



Scoping review of research on environmental effects of biodegradable plastics relevant to Norwegian conditions

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Panel on Microbial Ecology of the Norwegian Scientific Committee for Food and Environment

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Preparation of the Scoping Review

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to prepare a scoping review. The group consisted of VKM members, one external expert and VKM staff. The Committee, by the Panel on Microbial Ecology has assessed and approved the final Scoping Review.

Authors of the opinion

The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2023). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and/or the VKM Panel on Microbial Ecology as approval group, appointed specifically for the assignment.

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Expertise of VKM experts

Individuals working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The provisions on impartiality in the Norwegian Public Administration Act apply to all work carried out by VKM.

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Summary

Introduction

There is an increasing global production and demand for biodegradable plastics. But there are still many uncertainties about how and to what extent these plastics degrade and their environmental impacts. To gain a better understanding of these aspects, the Scientific Committee for Food and Environment (VKM) has conducted a self-initiated scoping review of existing scientific literature on biodegradable plastics and their environmental impacts.

Methods

VKM has specifically focused on studies that are relevant to Norwegian and Nordic conditions. The first literature search (June 2024) revealed 2428 international research studies, including primary studies and systematic and non-systematic review articles. The primary studies were divided into three categories: materials, microbiology and ecotoxicology, based on the main focus of the studies. From each category, a quarter of the primary studies and non-systematic review articles were randomly selected for full text analysis. A total of 168 articles were included in the final mapping. A new literature search (October 2025), with a focus on Nordic research and particularly Norwegian conditions, revealed 178 articles, of which 19 were subject to further analysis.

Results

The most studied types of biodegradable plastics were polylactic acid (PLA), polyhydroxyalkanoate (PHA) and polybutylene adipate terephthalate (PBAT). Many of the studies focused on the degradation process of biodegradable mulch film used in agriculture, and how their use affects the environmental conditions in agricultural soils. Most studies reported incomplete degradation during the trial period, which underlines the concern for accumulation of plastic material with repeated use. Other studies simulated different pollution scenarios, such as lost fishing gear, an area that has received attention in recent Nordic studies. Ecotoxicological effects of biodegradable plastics were often only observed at concentrations far above those expected to occur in natural environments. There were indications that effects observed in soil and aquatic ecosystems could just as well be indirect, resulting from changes in physical and chemical properties of soil and water. In general, the effects of biodegradable plastics are comparable to those of conventional (micro)plastics in both terrestrial and aquatic ecosystems. However, there were studies that suggest that biodegradable plastics are more toxic than conventional plastics under specific conditions, such as after UV exposure, or for certain test organisms. Testing the ecotoxicity of commercial biodegradable plastics was complicated by the lack of transparency about their chemical composition. Only a minority of studies investigated the ecotoxicity of chemical substances leaching from plastic materials, and the results reported were inconsistent.

Uncertainty

There is a lack of studies that combined degradation studies with toxicological effects. This knowledge gap has also been pointed out in systematic review articles. The review revealed several weaknesses in the existing research, related to study design, analytical methods, definitions and terminology.

Conclusion

Current research practice provides many individual studies that are difficult to compare. Thus, they provide limited insight into how degradation and environmental impact occur over time, and in different environments. The review points to the need for strengthened and standardized research, so that the knowledge base becomes more robust and a better understanding of the environmental impact of plastics over time and in different environments can be gained.

Sammendrag

Introduksjon

Produksjonen og etterspørselen etter bionedbrytbar plast øker globalt. Likevel er det fortsatt mange uklarheter rundt hvordan og i hvilken grad plasten brytes ned, og hva dens miljøpåvirkninger er. For å få en bedre forståelse av disse aspektene, har Vitenskapskomiteen for mat og miljø (VKM) gjennomført en omfattende selvinitiert systematisk kartlegging av eksisterende vitenskapelig litteratur om bionedbrytbar plast og dens miljøeffekter.

Metoder

VKM har spesielt satt søkelys på studier som er relevante for norske og nordiske forhold. Det første litteratursøket (juni 2024) avdekket 2428 internasjonale forskningsstudier, inkludert primærstudier og systematiske og ikke-systematiske oversiktsartikler. Primærstudiene ble delt inn i tre kategorier: materialer, mikrobiologi og økotoksikologi, ut fra studienes hovedfokus. Fra hver kategori ble en fjerdedel av primærstudiene og ikke-systematiske oversiktsartikler tilfeldig valgt ut for en grundigere analyse. Totalt ble 168 artikler inkludert i den endelige kartleggingen. Et nytt litteratursøk (oktober 2025), med søkelys på nordisk forskning og særlig norske forhold, avdekket 178 artikler, hvorav 19 ble gjenstand for videre analyse.

