Spreadsheet, and the potential impact pathways documented were:

- Ingestion; and
- Habitat provision.

There is recent evidence that ingested microplastics can transfer to other trophic levels via prey consumption. Farrell and Nelson (2013) showed that following ingestion of microplastic-containing mussels, *C. maenas* incorporated the plastics in their haemolymph as well as in the stomach, hepatopancreas, ovary and gills. There was no obvious change in the physical or behavioural condition of the crabs after ingestion of the microspheres. Similar results were also found by Crooks *et al.* (2019) after velvet swimming crabs *Necora puber* were fed microplastic-fed mussels, with microplastics entering the brain. This conflicts with laboratory experiments by Welden and Cowie (2016) who noted effects at supposed environmental concentrations. It was observed that Norway lobsters *Nephrops norvengicus* fed with 5 polypropylene fibres per feed (3 – 5 mm in length, 0.2 mm in diameter) had changes in body condition similar to a control group of starved individuals. *N. norvengicus* had a reduction in body mass, blood protein and stored lipids and a mortality rate of 41.6% over eight months. The observed effects in this study may reflect natural conditions if *N. norvengicus* feed in areas with high concentrations of microplastics, and therefore, the potential for impact is considered **Medium** (Table 11).

Hermit crab *Cestopagurus timidus* abundance was found to increase after plastic litter was introduced suggesting the litter provided refuge, either by direct use of cavities or by digging down into the sediment beneath them (Katsanevakis *et al*., 2007). For habitat provision, the potential for impact is **No effect** (Table 11) as effects on the health of organisms are unlikely to result and may be beneficial (though this is not determined in the literature).

Table 11. Potential for impact from marine plastics on crustacean habitat sub-features

Impact pathway	Amphipod	Barnacle	*Neomysis integer*	*Eurydice pulchra*	Other crustaceans
Ingestion	Low	Medium	Low	Low	Medium
Toxicity	Undetermined	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	No effect	No effect	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	No effect
Overall impact	**Low**	**Medium**	**Low**	**Low**	**Medium**

3.3.3 Echinoderms

The review identified relatively little literature relevant to echinoderms. Species have been grouped as purple sea urchin *Paracentrotus lividus,* Spiny mudlark *Brissopsis lyrifera,* brittlestars, holothurians, and other echinoderms.

For ***Paracentrotus lividus*** the only impact pathway documented in the literature related to ingestion.

Literature on *P. lividus* suggests that ingestion of microplastics and nanoplastics results in sub-lethal effects but at one to three orders of magnitude higher concentrations than expected in the environment. Resulting effects include alteration of post-embryonic development and/or growth (Messinetti *et al.*, 2018; polystyrene microplastics at 25 μg/ml), and developmental defects (Della Torre *et al.*, 2014; amino-modified polystyrene nanoplastic, EC_{50} of 2.61 μg/ml after 48 h). Della Torre *et al.* (2014) found that a different nanoparticle (carboxylated polystyrene) showed no embryo toxicity up to 50 μg/ml, suggesting amino-modified polystyrene is more toxic, though the authors notes that it is less common in the environment. Consequently, a **Low** potential for impact has been attributed to *P. lividus* for ingestion (Table 12).

Only ingestion was documented in relation to ***Brissopsis lyrifera*** in the literature.

Bour *et al.* (2018) found microplastics to be ingested in 40% of the urchins *B. lyrifera* off the coast of Oslo, Norway; the effect of this on the organism was not studied. Therefore, the potential for impact is considered to be **Undetermined**.

Bour *et al.* (2018) suggest feeding mode could influence the uptake (lower in filter feeders compared with deposit feeders and predators). This could be due to lower availability of microplastics in the water column above the sediment surface, or selectivity by filter feeders.

Habitat provision was the only impact pathway documented in the literature relating to **brittlestars**. Chiba (2018) found brittlestars attached to plastic debris in the deep sea, suggesting plastics provide benthic organisms with new habitats. In soft bottom habitats, new habitat might be offered by plastic. The effect of this on organism health or populations is unlikely to be detrimental and may be beneficial (though this is not determined in the literature), and therefore the potential for impact is **No effect**.

The potential impact pathways on **holothurians** documented in the literature review were:

- Ingestion; and
- Toxicity.

Ingestion of plastics by holothurians was found to be linked to foraging techniques and microplastic concentration in the sediment (Graham and Thompson, 2009). Assidqi (2015) identified that no significant effects on physiology were recorded in black sea cucumber *Holothuria leucospilota* at any concentration (up to 3% by weight of sediment) of polyvinyl chloride fragments and pellets. Therefore, the potential for impact is considered **Low** for ingestion (Table 12).

Assidqi (2015) also studied toxicity of polyvinyl chloride with fluoranthene. Significant effects on physiology were not recorded in *H. leucospilota* and therefore the potential for impact is considered **Low** for toxicity (Table 12).

For other **echinoderms** (as well as the species noted above), impact pathways that were documented in the literature included ingestion only.

Kaposi *et al.* (2014) recorded that larvae of the sea urchin *Tripneustes gratilla* ingests microplastics but no significant effect on the survival of the larvae was recorded. The concentrations tested (1 – 300 microspheres/ml) are likely above those encountered in the environment. As such, a **Low** potential for impact is expected for ingestion, based on the available evidence (Table 12).

Table 12. Potential for impact from marine plastics on echinoderm habitat sub-features

Impact pathway	***Paracentrotus lividus***	***Brissopsis lyrifera***	**Brittlestars**	**Holothurians**	**Other echinoderms**
Ingestion	Low	Undetermined	Theoretically possible but with no direct evidence available	Low	Low
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Low	Theoretically possible but with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Theoretically possible but with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Substrate change	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	No effect	Unlikely to be relevant and with no direct evidence available	Theoretically possible but with no direct evidence available
Overall impact	**Low**	**Undetermined**	**No effect**	**Low**	**Low**

3.3.4 Molluscs

The majority of the literature on molluscs is on bivalve species such as blue mussel *Mytilus edulis,* native oyster *Ostrea edulis,* and clams such as *Abra nitida* and *Ennucula tenuis* and all have similar impact pathways and potential for impact. Peppery furrow shell *Scrobicularia plana*, and common periwinkle *Littorina littorea* differ and are therefore discussed separately.

Potential impact pathways documented in the literature for **bivalves** were:

- Ingestion; and
- Toxicity.

Generally, a **Medium** potential for impact was determined for most bivalve species due to ingestion (Table 13). This is because, for example, stress induced increases in respiration rates have been reported in *O. edulis* at concentrations of microplastic (80 µg/l) that have been found in the environment (Green, 2016), and a significant decrease in protein content was observed for *A. nitida* and *E. tenuis* exposed to microplastic particles (1 – 25 mg/kg in sediment) at concentrations observed in the environment (Bour *et al.,* 2018).

For mussels, evidence suggests polystyrene microbeads (2 and 6 µm) at 32 µg/l (whilst high, this concentration can be considered environmentally relevant) can lead to an increase in hemocyte mortality and increases in reactive oxygen species; highest histopathological damages and levels of anti-oxidant markers were observed in mussels exposed to plastics together with fluoranthene (Paul-Pont *et al*., 2016). Therefore, toxicity has been assigned a **Medium** potential for impact (Table 13). However, other studies report lesser effects on mussels (e.g. Browne *et al.,* 2008; Van Cauwenberghe *et al*., 2015).

Potential impact pathways documented in the literature for ***Scrobicularia plana*** were:

- Ingestion; and
- Toxicity.

The potential for impact on *S. plana* is considered **Low** for ingestion (Table 13), as Riberio *et al.* (2017) report sub-lethal effects following polystyrene microsphere (20 µm) exposure at higher concentrations (1 mg/l) than expected in the environment (however, environmentally relevant concentrations were not tested and therefore this has low confidence). Effects included antioxidant capacity, DNA damage, neurotoxicity and oxidative damage in *S. plana.*

O'Donovan *et al.* (2018) examined impacts of polyethylene macroplastics with and without absorbed benzo(a)pyrene and perfluorooctane sulfonic acid contaminants and found evidence of oxidative stress in contaminated microplastics, but not in uncontaminated microplastics. The concentrations of microplastics used (1 mg/l) were higher than in the environment, and as such the potential for impact is considered **Low** for toxicity (Table 13).

Gastropod species for which literature on the impact of marine plastics was found in the review included ***Littorina littorea***. Potential impact pathways included:

- Ingestion; and
- Toxicity.

Gutow *et al.* (2016) showed bladder wrack *Fucus vesiculosus* to retain suspended microplastics on its surface in a laboratory. *L. littorea* feeding on this species ingested microplastic on the surface of the seaweed whilst grazing and did not distinguish between 'clean' algae and those with plastics present (and feeding rates were unaffected). Ingested microplastics were transferred into the stomach and gut but not found in the midgut gland and were excreted rapidly. However, specific effects of ingestion were not studied, and therefore the potential for impact for ingestion is **Undetermined** (Table 13).

The potential for impact on *L. littorea* is considered **Medium** for toxicity (Table 13), driven by a study by Seuront (2018) that found plastic leachates (at concentrations not uncommon in the environment) to impair and inhibit the ability of *L. littorea* to respond to predator (*C. maenas*) cues through a decrease in their chemosensory abilities, whilst not affecting *L. littorea* neuromuscular performance.

Table 13. Potential for impact from marine plastics on mollusc habitat sub-features

Impact pathway	Bivalves	*Scrobicularia plana*	*Littorina littorea*
Ingestion	Medium	Low	Undetermined
Toxicity	Medium	Low	Medium
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Medium**	**Low**	**Medium**

3.3.5 Polychaetes

The evidence suggests a similar potential for impact for most polychaetes. Differences exist for *Protodorvillea kefersteini,* fan worm *Serpula vermicularis* and *Spirobranchus triqueter*, so these have been grouped and discussed separately.

The potential impact pathways documented in the literature for **polychaetes** were:

- Ingestion;
- Toxicity;
- Smothering, abrasion and dislodgement; and
- Substrate change.

Most of the literature of polychaetes points towards a **Medium** potential for impact for ingestion (Table 14). Studies report depleted energy reserves at polyvinyl chloride (130 µm mean diameter) microplastic concentrations of 1 – 5% by sediment weight of (overlapping with environmental concentration) in lugworm *Arenicola marina* (Wright *et al.*, 2013), and fewer casts possibly due to stress induced by, in particular, micro-sized polyvinyl chloride (Green *et al.*, 2016).

However, other studies suggest lesser effects on lugworm (Van Cauwenberghe *et al*., 2015). Effects at environmental concentrations have also been reported for ragworm *Hediste diversicolor*, including a decreasing trend in segment regeneration after exposure to 0.005 – 0.5 mg/ml nanoplastic polystyrene (Silva *et al.,* 2020), and a slight but significant alteration in coelomocyte cell (immune cell) viability and immune-related enzymes following microplastic exposure at 10 and 100 µg/l (water) and 10 and 50 mg microplastic/kg (sediment) (Revel *et al*., 2018).

Studies also focus on the effects of other pollutants adhering to plastics and risks of bioaccumulation, but in general findings suggest exposure due to microplastic ingestion has limited/small effects on the bioaccumulation of other pollutants in *A. marina* (Besseling *et al*., 2013; 2017; Browne *et al.,* 2013). As such, for toxicity, a **Low** potential for impact is assigned (Table 14).

Regarding smothering, Clemente *et al*. (2018) observed significant differences in community structure between communities under a plastic bag on the benthic surface, around the border of the bag and distant locations (50 m) from the bag. The dominant and opportunistic polychaete *Streblospio* sp. showed a decrease in density under the plastic bag, and several other species had an increase in density (Clemente *et al.,* 2018). This is suggested to be due to the plastic bag reducing the ability for *Streblospio* sp. to suspension feed. This is considered a **Medium** potential for impact.

Uneputty and Evans (1997) investigated the effects of litter and substrate change on infaunal assemblages in the environment. It was found that littered areas supported large aggregations of meiofaunal polychaetes, whereas macrofaunal polychaetes dominated litter-free areas. The authors suggest a possible explanation for this difference is that decomposing organic matter, which is trapped beneath plastics, facilitates high production of bacteria and creates a suitable habitat for meiofauna. Therefore, the potential for impact for substrate change is **Medium** (Table 14).

Impact pathways documented within the literature on ***Protodorvillea kefersteini*** only related to substrate change.

Akoumianaki (2008) found that after littering, opportunistic species such as *P. kefersteini* increased, possibly due to a reduction in sediment oxygenation caused by the entrapment and subsequent accumulation of seagrass detritus causing hypoxia following decomposition. Therefore, the potential for impact is considered **Medium** for substrate change (Table 14).

The calcareous tube building worm ***Serpula vermicularis*** has been detailed in the literature, and documented impact pathways include:

- Ingestion; and
- Habitat provision.

S. vermicularis has been reported to ingest microplastics (La Beur *et al*., 2019). However, effects of ingestion were not studied, and therefore the potential for impact is **Undetermined** (Table 14).

S. vermicularis has also been recorded encrusting plastic debris (Gündoğdu *et al*., 2017). The effects of the colonisation of plastics by these worms are unlikely to be detrimental to the health of the organism and may be beneficial (though this is not determined in the literature), and therefore the potential for impact is **No effect** (Table 14).

Impact pathways documented within the literature on ***Spirobranchus triqueter*** related to habitat provision.

S. triqueter has been recorded encrusting plastic debris (Gündoğdu *et al*., 2017; Turner *et al*., 2019). The effects of the colonisation of plastics by these worms are unlikely to be detrimental to the health of the organism and may be beneficial (though this is not determined in the literature), and therefore the potential for impact is **No effect** (Table 14).

Table 14. Potential for impact from marine plastics on polychaete habitat sub-features

Impact pathway	**Polychaetes**	***Protodorvillea kefersteini***	***Serpula vermicularis***	***Spirobranchus triqueter***
Ingestion	Medium	Theoretically possible but with no direct evidence available	Undetermined	Theoretically possible but with no direct evidence available
Toxicity	Low	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Substrate change	Medium	Medium	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	No effect	No effect
Overall impact	**Medium**	**Medium**	**Undetermined**	**No effect**

3.3.6 Oligochaetes

The only oligochaete included in the review was the sludgeworm ***Tubifex tubifex***, and the only potential impact pathway documented in the literature relates to ingestion.

In a study by Redondo-Hasselerharm *et al.* (2018), microplastics (irregular fragments of polystyrene, 20 – 500 µm) caused no effects or significant differences on the survival, growth or egestion rates at concentrations ranging from 0 – 40% sediment dry weight. Consequently, the potential for impact following ingestion is considered **Low** (Table 15).

Table 15. Potential for impact from marine plastics on oligochaete habitat sub-features

Impact pathway	*Tubifex tubifex*
Ingestion	Low
Toxicity	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Theoretically possible but with no direct evidence available
Substrate change	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**

3.3.7 Ascidians

The following potential impact pathways have been documented in the literature on **ascidians**:

- Ingestion; and
- Habitat provision.

In terms of ingestion, one study found the metamorphosis of ascidian juveniles *Ciona robusta* was slowed down following exposure to 10 µm microbeads at 0.125,1.25,12.5 and 25 µg/ml, which are relatively high compared with environmental concentrations (Messinetti *et al.*, 2018). Therefore, given that effects were observed at unrealistic environmental concentrations, the potential for impact is considered **Low** (Table 16). The study also suggests that filter feeding ascidian juveniles are unable to distinguish between food and inorganic particles, and as such are likely to ingest high volumes of microplastics in areas of high microplastic contamination (Messinetti *et al.*, 2018). Vered *et al.* (2019) found microplastic fragments of 50 – 540 µm in ascidians *Herdmania momus* and *Microcosmus exasperatus* in the Mediterranean and Red Sea coasts of Israel.

Ascidians such as *Ciona intestinalis* (and other species) have been found to be one of the most common taxonomic groups to foul plastics (Katsanevakis *et al.*, 2007; Fazey and Ryan, 2016). The potential for impact due to habitat provision is **No effect** (Table 16) as effects on the health of individuals or populations are unlikely to be detrimental and effects may be beneficial (though this is not determined in the literature)).

Table 16. Potential for impact from marine plastics on ascidian habitat sub-features

Impact pathway	Ascidians
Ingestion	Low
Toxicity	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Theoretically possible but with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available
Habitat provision	No effect
Overall impact	**Low**

3.3.8 Hydrozoans and bryozoans

All of the literature documenting the impacts of plastics on **hydrozoans** and **bryozoans** relates to habitat provision and settlement of species on plastic.

Many authors have recorded colonisation of both mega- and macro-sized plastics, down to microplastics. Some authors also implicate plastic debris in the dispersal of bryozoan and hydrozoan species (which may be considered invasive species to some regions). Furthermore, Li *et al.* (2016) found bryozoan *Bugula neritina* settled in very high numbers on most plastics in the field (Beaufort, NC, USA) with much less settlement on glass and high-density polyethylene. The authors speculate that something leaching from the polyethylene interferes with bryozoan sensory capabilities. Nevertheless, the potential for impact for both species groups is **No effect** (Table 17) as the effects on individual or population health are unlikely to be detrimental and may be beneficial (though this is not determined in the literature).

Table 17. Potential for impact from marine plastics on hydrozoan and bryozoan habitat sub-features

Impact pathway	Hydrozoans	Bryozoans
Ingestion	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	No effect	No effect
Overall impact	**No effect**	**No effect**

3.3.9 Macroalgae and microalgae

There is limited evidence on the impact of marine plastics on **macroalgae**. Potential impact pathways documented in the literature include:

- Smothering, abrasion or dislodgement; and
- Habitat provision.

A few studies note the accumulation of plastic on the surface of fucoid species (Gutow *et al.*, 2016; Saley *et al.*, 2019). It is suggested this could lead to smothering and possibly reduced rates of photosynthesis, though these effects were not specifically investigated in the literature on fucoid species. Plastic adherence on freshwater microalgae (*Chlorella* sp. and *Scenedesmus* sp.) can inhibit photosynthesis and trigger an oxidative stress response, though this was recorded after exposure to microplastic concentrations much higher than those observed in nature (Bhattacharya *et al.*, 2010; Wright *et al.*, 2013). As such, the potential for impact is **Low** for smothering, abrasion or dislodgement (Table 18).

Some studies note that macroalgae colonise drifting and floating plastic debris (Gregory, 2009; Osborn and Stojkovic, 2014; Aliani and Molcard, 2003). The potential for impact is **No effect** for habitat provision as effects on the health of organisms are unlikely to be detrimental and may be beneficial (though this is not determined in the literature) (Table 18).

More evidence is available on **microalgae** species, and potential impact pathways documented in the literature again include:

- Smothering, abrasion or dislodgement; and
- Habitat provision.

Similar effects from micro and nano-sized plastics were found. Plastic adherence on microalgae can limit the exchange of substances between cells and the environment (Zhang *et al.*, 2017), and inhibit photosynthesis and growth (Bhattacharya *et al.,* 2010; Besseling *et al.*, 2014; Bergami *et al.*, 2017). These effects were generally observed only after exposure to concentrations higher than those found in the environment. However, Green *et al.* (2015) also found a reduction in oxygen and primary producers beneath plastic bags on intertidal mudflats under experimental conditions in the environment. As such, the potential for impact relating to smothering, abrasion or dislodgement is **Medium** (Table 18).

There is also evidence of microalgae adhering to plastics, but the potential for impact is **No effect** for habitat provision as effects on the health of organisms are unlikely to be detrimental and may be beneficial (Table 18).

Table 18. Potential for impact from marine plastics on macroalgae and microalgae habitat sub-features

Impact pathway	Macroalgae	Microalgae
Ingestion	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Low	Medium
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	No effect	No effect
Overall impact	**Low**	**Medium**

3.3.10 Angiosperms

There was a lack of available literature for most of the **angiosperm** species included in the review. The potential impact pathways that were documented in the literature include:

- Smothering, abrasion or dislodgement; and
- Substrate change.

One paper by Mazarrasa *et al.* (2019) reported on litter accumulation in estuarine vegetated communities with mention of some species (*Juncus maritimus*, *Puccinellia maritima*, *Salicornia* spp.). It was based on ‘expert elucidation’ and a qualitative multi-metric index (accounting for probability, vulnerability and consequence). Light reduction, erosion, encroachment, inhibition of sediment gas exchange and enhancement of the proliferation of new habitats was suggested as possible impacts, and the qualitative assessment resulted in a generally low level of potential impact of marine litter. As such, the potential for impact is considered **Low** for these species with respect to smothering, abrasion or dislodgement (Table 19). Jones *et al.* (2020) also recorded microplastics adhering to eelgrass *Zostera marina* blades in a seagrass bed in Deerness Sound, Orkney, with an average of 4.25 plastics particles per individual. However, the effect of this smothering was not examined.

Another study investigated the effects of pieces of biodegradable plastic bag on seagrass beds with dwarf eelgrass *Zostera noltii* and *Cymodocea nodosa* (Balestri *et al.,* 2017). Whilst it is unlikely that biodegradable plastic would congregate in seagrass beds to the extent set up in this experiment, the bags reduced sediment pore-water oxygen concentration and pH, and increased *C. nodosa* root spread and vegetative recruitment therefore impacting species growth patterns. This is assessed as a **Low** potential for impact for substrate change (Table 19).

Table 19. Potential for impact from marine plastics on angiosperm habitat sub-features

Impact pathway	Angiosperms
Ingestion	Unlikely to be relevant and with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Low
Substrate change	Low
Habitat provision	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**

3.4 Habitats

This section focusses on the impact of plastics to the habitat features themselves, rather than the sub-feature species that inhabit them (see Section 3.2). A summary of the potential for impact on the habitat features is described (either individually or grouped to aid the synthesis of information) and is presented in Table 20 to Table 26. The definition of the potential for impact is provided in Table 6, and further detail on the evidence is provided in the accompanying Evidence Spreadsheet.

Overriding potential for impact scores for habitat features, also taking into account habitat sub-features, can be deduced from the Evidence Spreadsheet, by using the filtering function on the 'habitat sub-features' tab. A summary of this overriding potential for impact score per habitat feature group is presented in Section 3.4.8

3.4.1 Rock

For the majority of rocky habitats included within the review, no direct evidence of the impact of marine plastics was found. As such, the information has been generalised across **rock** habitats.

Potential impact pathways that were documented in the literature reviewed include:

- Smothering, abrasion or dislodgement; and
- Substrate change.