Resultater

De mest studerte typene bionedbrytbar plast var polymelkesyre (PLA), polyhydroksyalkanoat (PHA) og polybutylen adipat tereftalat (PBAT). Mange av studiene hadde søkelys på nedbrytningsforløpet til bionedbrytbar plastdekket brukt i landbruket, og hvordan bruken påvirker miljøforholdene i landbruksjord. De fleste studiene rapporterte om ufullstendig nedbrytning i løpet av forsøksperioden, noe som understreker bekymringen for akkumulering av plastmateriale ved gjentatt bruk. Andre studier simulerte ulike forurensningsscenarioer, som tapt fiskeredskap, et område som har fått oppmerksomhet i nyere nordiske studier. Økotoksikologiske effekter av bionedbrytbar plast ble som regel først påvist ved konsentrasjoner som ligger langt over det som forventes forekomme i naturlige miljøer. Det var indikasjoner på at effekter observert i jord- og vannøkosystemer like gjerne kunne være indirekte, som følge av endringer i fysiske og kjemiske egenskaper i jord og vann. Generelt var effektene av bionedbrytbar plast sammenlignbare med effektene av konvensjonell (mikro)plast i både jord- og vannøkosystemer. Det var imidlertid studier som fant at bionedbrytbar plast kunne være *mer* giftig enn konvensjonell plast under spesifikke forhold, som for eksempel etter UV-eksponering, eller for bestemte testorganismer. Testing av økotoksisiteten til kommersiell bionedbrytbar plast var ofte vanskelig på grunn av mangelen på åpenhet om plastens kjemiske sammensetning. Bare et mindretall av studiene undersøkte økotoksisiteten til kjemiske substanser som lekker fra plastmaterialer, og resultatene beskrevet var uensartet.

Usikkerhet

Det er mangel på studier som kombinerte nedbrytningsstudier med toksikologiske effekter. Dette kunnskapshullet ble også påpekt i systematiske oversiktsartikler. Kartleggingsoversikten avslørte flere svakheter i den eksisterende forskningen, knyttet til studiedesign, analysemetoder, definisjoner og terminologi.

Konklusjon

Dagens forskningspraksis gir mange enkeltstudier som er vanskelige å sammenligne. Dermed gir de begrenset innsikt i hvordan nedbrytning og miljøpåvirkning skjer over tid, og i ulike miljøer. Kartleggingen peker på behovet for styrket og standardisert forskning, slik at kunnskapsbasen blir mer robust og man kan få en bedre forståelse av plastens miljøpåvirkning over tid og i ulike miljøer.

Abbreviations

APRIO	Agent, Pathway, Receptor, Intervention, and Output
ASTM	American Society for Testing and Materials
BDM	Biodegradable mulch
EFSA	European Food Safety Authority
ISO	International Organization for Standardization
PA	Polyamides
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PBSA	Polybutylene succinate co-adipate
PBSAT	Polybutylene succinate co-adipate-co-terephthalate
PCL	Polycaprolactone
PE	Polyethylene
PEG-PLA	Poly(ethylene glycol)–Poly(lactic acid)
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PHAs	Polyhydroxyalkanonates (refers to polymers included in the PHA-family)
PHB	Polyhydroxybutyrate (a type of PHA)
PLA	Poly(lactic acid)
PP	Polypropylene
PPC	Poly(propylene carbonate)
PPDO	Polydioxanone
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PS	Polystyrene
PVA	Polyvinyl alcohol
PVP	Polyvinylpyrrolidone
ScR	Scoping Review
TPS	Thermoplastic starch
VKM	Vitenskapskomiteen for mat og miljø (Norwegian Scientific Committee for Food and Environment)

Glossary

Additives are chemicals added to plastic products during manufacturing to enhance or modify their properties.

Bio-based plastics are obtained from renewable resources such as algae, bacteria and plants. They may be biodegradable or not. Feedstocks for microbial production (bacteria and microalgae) of bio-based plastics may include different organic waste categories or metabolites from their biotic or abiotic conversion (e.g. methane from biogas plants and pyrolysis wax).