Some studies note that rocky habitats generally accumulated fewer plastic items compared to other habitats such as sandy beaches (Smith, 2012; Thiel *et al.*, 2013). On this basis, the potential for impact from smothering, abrasion or dislodgement, and substrate change is considered **Low** (Table 20). However, Thiel *et al*. (2013) noted high levels of polystyrene on rocky shores in Chile, and Gestose *et al*. (2019) recognised the possibility that organisms inhabiting rocky habitats could be ingesting plastic.

Table 20. Potential for impact from marine plastics on rock habitat features

Impact pathway	Rock
Ingestion	Unlikely to be relevant and with no direct evidence available
Toxicity	Unlikely to be relevant and with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Low
Substrate change	Low
Habitat provision	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**

3.4.2 Sediment

Intertidal sediments (including intertidal coarse sediment, intertidal sand and muddy sand, intertidal mud, intertidal mixed sediments, Mudflats and sandflats not covered by seawater at low tide) generally have similar impacts from marine plastics. These features are therefore grouped and described together.

Potential impact pathways documented in the literature include:

- Smothering, abrasion or dislodgement; and
- Substrate change.

Evidence suggests plastic accumulates on the strandline on sandflats and mudflats (Mathalon and Hill, 2014). This is thought to be due to the low energy environments that induce higher deposition rates of easily transported, lower density plastics, or that microplastics can become associated with microbial films, thereby reducing their capacity to get washed out of the tidal flat with the tides (Liebezeit and Dubaish, 2012). There is evidence of some changes to habitat functioning through smothering, abrasion or dislodgement. For example, Green *et al*. (2015) found that the presence of conventional and biodegradable plastic bags in mudflats created anoxic conditions within the sediment along with reduced primary productivity and organic matter and significantly lower abundances of infaunal invertebrates. Therefore, for smothering, abrasion or dislodgement, the potential for impact has been assessed as **Medium** (Table 21).

Wright *et al*. (2013) also found plastic in intertidal sediment at environmental concentrations (1 – 5% sediment by weight, 130 µm diameter) impacted deposit-feeding marine worms by depleting energy reserves. This may have arisen from a combination of reduced feeding activity, longer gut residence times of ingested material and inflammation. This shows that plastic in intertidal sediments can have an impact on habitat functioning and key prey species. Therefore, the potential for impact has been assessed as **Medium** for substrate change (Table 21).
For **subtidal sediment** (including subtidal coarse sediment, subtidal sand, subtidal mud, subtidal mixed sediments, Sandbanks which are slightly covered by sea water all the time), effects are less studied.

The potential impact pathways documented in the literature include:

- Smothering, abrasion or dislodgement; and
- Substrate change.

There is evidence that microplastic and macroplastic accumulate in subtidal sediments. Microplastics with density greater than that of sea water sink down in sediments where they accumulate. An increase in density through biofouling by organisms can result in further sinking of microplastics, and as such marine sediments can be long-term sinks for microplastics (Kershaw, 2015; Auta *et al.*, 2017). The accumulation of such debris can inhibit gas exchange between the overlying waters and the pore waters of the sediments and disrupt or smother inhabitants of the benthos (Moore, 2008). However, no specific evidence was found that indicated habitat functioning in subtidal sediment was affected by plastic pollution. The potential for impact is therefore **Undetermined** for both smothering, abrasion or dislodgement and substrate change (Table 21).

Table 21. Potential for impact from marine plastics on sediment habitat features

Impact pathway	Intertidal sediment	Subtidal sediment
Ingestion	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Toxicity	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Medium	Undetermined
Substrate change	Medium	Undetermined
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Medium**	**Undetermined**

3.4.3 Reef

Reef habitats were collated, as similar findings existed between Reefs, intertidal biogenic reefs, subtidal biogenic reefs, as well as blue mussel (*Mytilus edulis*) beds and native oyster (*Ostrea edulis*) beds. Maerl beds and *Sabellaria* reefs returned different results and are therefore described separately below.

For **reefs**, the literature documented the following impact pathways:

- Ingestion;
- Entanglement;
- Smothering, abrasion and dislodgement; and
- Substrate change.

For ingestion, papers on oysters and mussels suggest sub-lethal effects at concentrations of microplastics that are found in the environment. For example, Green *et al.* (2016) found changes in filtration rates of *M. edulis* and *O. edulis* following exposure to 25 µg/l of microplastic in mesocosm studies. Therefore, the potential for impact for ingestion is considered to be **Medium** (Table 22).

Regarding entanglement, as well as smothering, abrasion or dislodgement, on biogenic reefs, the literature suggests a **Medium** potential for impact (Table 22). The literature provides evidence of entanglement and damage from macro- and megaplastics caused by smothering, abrasion and dislodgement on various coral reef species in Florida and the Bay of Biscay (Lewis *et al.*, 2009; Van den Beld, 2017).

Additionally, in the study by Green *et al.* (2016) it was found that the associated infaunal invertebrate assemblages differed following exposure of oysters to microplastic, with significantly less polychaetes and more oligochaetes in treatments exposed to microplastics. These findings highlight the potential of microplastics to impact the functioning and structure of bivalve habitats, and, for substrate change, the potential for impact is considered to be **Medium** (Table 22).

Regarding **maerl beds**, evidence on the impact of marine plastics is limited. Whilst it is known that plastic can occur alongside maerl beds (Renzi *et al.*, 2018; Papatheodorou *et al.*, 2015), the impact of this has not been investigated, and no impact pathways have been identified. Therefore, the potential for impact is **Undetermined** (Table 22).

No direct evidence on the impact of marine plastics on ***Sabellaria* reefs** was found. Therefore, no impact pathways have been identified, and the potential for impact is **Undetermined** (Table 22).

Table 22. Potential for impact from marine plastics on reef habitat features

Impact pathway	Reefs (including biogenic reefs, mussel and oyster beds)	Maerl beds	*Sabellaria* reef
Ingestion	Medium	Unlikely to be relevant and with no direct evidence available	Theoretically possible but with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Smothering, abrasion and dislodgement	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Substrate change	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Medium**	**Undetermined**	**Undetermined**

3.4.4 Saltmarsh

Similar findings from the literature were found for all saltmarsh habitats included in the review.

The potential impact pathway that was documented in the literature for **saltmarsh** was smothering, abrasion or dislodgement.

The potential for impact is considered to be **Low** for all saltmarsh habitats (Table 23). This is based on a study by Mazarrasa *et al.* (2019) that characterised marine litter deposits in three estuaries of the Gulf of Biscay and assessed its potential impact on estuarine habitats. It was found that estuarine vegetated communities act as litter traps; the largest litter densities were found in the high marsh strata formed by large, dense and perennial vegetated communities only inundated during extreme tidal events. Lower marsh communities had lower densities explained by smaller and less stiff perennial species and more frequent inundation by tides (thus allowing plastic to be washed away). Possible impacts from plastic included light reduction, erosion, encroachment, and inhibition of sediment gas exchange (all associated with the impact pathway smothering, abrasion and dislodgement). The assessment by Mazarrasa *et al.* (2019), based on a qualitative multi-metric index (accounting for probability, vulnerability and consequence), pointed at a generally low level of potential impact of marine litter in estuarine habitats from these impact pathways. Microplastics were also found in Morecambe Bay saltmarsh habitats, but the effects were not studied (Ball, 2019).

Table 23. Potential for impact from marine plastics on saltmarsh habitat features

Impact pathway	Saltmarsh
Ingestion	Unlikely to be relevant and with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Low
Substrate change	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**

3.4.5 Dunes

There is limited evidence on the impact of plastic litter and pollution on all dune habitats.

The only potential impact pathway to **dunes** documented in the literature was smothering, abrasion or dislodgement.

Studies report relatively high densities of litter in dune habitats (Šilc *et al.*, 2018; Poeta *et al.*, 2014). Nevertheless, the potential for impact is considered to be **Low** (Table 24). This is based on a study by Mazarrasa *et al.* (2019) that characterised marine litter deposits in three estuaries of the Gulf of Biscay and assessed its potential impact in estuarine habitats. Possible impacts from plastic were noted to include light reduction, erosion, encroachment, and inhibition of sediment gas exchange (all associated with the impact pathway smothering, abrasion and dislodgement). The assessment, based on a qualitative multi-metric index (accounting for probability, vulnerability and consequence), pointed at a generally low level of potential impact of marine litter in estuarine habitats from these impact pathways. The lowest impact was expected over embryonic shifting dunes.

Table 24. Potential for impact from marine plastics on dune habitat features

Impact pathway	Dunes
Ingestion	Unlikely to be relevant and with no direct evidence available

Impact pathway	Dunes
Toxicity	Unlikely to be relevant and with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Low
Substrate change	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**

3.4.6 Vegetated sediment

Vegetated sediment included in the review comprises seagrass beds and subtidal macrophyte-dominated sediment, for which the findings were similar. Other habitat features within this group are annual vegetation of drift lines, perennial vegetation of stony banks, and vegetated sea cliffs of the Atlantic and Baltic coasts.

For **seagrass beds** and **subtidal macrophyte-dominated sediment**, impact pathways documented in the literature include:

- Smothering, abrasion or dislodgement; and
- Substrate change.

Balestri *et al.* (2017) investigated the effects of pieces of biodegradable plastic bag on seagrass beds with dwarf eelgrass *Zostera noltii* and *Cymodocea nodosa*. Whilst it is unlikely that biodegradable plastic would congregate in seagrass beds to the extent set-up in this experiment, the bags reduced sediment pore-water oxygen concentration and pH, and increased *C. nodosa* root spread and vegetative recruitment therefore impacting species growth patterns. Smothering, abrasion or dislodgement and substrate change is therefore assessed as a **Low** potential for impact (Table 25). Jones *et al.* (2020) also recorded microplastics adhering to eelgrass *Zostera marina* blades in a seagrass bed in Deerness Sound, Orkney, with an average of 4.25 plastics particles per individual. However, the effect of this smothering was not examined.

No direct evidence on the impact of marine plastics on **Annual vegetation of drift lines**, **Perennial vegetation of stony banks**, and **Vegetated sea cliffs of the Atlantic and Baltic coasts** was found in the literature, and no impact pathways have been identified. Therefore, the potential for impact is **Undetermined** (Table 25).

Table 25. Potential for impact from marine plastics on vegetated sediment habitat features

Impact pathway	Seagrass beds, and Subtidal macrophyte-dominated sediment	Annual vegetation of drift lines, Perennial vegetation of stony banks, and Vegetated sea cliffs of the Atlantic and Baltic coasts
Ingestion	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Low	Theoretically possible but with no direct evidence available

Impact pathway	Seagrass beds, and Subtidal macrophyte-dominated sediment	Annual vegetation of drift lines, Perennial vegetation of stony banks, and Vegetated sea cliffs of the Atlantic and Baltic coasts
Substrate change	Low	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Low**	**Undetermined**

3.4.7 Physiographic habitats

Estuaries, Large shallow inlets and bays, and Coastal lagoons are included as **physiographic habitats**.

Whilst evidence has been gathered on these habitats relating to the presence and movement of plastics in these environments, no specific impact pathways have been documented in the literature.

Both Estuaries and Large shallow inlets and bays are complex habitat features which comprise an interdependent mosaic of subtidal and intertidal habitats. Both can include the habitats discussed throughout this section. The worst-case, pre-cautionary, potential for impact is for reef (Section 3.4.3) and therefore the potential for impact for these habitat features is considered to be **Medium** for ingestion, entanglement, smothering, abrasion and dislodgement, and substrate change (Table 26).

For Coastal lagoons, the potential for impact is **Undetermined** (Table 26).

Table 26. Potential for impact from marine plastics on physiographic habitat features

Impact pathway	Estuaries	Large shallow inlets and bays	Coastal lagoons
Ingestion	Medium	Medium	Unlikely to be relevant and with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Entanglement	Medium	Medium	Unlikely to be relevant and with no direct evidence available
Smothering, abrasion or dislodgement	Medium	Medium	Theoretically possible but with no direct evidence available
Substrate change	Medium	Medium	Theoretically possible but with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Medium**	**Medium**	**Undetermined**

3.4.8 Overriding potential for impact for habitat features

This section presents the overriding potential for impact for habitat features, accounting for the maximum potential for impact of any habitat sub-feature that can be found within the habitat. Table 27 summarises the overriding potential for impact for each habitat feature or habitat feature group described in Section 3.4.

Table 27. Overriding habitat feature potential for impact accounting for habitat sub-features

Habitat feature or habitat group	Habitat-level potential for impact	Overriding potential for impact	Overriding habitat sub-feature
Rock	Low	Medium	Anthozoans, Barnacles, Cup corals, green algae, *Littorina* sp., *Mytilus edulis*, *Alcyonium glomeratum*, *Caryophyllia smithii*, *Eunicella verrucosa*, *Swiftia pallida*
Intertidal sediment	Medium	Medium	*Ennucula tenuis*, *Littorina* sp., *Modiolus modiolus*, *Mytilus edulis*, *Ostrea edulis*, Polychaetes, *Protodorvillea kefersteini*, *Streblospio shrubsolii*
Subtidal sediment	Undetermined	Medium	Polychaetes, *Abra alba*, *Ennucula tenuis*, *Littorina* sp., *Modiolus modiolus*, *Mytilus edulis*, *Ostrea edulis*
Reefs (including biogenic reefs, mussel and oyster beds)	Medium	Medium	Anthozoans, Barnacles, *Caryophyllia smithii*, Crustaceans, *Eunicella verrucosa*, Green algae, *Littorina* sp., *Lophelia* sp., *Modiolus modiolus*, *Mytilus edulis*, *Sarcodictyon roseum*, *Swiftia pallida*
Maerl beds	Undetermined	Low	Echinoderms
Sabellaria reef	Undetermined	Undetermined	*Sabellaria alveolata*
Saltmarsh	Low	Low	*Juncus maritimus*, *Plantago maritima*, *Puccinellia maritima*, *Salicornia* sp.
Dunes	Low	n/a	n/a
Seagrass beds	Low	Low	*Zostera angustifolia, Zostera marina, Zostera noltii*
Subtidal macrophyte-dominated sediment	Low	Medium	*Modiolus modiolus*
Annual vegetation of drift lines	Undetermined	Undetermined	*Elymus pycnanthus, Elymus repens*
Perennial vegetation of stony banks	Undetermined	n/a	n/a

Habitat feature or habitat group	Habitat-level potential for impact	Overriding potential for impact	Overriding habitat sub-feature
Vegetated sea cliffs of the Atlantic and Baltic coasts	Undetermined	n/a	n/a
Estuaries	Medium	Medium	Polychaetes, *Mytilus edulis*
Large shallow inlets and bays	Medium	Medium	Polychaetes, Barnacles, *Modiolus modiolus*
Coastal lagoons	Undetermined	Medium	*Streblospio shrubsolii*

3.5 Species features

This section focusses on the impact of plastics to species features. A summary of the potential for impact on the features is described (either individually or grouped to aid the synthesis of information) and is presented in Table 28 to Table 29. The definition of the potential for impact is provided in Table 6, and further detail on the evidence is provided in the accompanying Evidence Spreadsheet.

3.5.1 Marine mammals

Marine mammal species features include harbour porpoise *Phocoena phocoena*, bottlenose dolphin *Tursiops truncatus*, Eurasian otter *Lutra lutra*, grey seal *Halichoerus grypus* and harbour (common) seal *Phoca vitulina*.

For **bottlenose dolphin**, the following impacts pathways have been documented in the literature:

- Ingestion;
- Toxicity; and
- Entanglement.

Generally, bottlenose dolphin is thought to primarily ingest plastic indirectly, through trophic transfer from their prey. Conflicting evidence exists regarding the ingestion rates and impacts of ingested plastics. For example, Gorzelany (1998) described how fishing line had asphyxiated a bottlenose dolphin after its attempt to ingest prey. However, other studies that recorded plastic ingestion do not link it to the cause of death or even sub-lethal effects. Along the Irish coast, Lusher *et al.* (2018) found both macroplastics and mesoplastics in the digestive tracts of cetaceans which had stranded or were found as bycatch. Out of the 15 bottlenose dolphins examined, one was found with macroplastics (6.7%) and two with microplastics (13.3%). Nelms *et al.* (2019a) investigated the presence of microplastics in 50 stranded cetaceans and pinnipeds around the British coast. Low amounts of microplastics were found in all bottlenose dolphin individuals (mean = 5.5 plastics per individual, based on all cetaceans and pinnipeds studied). Approximately 85% of the plastics were fibres and 16% were plastic fragments. The relatively low number of plastics in the guts/intestines of the individuals could be due to the fact that plastics are passed in faeces. The cause of death was also not directly linked to plastic presence, and it was also suggested that sub-lethal effects, from the microplastics themselves or the chemical contaminants present on or within them, are unlikely to be attributable to plastic ingestion at the low levels recorded. In another study, plastic was not found in stranded bottlenose dolphins in Fernández *et al.* (2009) in the Canary Islands with plastic items mostly found in deep diving whales. Therefore, as the effects of ingested plastic were not determined in the literature, the potential for impact from ingestion is considered **Undetermined** (Table 28).

Limited information is available on the toxicity of plastics in bottlenose dolphin. Skin biopsy samples have been used to detect the presence of chemicals which are commonly used in the plastic making process (Baini *et al.*, 2017). The leaching of phthalate esters from plastics was detected in bottlenose, striped and Risso's dolphins and fin whale tissues from the Mediterranean Sea, likely from the accidental ingestion of plastics. However, the toxic effects of this were not studied, and therefore the potential for impact is **Undetermined** (Table 28).

Entanglement with fishing gear has been observed by Levy *et al.* (2009), and lead to the death of a bottlenose dolphin in Israel. Nylon filaments had wrapped around the larynx cutting the soft tissue of the animal down towards the forestomach where a mass of netting was found. It is likely that the blockage of the larynx led to starvation of the dolphin before stranding. This is considered to be a **Medium** potential for impact but with low confidence due to the singular study (Table 28).

For **harbour porpoise**, the following potential impact pathways have been documented in the literature:

- Ingestion; and
- Entanglement.

Ingestion rates (or retention) of plastic by harbour porpoise are generally low. Van Franeker *et al.* (2018) investigated the presence of microplastics and foreign bodies in 654 beached harbour porpoises in Texel, Holland. In total, 76 litter items were recorded (71 plastic, three paper, one non-synthetic rope, one fishing hook), and in most cases there was just one item per individual, with a maximum of five items in one individual. No litter was found in calves, however, 7% of juveniles and 8% of adults had plastic in the stomach. As low quantities of plastics were ingested, with a maximum of five items and 2.6 g of plastic occurring within individual animals, they are unlikely to have had fatal or near-fatal implications (Van Franeker *et al.*, 2018). Furthermore, less than 1% of necropsied individuals on the German North and Baltic Sea had ingested marine litter (Unger *et al.*, 2017), and zero deaths were attributed to plastic ingestion in harbour porpoise strandings on the Belgium and UK coasts (Baulch and Perry, 2014). Therefore, the potential for impact from ingestion on harbour porpoise is considered to be **Low** (Table 28). However, it is still unclear what constitutes a "lethal" level of ingested plastic, and sub-lethal effects are difficult to determine.

Unger *et al.* (2017) also recorded entanglement of stranded harbour porpoise from German waters. Entanglement was found in 0.1% (5 out of 4,006) of all harbour porpoise carcasses collected. This suggests low rates of entanglement for harbour porpoise, and as such the potential for impact is also considered to be **Low** for entanglement (Table 28).

Evidence of the impact of marine plastics on **otter** is limited, and the only potential impact pathway documented in the literature is ingestion.

There is evidence of ingestion of plastics, and it is suggested that otter is susceptible to trophic microplastic contamination. However, the impacts are not studied and therefore the potential for impact is **Undetermined** (Table 28).

The literature documents evidence on the following impact pathways for both **grey seal** and **harbour seal**:

- Ingestion; and
- Entanglement.

It is suggested that plastics are consumed when feeding on fish prey (Rebolledo *et al.,* 2013; Nelms *et al*., 2018; Nelms *et al*., 2019b), or when accidentally ingested while the seals forage on bottom dwelling or burrowed prey (Bowen *et al*., 2002). However, the impact of ingestion on seals was not studied, and therefore the potential for impact is **Undetermined** (Table 28).

With respect to entanglement in plastic, the potential for impact on seals is **Medium** (Table 28). A study conducted by Allen *et al.* (2012) on a seal haul-out site in Cornwall, UK, found 58 entangled individuals over a four-year period, with annual entanglement rates between 3.6% and 5%. Fishing nets were often wrapped tightly around the neck, causing deep lacerations, and occasionally around one or both front flippers. It has been suggested that, generally, younger seals are more often entangled than adults (Hofmeyr *et al*., 2006; Lucas, 1992), and are susceptible to becoming trapped in items that encircle the neck, creating problems during growth and significantly reducing their longer-term survival. Entanglement may also cause seals to spend more time at sea trying to feed, as injuries sustained by debris, or drag caused by trailing material, increases energetic cost and impairs movement, negatively impacting the ability to catch prey (Allen *et al.,* 2012).

Table 28. Potential for impact from marine plastics on marine mammal species features

Impact pathway	**Bottlenose dolphin**	**Harbour porpoise**	**Otter**	**Grey seal, harbour seal**
Ingestion	Undetermined	Low	Undetermined	Undetermined
Toxicity	Undetermined	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Medium	Low	Theoretically possible but with no direct evidence available	Medium
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Medium**	**Low**	**Undetermined**	**Medium**

3.5.2 Fish

Evidence on the impact of plastics was only found for European smelt *Osmerus eperlanus*, black seabream *Spondyliosoma cantharus*, allis shad *Alosa alosa* and twaite shad *Alosa fallax*. Other fish species features included giant goby *Gobius cobitis*, couch's goby *Gobius couchi*, long snouted seahorse *Hippocampus guttulatus*, short snouted seahorse *Hippocampus hippocampus*, sea lamprey *Petromyzon marinus*, and river lamprey *Lampetra fluviatilis*.

For **smelt**, the following potential impact pathways were documented from the literature:

- Ingestion; and
- Toxicity.

McGoran *et al*. (2017) studied plastic ingestion in European smelt in the River Thames. Whilst ingestion of plastics was recorded, the effect of this was not examined, and the potential for impact is **Undetermined** (Table 29).