Biodegradable plastics are bio-based or fossil-based polymeric materials that are designed to be converted to CO₂ (and methane under anoxic conditions), mineral salts and biomass through the action of microorganisms.

Biodegradable plastic products are certified to biodegrade in specific types of environments (e.g. soil or marine environment) within a given temperature range and timespan. Like conventional plastic products, biodegradable plastic products contain various additives for desired performance, functionality and appearance.

Composites are material blends. An example of polymer blend is PBAT/PLA, which most often combines a fossil-based biodegradable polymer (PBAT, although biobased versions exist) with PLA, which is a biobased polymer.

Compostable plastics are a subset of biodegradable plastics that require industrial composting at high temperature (~58°C) for efficient biodegradation to occur.

Ecotoxicology concerns the study of the harmful effects caused by natural and synthetic pollutants to biota in aquatic and terrestrial ecosystems.

Environmental effects are the result of the impacts left on organisms, their habitats and ecosystems, and the environment as a biogeochemical entity, from actions of anthropogenic or natural origin. The effects may be beneficial or detrimental.

Fossil-based plastics are polymeric materials derived from petrochemicals.

Leachates are in the context of this report plastic additives and other chemical substances that leach from plastic materials to the environment.

Life cycle analysis is used as a method to understand impacts of a commercial product, process, or service through all life stages.

Mesocosms are simulated outdoor experimental systems that replicate the natural environment under controlled conditions.

Microbial ecotoxicology is a multidisciplinary scientific research area including microbial ecology, microbial toxicology, physics and chemistry (Ghiglione et al., 2016)

Microorganisms are micro-sized living organisms that are not visible to the naked eye when in unicellular form but may form visible biofilms when growing in arranged multicellular form. The definition technically includes bacteria, archaea, fungi, microalgae (single-celled plants) and protists. Although incapable of reproducing outside a host, viruses and prions are often included in the term.

Microplastics are particles of synthetic or semi-synthetic organic polymer or rubber between 1 µm and 5 mm in size along their largest dimension (NAMC)¹. Particles between 1 nm and 1 µm are considered nanoplastics (Gigault et al., 2018).

Outdoor environments are all natural ecosystems including terrestrial, riverine, lacustrine, and marine environments. This includes also human-impacted ecosystems, such as agro-environments and recreational areas.

Plastics are synthetic or semi-synthetic materials made of one or more organic polymeric substances as the main ingredient.

Plastisphere is an ecosystem consisting of microorganisms that live on plastic surfaces.

Polymers/polymeric materials are natural or synthetic macromolecules that consist of repeated units (building blocks) called monomers. All plastics are polymers, but not all polymers are plastics.

¹ Definition developed by NAMC, North Atlantic Microplastic Centre

1 Introduction

1.1 Background

In this self-initiated scoping review, VKM mapped research on the environmental impacts of biodegradable plastics, including (bio)degradation rates and material persistence in different environments and geographical regions, the influence on microbial activity and ecology, and ecotoxicological effects of materials and associated chemical substances. Related to this is also research associated with the development of methodology, standards, environmental risk assessment, life-cycle impact analysis, material sources, and other characteristics of biodegradable plastics and products.

Plastic pollution and the release and spreading of micro- and nano plastics and plastic additives is a serious and growing global environmental challenge that affects wildlife, humans and ecosystems (Agamunthu et al., 2019). Plastics that can degrade in the environment through natural microbial processes have been developed with the aim to reduce persistent plastic pollution (SAPEA, 2020).

Biodegradable plastics are generally considered environmentally friendly, and many stakeholders view this diverse group of polymers as part of the solution to reduce the accumulation of plastic in the environment (Kumar et al., 2024). There are currently numerous plastic products on the market that are claimed to be biodegradable in the environment. However, there is limited knowledge about the polymer characteristics and additive compositions of these products, their biodegradation timespan in the environment, and the environmental consequences of their intended use or unintended spread to other environments.

Biodegradation in the open environment is a system property.

Biodegradable plastics intended to biodegrade in the open environment require the presence of microorganisms able to biodegrade the polymers in question, as well as the final products that may have different biodegradability characteristics compared to the pristine polymers. If biodegradability in a certain type of environment is proven, the biodegradation rate will rely on the same environmental factors that govern microbial activity in general, with temperature, moisture, pH, and availability of oxygen and mineral nutrients being the main drivers. As such, the biodegradation of biodegradable plastics is a system property with significant variables associated with both material properties across polymers, composites and products, and the environmental conditions that determine their biodegradation rate, and hence residence time in the environment (SAPEA, 2020). Microorganisms are categorized into four distinct groups based on their temperature span for growth, named psychrophiles (<0 to 20 °C, optimum ~15 °C), mesophiles (15 to 45 °C, optimum ~20 °C), thermophiles (45 to 70 °C) and extreme and hyperthermophiles (70 to 122 °C), illustrating their capacity for adaption to temperature conditions across environments and geographical regions. As a general rule, microbial activity increases with temperature up to the organisms' optimal growth temperature, after which it declines as the maximum temperature tolerance approaches. The ability of microorganisms to inhabit and adapt to a wide range of temperatures is not the only factor influencing the biodegradability of plastics in the environment. The native microbiomes must also possess the genetic capacity to biodegrade the plastic polymers in question; a trait associated with the ability to produce hydrolytic enzymes.

Adding to the complexity, different types of environments, like soil, freshwater and marine environments, harbor distinct microbiomes with unique phylogenetic and metabolic composition, as well as growth dynamics adapted to the physicochemical characteristics of their respective environments. Furthermore, there are compartments within each type of environment where the conditions for and level of microbial activity may vary significantly; for example, nutrient-rich marine sediments differ greatly from oligotrophic marine waters. This complexity necessitates at a minimum separate certifications for biodegradability in soil, marine and freshwater environments, as well as for different climate zones given the substantial impact that temperature has on biodegradation rates.

From the perspective of producers, users and waste managers of biodegradable plastics, there are also significant challenges regarding the application and management of biodegradable plastics. In the absence of comprehensive regulation, there is a potential for misinformation, inaccurate labelling and greenwashing (Dijkstra et al., 2020; Nazareth et al., 2019). This may lead to unintentional misuse and improper waste handling, increasing the risk of plastic pollution in the open environment. Inaccurate waste handling may also compromise other waste categories, such as conventional plastics collected for recycling, with negative consequences including reduced quality of recycled conventional plastic material (Staplevan et al., 2024). There is also a risk of microplastic pollution in agricultural soils from the use of compost derived from composting of compostable plastics (Nourozi et al., 2024). Furthermore, there are reports on operational issues in biogas plants and presence of biodegradable plastics in biogas digestates due to the lack of degradability of biodegradable plastic food-waste bags under anaerobic digestion (Coutris et al., 2025a; Larsen et al., 2025). Biogas plants, unlike industrial composting facilities, are a growing waste management industry in Norway. This warrants special attention to the quality of biogas digestates produced, with (micro)plastic content being an important factor.

Biodegradable plastics have found common use in Norway as mulching film in agriculture, as single use plastic bags for food waste, single use glasses for beverages, single use cutlery, and various types of packaging for transport of consumer goods. While mulch film is intended for incorporation into soil after a growing season and presumably biodegradable in soil at ambient temperatures, most packaging materials are intended for composting at their end of life. There are standards for biodegradation of biodegradable plastics in agricultural soils (EN 17033:2018) and for industrial composting of compostable plastics (EN 13432:2000, EN 14995:2006). Compostable plastic bags used for food waste collection must be removed prior to waste treatment involving biogas production, which is now the most common waste treatment method for food waste in Norway. Discarded biodegradable plastics from food waste collection are then commonly incinerated.

Biodegradable agricultural mulch films are seeing an increasing popularity in Norwegian vegetable production, compared to reusable and recyclable plastic mulch films, as the latter require labour intensive operations of collection and storage. Biodegradable mulch films commonly serve a single growth season, before they are incorporated into soil by rototilling at the end of the season. However, up to three annual applications have been reported in lettuce production by Norwegian farmers (pers. comm. Cecilie Baann, NIVA). While users are mainly satisfied with this practice, fragments of wind-borne mulch film have been observed to settle in surrounding vegetation ([DGRADE](#), NIBIO)¹.

Norway has well-functioning systems for domestic and corporate source separation of plastic waste, organized by Grønt Punkt as well as Norsirk, Plastretur and Felleskjøpet Agri for

agricultural plastics. However, one concern regarding biodegradable plastics is that even small amounts entering the waste streams of conventional plastics can compromise the recyclability of collected plastic waste, since biodegradable plastics contaminating conventional plastic waste will cause malfunctioning of recycling processes and render the recycled material unsuitable for reuse.