Within the McGoran *et al*. (2017) study, Rochman *et al*. (2013) is cited, who exposed Japanese medaka fish *Oryzias latipes* to 8 ng/ml of polyethylene with persistent bioaccumulative and toxic substances adsorbed on the surface (e.g. polycyclic aromatic hydrocarbons and polychlorinated biphenyls – adsorbed following deployment in San Diego Bay). The fish showed signs of stress in their livers, including glycogen depletion, fatty vacuolation and single cell necrosis. Glycogen depletion was seen in 74% of fishes exposed to this dosage, as well as a mortality rate of 6%. The concentration used is considered environmentally relevant and therefore, for toxicity, the potential for impact is considered **Medium** (Table 29).

For **black seabream**, **allis shad**, and **twaite shad**, the only impact pathway documented in the literature was ingestion.

In general, the potential for impact is considered to be **Undetermined** for ingestion in both these species (Table 29). This is because, whilst there is evidence of ingestion of microplastic in these species, the effects on health have not been quantified (though possible effects have been the subject of speculation).

No direct evidence on the impact of marine plastics on **other fish** species features was found. Therefore, the potential for impact is **Undetermined** (Table 29). However, for lamprey species it may be unlikely they will be exposed to high concentrations given they feed on the blood of other fish.

Table 29. Potential for impact from marine plastics on fish species features

Impact pathway	Black seabream	Smelt	Allis shad	Twaite shad	Other fish
Ingestion	Undetermined	Undetermined	Undetermined	Undetermined	Theoretically possible but with no direct evidence available

Impact pathway	Black seabream	Smelt	Allis shad	Twaite shad	Other fish
Toxicity	Theoretically possible but with no direct evidence available	Medium	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Overall impact	**Undetermined**	**Medium**	**Undetermined**	**Undetermined**	**Undetermined**

3.5.3 Anthozoans and cnidarians

The only cnidarian within the review for which evidence of marine plastic impacts has been found is for pink sea-fan *Eunicella verrucosa*. The impacts on this species are summarised in Section 3.3.1. The potential for impact to this species is assessed as **Medium** due to entanglement, and smothering, abrasion and dislodgement from plastic debris and litter.

3.5.4 Molluscs

For molluscs, only the native oyster *Ostrea edulis* is included as a species feature. As summarised in Section 3.3.4, the potential for impact from ingestion of microplastics is considered to be **Medium**.

3.5.5 Crustaceans

For crustaceans, only spiny lobster *Palinurus elephas* and lagoon sand shrimp *Gammarus insensibilis* are included as species features. For spiny lobster, the potential for impact is based on the information summarised for other crustaceans in Section 3.3.2, and as such is assessed as **Medium** due to ingestion. For lagoon sand shrimp, the assessment is based on the same evidence summarised for amphipods in Section 3.3.2 and as such has a **Low** potential for impact from ingestion.

3.6 Bird features

This section focusses on the impact of plastics to bird features. A summary of the potential for impact on bird features is described (either individually or grouped to aid the synthesis of information) and is presented in Table 30 to Table 36. The definition of the potential for impact is provided in Table 6, and further detail on the evidence is provided in the accompanying Evidence Spreadsheet.

3.6.1 Procellariiformes (tubenoses: shearwaters, storm/diving petrels, albatross)

The Procellariiformes or tubenoses are the group of birds most widely associated with plastic pollution in the marine environment and as a group have been identified as being at higher risk than other seabirds due to their unique gizzard morphology (Roman *et al*. 2019). Within English and Welsh SPAs and SSSIs, this group incorporates three species: European storm petrel *Hydrobates pelagicus* (Leach's storm-petrel *Oceanodroma leucorhoa* is also a feature of SPAs in Scotland), fulmar *Fulmaris glacialis* and Manx shearwater *Puffinus puffinus*.

For **fulmar**, ingestion was the only potential impact pathway documented in the literature.

The literature provides evidence of ingestion for fulmar, which has been adopted under the Marine Strategy Framework Directive as an indicator species for the abundance of plastic in the environment (because fulmar are abundant and widespread seabirds known to regularly ingest litter, with nearly all individuals having at least some plastic in their stomachs indicative of recently ingested material due to low residence times in the stomach) (OSPAR, 2020). Fulmar has been assessed as having a **Medium** potential for impact (Table 30), based on high levels of incidence in sampled birds. For example, around the North Sea, van Franeker *et al.* (2011) found that that 95% of 1,295 beached fulmars had plastic in their stomachs, and 58% had >0.1 g of plastic in their stomachs (critical level based on OSPAR Quality Objective for marine litter). Furthermore, unlike other bird species (e.g. gulls), fulmarine petrels do not usually regurgitate indigestible hard items, as explained by Van Franeker *et al.* (2015). They only spit out stomach contents in fear, in fights, or when feeding their chicks, and in these cases only materials from the glandular first stomach (proventriculus) are lost as the narrow passage to the second muscular stomach (gizzard) prevents materials in the gizzard from returning to the proventriculus. Therefore, most plastic particles accumulate in the muscular gizzard and are ground up until they are small enough to pass into the intestines (along with other hard food or debris items).

However, the subsequent impact of the ingested plastic is less well understood, as fulmar are known to be able to break down and excrete plastic material in relatively short time frames (at most every few weeks or even a number of days) (Van Franeker *et al.*, 2011). Whilst this may indicate a lower potential for impact, Acampora *et al*. (2017) hypothesise that regurgitating recently ingested marine plastics to feed chicks may lead to the observed higher incidences of plastic in juveniles of the species, and this may result in a higher impact on the young fulmar. In addition, potential inefficiencies in foraging may lead to post-fledging juveniles ingesting higher quantities of plastics than adult individuals (Trevail *et al*., 2015, Riotte-Lambert *et al.*, 2013). This is supported by evidence on another Procellariiform species, the Layan albatross. Auman *et al.* (1997) identified that chicks dying of natural causes in the Midway Atolls had significantly greater masses of plastic, lighter body masses and lower fat indices than chicks considered otherwise healthy but killed through injury / accident.

For **Manx shearwater**, the potential impact pathways documented in the literature were:

- Ingestion; and
- Toxicity.

Approximately 30 – 60% of Manx shearwater across several studies had ingested plastic. In one example Manx shearwater was found to have the highest average mass of ingested plastic of all seabirds (3 g per bird; Moser and Lee, 1992). Therefore, the potential for impact is considered **Medium** (Table 30).

Regarding toxicity, plastic was also observed to increase the concentration of lower chlorinated polychlorinated biphenyls in the tissues of short-tailed shearwaters (Yamashita *et al*., 2011). Tanaka *et al.* (2020) also fed five plastic resin pellets laced with flame retardant and ultraviolet stabilizers to 37-day old streaked shearwater chicks in Japan. Leaching led to the exposed chicks (N=11) accumulating these additives in the liver and adipose fat, with up to 120,000 times more than from a natural diet. Short-tailed shearwaters *Puffinus tenuirostris* in the north Pacific Ocean were also found to have plastic derived chemicals (polybrominated diphenyl ethers) in abdominal adipose from ingested plastic (Tanaka *et al.,* 2013). The direct effects of accumulation of the additives in the body tissues were not investigated, and therefore the potential for impact is **Undetermined**.

Ingestion was also the only potential impact pathway documented in the literature on **storm petrel**.

Storm petrel is assessed as of **Medium** potential for impact (Table 30). Significantly lower recorded incidences of ingestion were found by Furness (1985), where zero of 21 sampled individuals had ingested plastic in its stomach contents in Dun, St Kilda, Scotland. However, the results of this single study may be outdated and unreliable. Therefore, fulmar and Manx shearwater are considered viable proxies. A low confidence score, however, recognises that this score is based on proxy species, and future research outcomes may identify different incidences and lead to a revision of the potential for impact.

Table 30. Potential for impact from marine plastics on Procellariiformes bird features

Impact pathway	Fulmar	Manx shearwater	Storm petrel
Ingestion	Medium	Medium	Medium
Toxicity	Theoretically possible but with no direct evidence available	Undetermined	Theoretically possible but with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Overall impact	**Medium**	**Medium**	**Medium**

3.6.2 Suliformes (gannets, cormorants, frigate birds)

Suliformes are grouped and include cormorant *Phalacrocorax carbo*, shag *Phalacrocorax aristotelis* and gannet *Morus bassanus*.

The potential impact pathways that have been documented in the literature include:

- Ingestion;
- Entanglement; and
- Habitat provision.

In general, significantly lower rates of ingestion is evidenced compared with the Procellariiformes discussed above, and therefore the potential impact for this pathway is **Low** for all species (Table 31).

There is significant evidence for both gannet and cormorant of entanglement in the marine environment, which supports an assessment of **Medium** potential for impact across the three species in English and Welsh designated marine sites (Table 31). There is evidence of the interaction between marine debris and birds swimming or floating in the marine environment. The literature predominantly reports interactions with derelict 'ghost' fishing gear, although other marine plastics may also pose a risk. Good *et al.* (2009) identify *Phalacrocorax* sp.as the most commonly found birds entangled in ghost fishing gear, making up 40% of the birds recorded entangled off the coast of Washington, USA (approximately 200 of 500 seabirds found). Similarly, gannet are at risk from ghost fishing, and multiple studies record entangled individuals. One study identified rates of entanglement between 1% and 20% of gannet individuals observed in offshore surveys (Spain / North-Africa; Rodriguez *et al.* 2013).

Habitat provision is also documented in the literature for these species, linked with the incorporation of marine plastic debris into nests. Montevecchi (1991) identified that 97% of gannet nests incorporated plastic in Canada, and Podolsky and Kress (1989) reported plastic incorporated into up to 40% of double-crested cormorant nests. Votier *et al.* (2011) identified 80% of gannet nests in Wales contained plastic and recorded 65 incidences of mortality from entanglement (predominantly juveniles); it was considered that this rate of entanglement is unlikely to represent a population level impact on the 78,000 strong colony. Therefore, the potential for impact is considered **Medium**. Whilst gannet nests show the highest levels of plastic incorporation into nests and evidence of resulting mortality, other species may also be impacted through this pathway.

Table 31. Potential for impact from marine plastics on Suliformes bird features

Impact pathway	Cormorant, shag, gannet
Ingestion	Low
Toxicity	Theoretically possible but with no direct evidence available
Entanglement	Medium[5]
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available
Habitat provision	Medium[6]
Overall impact	**Medium**

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[5] Literature has not specifically been identified for shag, however sufficient evidence is available for cormorant that this can be considered as a proxy, particularly given the similarities in environmental niche and behaviour between the species.

[6] Evidence of a detrimental effect has only been identified for gannet, though other species are known to use plastic as a nest building material and may have a similar potential for impact.

3.6.3 Charadriiformes (skua, gulls, terns, auks, waders)

The Charadriiformes include a wide range of birds in the marine environment, with differing feeding strategies and therefore differing interactions with marine plastics.

Auks have been grouped together and potential impact pathways that have been documented include:

- Ingestion; and
- Entanglement.

The nature of the pursuit divers in prey selection means that auks on average ingest less marine plastic directly, with few razorbill *Alca torda* or guillemot *Uria aalge* sampled across multiple studies having ingested plastics. Therefore, the potential for impact from ingestion is considered **Low** (Table 32). It should be noted that puffin *Fratercula arctica* shows a greater incidence, but no mechanism for direct ingestion is suggested, and this may therefore be linked to marine plastics in prey species.

Auks (guillemot, black guillemot *Cepphus grylle*, puffin and razorbill), as pursuit divers, spend more time in the water column, and therefore may to be at greater risk of entanglement. Therefore, a **Medium** potential impact is assigned (Table 32). However, significant literature evidence is only available to draw this conclusion for puffin (Gall and Thomson, 2015) and this proxy is used for other species, although sufficient data to assess potential population level impacts is not available.

The potential impact pathways documented in the literature on **waders** are:

- Ingestion; and
- Entanglement.

With regard to ingestion of plastics, waders spend the majority of their time at the edge of the marine environment, foraging in shallow waters or in intertidal areas. The majority of waders are therefore expected to exhibit a similar potential for impact, allowing proxy information to be widely used. One study (Lourenço *et al.*, 2017) reviews the incidence of plastic in multiple wading species faeces, and the incidence of plastics in the gizzard of dunlin *Calidris alpina*. Whilst incidence of plastics, particularly microplastic fibres, in faeces is found to be high across all species, the incidence of plastic in dunlin gizzards indicates that plastic has, on average, a low residence time within the birds. This supports a conclusion of **Low** potential for impact via an ingestion pathway across all wader species (Table 32).

There is limited evidence across wading species for entanglement, with some examples recorded for some species, but on average at a low rate of incidence. This indicates that the potential for impact from entanglement for wader species is also **Low** (Table 32), but the confidence in this assessment is less than that for the ingestion pathway.

Gull impact pathways that have documented also include:

- Ingestion;
- Entanglement; and
- Habitat provision.

Gulls tend towards scavenging type behaviours, including a number of species observed as thriving amongst terrestrial refuse dumps (Gyimesi *et al.*, 2016). Therefore, where exposure to plastic in the environment is high, incidence of plastic ingestion is also generally higher. However, gull species seem not to suffer detrimental effects due to this, and may benefit (Gyimesi *et al.*, 2016). Furthermore, Seif *et* *al.* (2018) examined the ingestion of plastics in herring gull *Larus argentatus*, greater black-backed gull *Larus marinus* and Icelandic gulls *Larus glaucoides* in Newfoundland, Canada, to assess how plastics may impact body condition. They found no correlation between ingested plastic burden and individual condition; it was suggested that gulls can eject debris (boluses) to maintain levels below thresholds that influence body condition. Therefore, the potential for impact on gulls from ingestion is considered to be **Low** (Table 32).

Similarly, the potential for impact from entanglement is considered to be **Low** (Table 32), as there are few examples of entanglement of gulls in the marine environment (literature records are only found for two out of seven species). For example, Camphuysen (1990) recorded a total of 3,223 individuals washed up dead on Dutch beaches, of which five (0.2%) were recorded as entangled in marine debris.

Regarding habitat provision, Hartwig *et al.* (2007) record plastic in 57% of kittiwake *Rissa tridactyla* nests at a colony in Denmark. However, no assessment of the impact of this is undertaken, and therefore the potential for impact is **Undetermined**.

For **terns**, the literature documented two impact pathways:

- Ingestion; and
- Entanglement.

The majority of tern species are active hunters, hovering to identify prey before diving through the sea surface. As such, the incidence of direct plastic ingestion would be expected to be lower than for other species which are less selective. This is borne out by the evidence available, where across the species of tern studied, incidence of ingested plastic is observed to be low (Tavares *et al.*, 2017, Moser and Lee, 1992, Franco *et al.*, 2019) and therefore the potential for impact from ingestion on tern species is considered to be **Low** (Table 32).

Similarly to gulls, there are few records for entanglement of tern species in the marine environment, with only one study undertaking a quantitative analysis (Camphuysen, 1990; one out of 67 birds washed up dead on Dutch beaches was entangled) and one study recording qualitatively that Arctic tern *Sterna paradisaea* have been observed as entangled in fishing net (Bergmann *et al.*, 2017). The potential for impact from entanglement is therefore considered to be **Low** (Table 32), but the confidence in this assessment is also low given the paucity of data available.

Table 32. Potential for impact from marine plastics on Charadriiformes bird features

Impact pathway	Auks	Waders	Gulls	Terns
Ingestion	Low	Low	Low	Low
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Medium[7]	Low	Low	Low
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct	Unlikely to be relevant and with no direct	Unlikely to be relevant and with no direct	Unlikely to be relevant and with no direct

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[7] This assessment of medium is based on records of entanglement for Atlantic puffin *Fratercula arctica*, which is the only auk species for which entanglement risk has been defined.

Impact pathway	Auks	Waders	Gulls	Terns
	evidence available	evidence available	evidence available	evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Undetermined	Theoretically possible but with no direct evidence available
Overall impact	**Medium**	**Low**	**Low**	**Low**

3.6.4 Gaviiformes (divers) and Podicipediformes (grebes)

Both divers and grebes are pursuit divers, fulfilling similar ecological niches, and are therefore discussed together here.

The literature documented the following potential impact pathways for **divers**:

- Ingestion; and
- Entanglement.

There are a number of different studies which report rates of ingestion in red-throated diver *Gavia stellata* and great northern diver *Gavia immer*. The results of these studies identify generally low ingestion across the species, with the largest study (Forrester *et al*., 1997) identifying zero incidences across 434 sampled great northern diver between 1970 and 1994. The potential for impact from ingestion across the diver species is therefore considered to be **Low** (Table 33).

There are records of entanglement for diver species, indicating some risk. However, these records tend to be qualitative (such as Gilardi *et al.*, 2010) and where a more quantitative approach was taken a relatively low rate of entanglement was encountered (Camphuysen, 2008). The potential for impact is therefore considered **Low** for entanglement (Table 33).

There is no literature evidence documented for **Slavonian grebe** *Podiceps auritus* for any impact pathway (aside from some information of set-net entanglement).

Whilst the evidence against diver species could potentially be considered as a proxy for the risk of plastic ingestion, grebes have a specific physiological adaptation, using ingested feathers to form a 'plug' in their digestive tract (Piersma and Van Eerden, 1989). This may increase or decrease the potential for impact from ingestion of plastics depending on its function. It is currently uncertain whether it supports bolus (regurgitate) production (Piersma and Van Eerden, 1989), or extends the residence time of less digestible matter (Jehl, 2017). The potential for impact for Slavonian grebe is therefore **Undetermined** (Table 33).

Table 33. **Potential for impact from marine plastics on Gaviiformes and Podicipediformes bird features**

Impact pathway	Red-throated diver, black-throated diver, great northern diver	Slavonian grebe
Ingestion	Low[8]	Theoretically possible but with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Low	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Overall impact	**Low**	**Undetermined**

3.6.5 Anseriformes (ducks, geese, swans)

Whilst the variation in body type is generally less across the Anseriformes than for Charadriiformes discussed above, there is significant variation in feeding mechanism.

For **dabbling ducks**, the following impact pathways have been documented in the literature:

- Ingestion; and
- Entanglement.

The dabbling ducks (four species in English and Welsh SPA / SSSI) are generally freshwater species, and feed by upending and selecting vegetation from the underwater environment. Based on this selective behaviour, rates of ingestion are likely to be low, as supported by the available evidence such as in Holland *et al*. (2016), which identifies that 10 of 185 sampled dabbling ducks had ingested plastic. The potential impact from ingestion is therefore considered to be **Low** (Table 34).

No direct literature is available for entanglement but given the predominantly freshwater environment where dabbling ducks are generally found, potential for interaction with ghost fishing gear or other entangling plastic in the marine environment is also likely to be **Low** (Table 34).

For **diving duck**, only entanglement is documented in the literature.

There are two species of diving duck within English and Welsh SPA or SSSI (pochard *Aythya ferina* and scaup *Aythya marila*). There is very limited evidence available for these species, with no specific evidence regarding the ingestion impact pathway. Based on the selective feeding technique employed by diving ducks, and the evidence available for dabbling ducks (above) and seaducks (below) it could be inferred that potential impact from ingestion is likely to be low, however insufficient evidence is

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[8] This assessment of low potential for impact against the ingestion pathway is based on evidence available for red-throated diver and great northern diver as proxy species.

available to support this. There is only a single reference to entangled scaup (Good *et al.*, 2009). The potential impact on diving ducks is therefore currently **Undetermined** (Table 34).

In comparison to the diving ducks there is a larger evidence base for **seaduck** (five species in English and Welsh SPA / SSSI). Two impact pathways have been documented in the literature:

- Ingestion; and
- Entanglement.

The majority of the evidence relates to eider *Somateria mollissima* and indicates a **Low** potential for impact from ingestion (Table 34). English *et al.* (2015) and Holland *et al.* (2016) both identify low (2-3%) incidence of ingested plastic in Eider. There is less evidence available for other seaduck species, but eider is considered an appropriate proxy to conclude (although with low confidence) low potential for impact. It is, however, recognised that depending on prey species some seaduck species may be at risk from bioaccumulation of plastic from their diet (e.g. through grazing on mussel beds).

A **Low** potential for impact from entanglement has been identified for seaducks (Table 34). Camphuysen (2008) identified that of a large sample size (19,494) only 0.2% of beached eider were entangled in plastic.

There are seven species of **goose** designated in English and Welsh SPAs, with limited information available for any of them. The only impact pathway documented in the literature was ingestion.

There are two papers which consider the ingestion of plastic by goose species in Canada and South Africa (Holland *et al.*, 2016, Reynolds and Ryan, 2018). Both papers identified low rates (1 – 4%) of ingestion across the geese sampled, indicating that the potential for impact on geese from the ingestion of plastic is **Low** (Table 34).

No literature evidence has been found for **swans**, and therefore the potential for impact is **Undetermined** (Table 34).

Table 34. Potential for impact from marine plastics on Anseriformes bird features

Impact pathway	Dabbling duck	Diving duck	Seaduck	Geese	Swans
Ingestion	Low	Theoretically possible but with no direct evidence available	Low	Low	Theoretically possible but with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Low	Undetermined	Low	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available

Impact pathway	Dabbling duck	Diving duck	Seaduck	Geese	Swans
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Overall impact	Low	Undetermined	Low	Low	Undetermined

3.6.6 Pelecaniformes (spoonbill, egret, bittern)

There is very little evidence available for Pelecaniformes in relation to either ingestion or entanglement.

For **bittern** *Botaurus stellaris*, no evidence is documented in the literature reviewed for any impact pathway and therefore the potential for impact is **Undetermined** (Table 35).

For **little egret** *Egretta garzetta*, only evidence on the subject of ingestion is documented in the literature reviewed.

Evidence is limited to investigations of the stomach contents of one individual little egret where no plastic was found (Basto *et al.*, 2019). The potential for impact is therefore **Undetermined** (Table 35).

For **spoonbill** *Platalea leucorodia*, the impact pathways documented in the literature include:

- Ingestion;
- Entanglement; and
- Habitat provision.

No plastic was found to be ingested in one individual spoonbill (Basto *et al.*, 2019). Therefore, as only one individual was examined, the potential for impact is **Undetermined** (Table 35).

For habitat provision, Lee *et al.* (2015) report the use of plastic marine debris (plastic food wraps, sheets, films, strings, ropes and nets) as nesting materials by Spoonbill in Korea. There is only one instance of spoonbill entangled in plastic fishing wire in its nest (Hong *et al.*, 2013). The potential for impact for both entanglement and habitat provision is therefore **Undetermined** (Table 35).

Table 35. Potential for impact from marine plastics on Pelecaniformes bird features

Impact pathway	Bittern	Little egret	Spoonbill
Ingestion	Theoretically possible but with no direct evidence available	Undetermined	Undetermined
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Undetermined
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Undetermined
Overall impact	**Undetermined**	**Undetermined**	**Undetermined**

3.6.7 Terrestrial Birds (Accipitriformes / Caprimulgiformes / Passeriformes)

There are very few sources of literature for the terrestrial birds that have been identified as specific protected bird features.

For **harriers**, no evidence is documented in the literature reviewed for any specific impact pathway.

The only information found was an assessment of potential risk based on a developed metric on hen harrier *Circus cyaneus* (Mahon *et al.*, 2014), or as part of more general pressure on the habitat supporting Montagu's harrier *Circus pygargus* (Cvitanic, 1999). Therefore, the potential for impact is **Undetermined** (Table 36).

For **nightjar** *Caprimulgus europaeus*, only entanglement is documented in the literature as a potential impact pathway.

A single instance of entanglement is available for nightjar (Ryan, 2018). Therefore, the potential for impact is **Undetermined** (Table 36).

For **aquatic warbler** *Acrocephalus paludicola*, no evidence is documented in the literature reviewed for any impact pathway and therefore the potential for impact is **Undetermined** (Table 36).

Table 36. Potential for impact from marine plastics on terrestrial bird features

Impact pathway	Accipitriformes (harriers)	Caprimulgiformes (nightjar)	Passeriformes (aquatic warbler)
Ingestion	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Toxicity	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Entanglement	Theoretically possible but with no direct evidence available	Undetermined	Theoretically possible but with no direct evidence available
Smothering, abrasion or dislodgement	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Substrate change	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available	Unlikely to be relevant and with no direct evidence available
Habitat provision	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available	Theoretically possible but with no direct evidence available
Overall impact	**Undetermined**	**Undetermined**	**Undetermined**

4 Prioritisation

The outputs of the literature review and impact assessment have been used to undertake a prioritisation exercise in order to identify which protected habitat and species have the highest potential for impact, and thus are most at risk from marine plastic.

The highest potential for impact of any habitat feature, sub-feature, species or bird feature is Medium, this means that generally either:

- Sub-lethal effects on species were found in the environment or at environmental concentrations following exposure to plastic;
- Effects on species from marine plastic have been observed in the environment at the species level (i.e. there is no evidence of population level effects); or
- There is some evidence of altered habitat functioning due to marine plastic.

Table 37 summarises the protected species or habitat groups and their corresponding potential for impact from marine plastic pollution. The degree of confidence in the assessment is also provided to indicate the associated uncertainty. This priority list should be kept under regular review in the light of new evidence on effects to these important habitats and species.

The prioritisation of protected habitats and species helps to inform where the greatest risks of impact from marine plastic pollution lie. . In the future it may be possible to use this sensitivity and exposure information to target monitoring, regulatory action and conservation effort. For example, in instances where high densities of plastic pollution are measured near habiatats and species which have high sensitivity, it may be appropriate to prioritise these areas for further investigation and intervention, where possible. Whilst plastic pollution is a widespread issue and comes from a variety of sources, many of these are regulated activities or processes and therefore are subject to assessment at the permitting stage which allows for the potential environmental impacts to be addressed. If the sensitivity of the receiving environment is understood, then SNCBs are better placed to advise regulators on the level of risk and approporiate avoidance and mitigation measures can be employed to prevent a negative impact occurring.

Table 37. protected habitats and speceis and corresponding potential for impact in order of prioritisation

Protected species/habitat group	Species/habitat group	Potential for impact	Confidence
Habitat sub-features			
Corals	Anthozoan	Medium	Low - Medium
Barnacle	Crustacean	Medium	Low - Medium
Other crustaceans	Crustacean	Medium	Medium
Bivalves (incl. blue mussel *Mytilus edulis,* and native oyster *Ostrea edulis*)	Mollusc	Medium	Low - Medium
Common periwinkle *Littorina littorea*	Mollusc	Medium	Medium
Microalgae	Microalgae	Medium	Medium
Polychaetes	Polychaete	Medium	Low - Medium

Protected species/habitat group	Species/habitat group	Potential for impact	Confidence
Protodorvillea kefersteini	Polychaete	Medium	Low
Anemones	Anthozoan	Low	Low
Amphipod	Crustacean	Low	Low - Medium
Opossum shrimp *Neomysis integer*	Crustacean	Low	Low
Speckled sea louse *Eurydice pulchra*	Crustacean	Low	Low
Purple sea urchin *Paracentrotus lividus*	Echinoderm	Low	Medium
Holothurians	Echinoderm	Low	Low
Other echinoderms	Echinoderm	Low	Low
Peppery furrow shell *Scrobicularia plana*	Mollusc	Low	Low
Sludge worm *Tubifex tubifex*	Oligochaete	Low	Low
Ascidians	Ascidian	Low	Low
Macroalgae	Macroalgae	Low	Low
Angiosperms	Angiosperms	Low	Low
Brittlestars	Echinoderm	No effect	Low
Hydrozoans	Hydrozoan	No effect	Low
Bryozoans	Bryozoan	No effect	Low
Spirobranchus triqueter	Polychaete	No effect	Low
Spiny mudlark *Brissopsis lyrifera*	Echinoderm	Undetermined	n/a
Fan worm *Serpula vermicularis*	Polychaete	Undetermined	n/a
Habitat features			
Intertidal sediment	Sediments	Medium (Medium based on sub-features)	Low (Low - Medium based on sub-features)
Reefs (incl. biogenic reefs, mussel and oyster beds)	Reef	Medium (Medium based on sub-features)	Low - Medium (Low - Medium based on sub-features)
Estuaries	Physiographic habitats	Medium (Medium based on sub-features)	Low (Medium based on sub-features)
Large shallow inlets and bays	Physiographic habitats	Medium (Medium based on sub-features)	Low (Low - Medium based on sub-features)
Rock	Rock	Low (Medium based on sub-features)	Low (Low - Medium based on sub-features)
Subtidal macrophyte-dominated sediment	Vegetated sediment	Low (Medium based on sub-features)	Low (Low based on sub-features)

Protected species/habitat group	Species/habitat group	Potential for impact	Confidence
Subtidal sediment	Sediments	Undetermined (Medium based on sub-features)	n/a (Low - Medium based on sub-features)
Coastal lagoons	Physiographic habitats	Undetermined (Medium based on sub-features)	n/a (Medium based on sub-features)
Saltmarsh	Saltmarsh	Low (Low based on sub-features)	Low (Low based on sub-features)
Dunes	Dunes	Low	Low
Seagrass beds	Vegetated sediment	Low (Low based on sub-features)	Low (Low based on sub-features)
Maerl beds	Reef	Undetermined (Low based on sub-features)	n/a (Low based on sub-features)
Sabellaria reef	Reef	Undetermined (Undetermined based on sub-features)	n/a
Annual vegetation of drift lines	Vegetated sediment	Undetermined (Undetermined based on sub-features)	n/a
Perennial vegetation of stony banks	Vegetated sediment	Undetermined	n/a
Vegetated sea cliffs of the Atlantic and Baltic coasts	Vegetated sediment	Undetermined	n/a
Species features			
Bottlenose dolphin *Tursiops truncatus*	Marine mammal	Medium	Low
Grey seal *Halichoerus grypus*	Marine mammal	Medium	High
Harbour seal *Phoca vitulina*	Marine mammal	Medium	Medium
Smelt *Osmerus eperlanus*	Fish	Medium	Low
Pink sea-fan *Eunicella verrucosa*	Anthozoan	Medium	Medium
Native oyster *Ostrea edulis*	Mollusc	Medium	Medium
Spiny lobster *Palinurus elephas*	Crustacean	Medium	Low
Harbour porpoise *Phocoena phocoena*	Marine mammal	Low	Medium
Lagoon sand shrimp *Gammarus insensibilis*	Crustacean	Low	Medium
Otter *Lutra lutra*	Marine mammal	Undetermined	n/a

Protected species/habitat group	Species/habitat group	Potential for impact	Confidence
Black seabream *Spondyliosoma cantharus*	Fish	Undetermined	n/a
Allis shad *Alosa alosa*	Fish	Undetermined	n/a
Twaite shad *Alosa fallax*	Fish	Undetermined	n/a
Other fish	Fish	Undetermined	n/a
Other cnidarians	Cnidarian	Undetermined	n/a
Bird features			
Fulmar *Fulmarus glacialis*	Procellariiformes	Medium	Medium
Manx shearwater *Puffinus puffinus*	Procellariiformes	Medium	Low
Storm petrel *Hydrobates pelagicus*	Procellariiformes	Medium	Low
Cormorant *Phalacrocorax carbo carbo*	Suliformes	Medium	Low
Shag *Phalacrocorax aristotelis*	Suliformes	Medium	Low
Gannet *Morus bassanus*	Suliformes	Medium	Medium
Auks	Charadriiformes	Medium	Low - Medium
Waders	Charadriiformes	Low	Low - Medium
Gulls	Charadriiformes	Low	Low
Terns	Charadriiformes	Low	Low
Black-throated diver *Gavia arctica*	Gaviiformes	Low	Low
Red-throated diver *Gavia stellata*	Gaviiformes	Low	Medium
Great northern diver *Gavia immer*	Gaviiformes	Low	Medium
Dabbling duck	Anseriformes	Low	Low
Seaduck	Anseriformes	Low	Low - Medium
Geese	Anseriformes	Low	Low
Slavonian grebe *Podiceps auritus*	Podicipediformes	Undetermined	n/a
Diving duck	Anseriformes	Undetermined	n/a
Swans	Anseriformes	Undetermined	n/a
Bittern *Botaurus stellaris*	Pelecaniformes	Undetermined	n/a
Little egret *Egretta garzetta*	Pelecaniformes	Undetermined	n/a
Spoonbill	Pelecaniformes	Undetermined	n/a

Protected species/habitat group	Species/habitat group	Potential for impact	Confidence
Platalea leucorodia			
Harriers	Accipitriformes	Undetermined	n/a
Nightjar *Caprimulgus europaeus*	Caprimulgiformes	Undetermined	n/a
Aquatic warbler *Acrocephalus paludicola*	Passeriformes	Undetermined	n/a

5 Evidence Gaps

5.1 Gap analysis

The outcomes of the gap analysis are discussed in this section of the report. This has also been recorded in the Evidence Spreadsheet. The definitions of the categories used in the gap analysis are presented again in Table 38, for ease of reference, as well as in Table 5 (Section 2.1.1).

Table 38. Gap analysis definitions

Gap analysis	Definition
Mutually exclusive definitions	
No evidence	No evidence was found for habitats or species and interactions with, or effects of, marine plastic (i.e. no literature)
Limited evidence	There is a limited amount of evidence on the interactions with, and/or effects of, marine plastic on a species or habitat
Multiple evidence	There are multiple pieces of evidence on the interactions with, and/or effects of, marine plastic on a species or habitat (this does not imply that impacts/effects are well-known and should not be studied further)
Compatible definitions	
Proxy evidence	No evidence on specific habitats or species and interactions with, or effects of, marine plastic, but evidence is available for similar habitats or species that can be used as proxies
No UK evidence	The available evidence is not based on studies in the field in UK waters
Conflicting evidence	There is conflicting evidence on the interactions with, or effects of, marine plastic on a species or habitat

Although the issues of plastic pollution have garnered a lot of attention in the public domain and scientific community, effects on specific protected habitats and species of biodiversity interest features in England and Wales are still relatively poorly understood. Many of the habiatats and species, particularly the characterising species of the habitat sub-features, had no information at all on the impact of plastics in the marine environment. Approximately 74%, 46%, 60% and 8% of habitat sub-features, habitat features, species features and bird features respectively did not return any relevant literature on marine plastic impacts (Table 39).

Where information did exist, the majority of features had limited evidence (Table 39). Most of the existing studies investigated a limited amount of plastic types, at specific sizes, shapes, and concentrations, and only examined certain biological end points. Limited evidence was available for 21% of habitat sub-features, with only 5% considered to have multiple evidence. For habitat features, 54% had limited evidence, and no habitat features were considered to have multiple evidence. Approximately 20% of species features had limited evidence, and a further 20% of species features were considered to have multiple evidence on the impact of marine plastics. For bird features, 81% were considered to have limited evidence, and 12% had multiple evidence.

As a result of the sparsity of evidence at an protected feature level, the potential for impact for the majority of MPA features was assessed as Undetermined. This was the case for 224 of 310 (72%) habitat sub-features, 24 of 59 (41%) habitat features, 21 of 30 (70%) of species features, and 24 of 103 (23%) of bird features. These features are detailed in the accompanying Evidence Spreadsheet.

Even for the features where there was evidence available (either direct or proxy evidence), most evidence was not gathered in the UK (i.e. 'No UK evidence') thereby reducing the confidence in the applicability of the information (see Table 7). This was case for 78% of habitat sub-features, 63% of habitat features, 58% species features, and 59% of bird features (Table 39). This lack of evidence of impacts arising from plastic in UK waters is verified by the fact that a High confidence score has only been assigned to the evidence gathered for one protected feature. The only High confidence score is associated with grey seal *Halichoerus grypus*, as Allen *et al.* (2012) report on entanglement of grey seals at a haul out site in Cornwall, UK (thereby increasing the applicability of that evidence to the interest feature). There are other instances where evidence has been gathered in the UK, but this rarely investigates the effects of marine plastic, and is often not accompanied with other lines of evidence.

For some MPA features, proxy evidence was relied upon to gather information on the impact of marine plastics. This was the case for 24 habitat sub-features, two species features, and 17 bird features (Table 39) (though proxy information was also used to determine the potential for impact – see Section 2.1.1). Conflicting evidence was also identified for three of 81 habitat sub-features (4%), one of 12 species features (8%), and two of 95 bird features (2%) (Table 39). This apparent agreement in the literature might be partly attributable to the relative infancy of marine plastic research (i.e. there are a limited amount of comparable studies that replicated experiments or have examined similar impact pathways, in similar species).

Those features with multiple evidence tended to have slightly higher potential for impact scores. For example, 12 of 15 habitat sub-features that were considered to have multiple evidence were assessed as having a Medium potential for impact. This might suggest that as the evidence base grows for a particular species or habitat, and more impact pathways are identified and different plastics are tested (types, sizes, and shapes), deleterious effects are more likely to be identified. With lesser studied organisms, it is possible impact pathways have been missed that might be important. The fact that most of the Protected features included in this review have limited or no evidence available might allude that the potential for impact is underestimated in some cases. A good example of this is the lack of evidence on juvenile life stages (see Section 5.2). The counter argument to this is that researchers have so far focussed on the most obvious problem issues, and further research may not uncover more significant or previously unrecognised problems related to marine plastics.

Table 39. Evidence gap analysis for information on plastic impacts on MPA habitat features

Gap analysis	Habitat sub-feature	Habitat feature	Species feature	Bird feature
No evidence	229/310 (74%)	27/59 (46%)	18/30 (60%)	8/103 (8%)
Limited evidence	66/310 (21%)	32/59 (54%)	6/30 (20%)	83/103 (81%)
Multiple evidence	15/310 (5%)	0/59 (0%)	6/30 (20%)	12/103 (12%)
Proxy evidence	24/81 (30%)	0/32 (0%)	2/12 (17%)	17/95 (18%)
No UK evidence	63/81 (78%)	20/32 (63%)	7/12 (58%)	56/95 (59%)
Conflicting evidence	3/81 (4%)	0/32 (0%)	1/12 (8%)	2/95 (2%)

5.2 Wider evidence gaps

Alongside the high-level implications associated with the generally limited evidence that is available of marine plastic and MPA features (discussed above), evidence gaps relating to impact pathways and receptors have been identified from the review and in the wider literature. These include (but are not limited to):

- Nanoplastic effects;
- Effects at juvenile and larval life stages;
- Toxicity effects either from plastic leachates or other pollutants adsorbed to plastic surfaces; and
- Sub-lethal effects for larger marine organisms (e.g. birds and marine mammals).

Research on microplastics and nanoplastics has received increasing attention in recent years, driven by the concern of the continuous degradation of larger plastics in the environment (Alimi *et al.*, 2018). However, of the two, nanoplastic has received less attention. This represents a significant evidence gap, as there are studies that show limits to the size of microplastics that can traverse digestive gland tissue and enter the circulatory system and other organs. Nanoplastics are small enough to cross biological membranes, and therefore their potential to cause impact might be increased. Furthermore, the concentrations of nanoplastic in the environment are generally unknown due to the lack of reliable detection and quantification technologies (Koelmans *et al.,* 2017; Silva *et al.*, 2020).

Effects of plastics at early life stages are also studied less in comparison with adult life stages. There is evidence that deleterious effects are realised at juvenile and larval life stages. For example, the larval stages of the barnacle *Amphibalanus amphitrite* were examined by Gambardella *et al.* (2017) and neurotoxic effects and oxidative stress were evident following exposure to environmentally relevant concentrations of nanoplastic beads (0.1 µm; 0.001 mg/l up 10 mg/l). Bhargava *et al.* (2018) also found that bioaccumulation occurred in *A. amphitrite* nauplii even at low concentrations (1 mg/l) and particles persisted through the subsequent cyprid and juvenile growth stages. Effects have also been found in ascidian and echinoderm larvae, and it is concluded that microplastics can affect sensitive stages of life cycle and this may have consequences on generation recruitment (Messinetti *et al.*, 2018). Furthermore, it is likely that exposure to plastics will differ at different life stages (e.g. free-floating life stages versus settled life stages), particularly where ingestion of certain particle sizes and diet changes with body size. Given the comparative lack of evidence on species at larval and juvenile life stages, further research should be undertaken to better understand risks to adult life stages and potential population level effects.

It is clear that there is potential for plastics to adsorb marine pollutants onto their surface, and that this could be another vector for harmful substances to enter marine organisms following uptake. This is sometimes likened to a ‘Trojan horse’ effect for pollutants (Galloway *et al.*, 2017). However, studies show that bioaccumulation of other pollutants (such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons) in marine species is not increased by the uptake of plastics (Browne *et al.*, 2013; Besseling *et al.*, 2013; Paul-Pont *et al.*, 2016; Besseling *et al.*, 2017) and therefore plastics are unlikely to increase the rate of bioaccumulation compared with natural particles. However, synergistic effects may occur. For example, small sized plastics may reach animal tissues more directly (Browne *et al.*, 2013), or there may be a reduced ability to detoxify pollutants with plastics accumulated in the body (Paul-Pont *et al.*, 2016). Li *et al.* (2015) also showed toxic effects of plastic leachate complexes, though the specific plastic additive responsible for the effect was difficult to determine. As such, chemical toxicity effects associated with plastics is less well understood, compared with ingestion impact pathways that impact feeding, digestion, and energy stores.

In this literature review, invertebrates were commonly studied with multiple evidence available. de Sá (2018) highlights that among the reports of microplastics in marine organisms, fish are the most commonly studied group (25%), followed by molluscs (15%), small crustacea (11%), large crustacea (8%) annelid worms (6%), mammals and echinoderms (both 3%), birds and cnidaria (both 2%), and porifera

(<1%). The large volume of literature on smaller organisms is possibly because laboratory studies can easily be undertaken, and sub-lethal biological endpoints can be readily examined, whereas research on the impacts of marine plastics on larger species such as birds and marine mammals must be done in the field. It is sometimes possible to determine if interactions with plastics caused lethal effects from field studies (e.g. entanglement). However, there are many examples of birds and marine mammals having ingested plastics in the environment, but the actual effect of that plastic, particularly at a sub-lethal level, is very difficult to determine (and whether this has the potential to cause population level effects). This represents an evidence gap.

6 Conclusion

A total of 326 unique references were gathered and reviewed as part of the literature review. Based on this evidence, marine plastic pollution is at current levels unlikely to pose a high risk to protected features in England and Wales at concentrations of plastic that can be considered currently environmentally relevant levels, although it is expected that these levels could rise. Smaller marine organisms (such as fish and invertebrates) are exposed to smaller plastic particles (microplastics and nanoplastics) and have been shown to exhibit biological effects. However, lethal effects have rarely been observed, and where they are, the plastic concentrations tested tend to far exceed environmental relevance (Galloway *et al.*, 2017). Larger marine species (such as birds and marine mammals) are more vulnerable to larger plastic debris that they may ingest or become entangled with. However, no evidence currently suggests that this is having population level effects. Similarly, whilst studies suggest some localised effects on habitat functioning, such as smothering by plastic bags, the decline of habitats due to plastic pollution is not evidenced. As such, the maximum potential for impact assigned to any protected feature is Medium.

Notwithstanding the above, it is important to note that the issue of marine plastics is a relatively new topic in scientific research, and it can be argued that the impact and effects of plastics in the environment are relatively poorly understood. Furthermore, plastic in the marine environment will continue to increase (possibly quite rapidly) and degrade into smaller plastic particles, increasing exposure to marine organisms. Long-term risks or sub-lethal impacts of exposure to plastics are also particularly uncertain at the current time, and the persistent nature of plastic means exposure would be continuous throughout all life stages and would not decrease in the environment. Therefore, any assessment of the potential for impact provided in this review should be interpreted with an appropriate degree of caution (especially given that the potential for impact is based on the current available evidence, which in many cases is limited). The results discussed here use the available evidence on the impacts of marine plastic which is sparse in some areas. New studies on impacts of plastic are emerging all the time and this evidence should be considered as it becomes available. It is therefore recommended that this report and the accompanying Evidence Spreadsheet are kept under regular review to keep pace with emerging issues and research.

Based on the available evidence, a list of protected features can be inferred as being of relatively higher risk from plastics and therefore higher priority for conservation effort related to plastic pollution. When considering these potential priorities due regard should be given to the caveats associated with the generally limited available evidence and low confidence in the assessment discussed throughout this report. Furthermore, the wider evidence gaps relating to plastic types (e.g. nanoplastic), impact pathways (e.g. toxicity effects), receptors (e.g. species at larval and juvenile life stages, and sub-lethal effects to birds and marine mammals) and scalability to the population level should be recognised.

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8 Abbreviations/Acronyms

Cefas	Centre for Environment, Fisheries and Aquaculture Science
Defra	Department for Environment, Food and Rural Affairs
DNA	Deoxyribonucleic Acid
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
IEG	Impact Evidence Group
JNCC	Joint Nature Conservation Committee
MarESA	Marine Evidence-based Sensitivity Assessment
MBIEWG	Marine Biodiversity Impacts Evidence Working Group
MCZ	Marine Conservation Zones
MMO	Marine Management Organisation
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive
NC	North Carolina
NRW	Natural Resources Wales
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
PCB	Polychlorinated Biphenyl
PSG	Project Steering Group
SAC	Special Areas of Conservation
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UK	United Kingdom
USA	United States of America

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