Besides the use of biodegradable food waste bags and agricultural applications, marine applications of biodegradable plastics for use in fisheries are currently assessed by research institutions in Norway associated to the research-based innovation centre Dsolve². Through this scoping review we provide an overview of the current research status on biodegradable plastics in Norway and other Nordic countries, as well as providing an overview of the status within global research on this emerging topic.

1.2 Terms of reference

According to the mandate for performing a scoping review, this self-task study will map and review literature addressing biodegradable plastics and their effects on the environment with focus on studies relevant to Norwegian and Nordic countries conditions.

There is an urgent need to map knowledge about the composition of products marketed as biodegradable plastics, their biodegradation efficiency in the environment and associated environmental effects to understand and predict the environmental consequences of the range of intended and increased use of these plastics in Norway.

The mandate for the project is as follows:

- Conduct a scoping review of the research on biodegradable plastics and possible effects on the environment (microbial, ecotoxicological), focusing on Norwegian/Nordic conditions.
- Identify and describe the environmental factors that may have a bearing on microbial degradation of biodegradable plastics used in agriculture, horticulture and aquaculture in Norway.

1.3 Aim

The aim of this scoping review was to map scientific literature on biodegradable plastics and their effects on the environment with a focus on conditions relevant to Norway and other Nordic countries.

The objectives were to 1) determine the extent of evidence summarized in reviews and original research papers within this emerging research area, and 2) map the evidence

¹<https://www.nibio.no/prosjekter/dgrade-nedbrytning-av-bionedbrytbar-plast-i-jord-og-avfallsstrommer>

² <https://dsolve-sfi.no/en>

according to the materials and chemicals studied, types of environments and geographical regions covered, the research questions addressed, the type of endpoints measured, and to summarize the reported key findings.

2 Methodology and data

VKM decided to perform a scoping review including systematic reviews, non-systematic reviews and primary studies to map research on this topic. VKM drafted a priori protocol for this scoping review, which was reviewed and approved by the Panel on Microbial Ecology (VKM Panel). The final protocol was published on March 20, 2025.

Two separate searches were conducted based on the same protocol and search words but differing regarding geographical inclusion/exclusion. The first literature search did not discriminate between geographical origins, and the studies included are considered to represent the generic pool of studies published within this scientific topic. The second Nordic search was designed to capture studies relevant to Norwegian and Nordic conditions.

The scoping review was conducted according to PRISMA-ScR guidelines (Tricco et al., 2018) and based on the included searches of databases. Uncertainties associated with research studies were assessed applying EFSA guidelines and their generic list of common types of uncertainty affecting scientific studies and assessments.

2.1 Global literature search and selection

The search strategy was based on the APRIO model adopted by EFSA for development of problem formulation of scientific assessment (Paoli et al., 2022), and the search words (see Appendix 2) were chosen in cooperation with a research librarian who also conducted the literature searches.

The search had no geographical restriction, but was restricted to the following languages, English, Norwegian, Danish and Swedish, and the following electronic databases, CAB Abstracts (2014 to 2024), Ovid MEDLINE(R), Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed Citations, Daily, and Versions (2014 to 2024), and Scopus. The global literature search was performed in June 2024.

After removing 12 duplicates, 2428 articles were evaluated. There were six researchers involved in the abstract and title screening. The researchers were divided into three pairs of reviewers that we call 'groups'. Thus, each abstract and title were screened by two reviewers. They assessed publications for relevance and coded them by study level (primary study, systematic review, non-systematic review) and themes (Material, Microbiology, and Ecotoxicology). Appendix 3 presents information regarding the statistical method used to select 25 % of the primary papers and non-systematic reviews which were used in data charting.

The complete abstract screening results were exported from Rayyan in the Comma Separated Values (csv) format. The sampling of articles relied on the base R function sample (Appendix 4). Library data.table, version 1.14.8, was used to handle the data. Information regarding sampling by using statistic program R, can be found in Appendix 4.

2.2 Nordic literature search

A dedicated Nordic literature search was conducted since the global search failed to capture sufficient data from studies from Norway and other Nordic countries. The literature search targeting Nordic studies was based on the same protocol as the global search but modified to capture studies performed in Norway or Nordic countries and/or by Norwegian/Nordic scientists.

Two differences were introduced in this search, compared to the global search. One was the limitation to Nordic conditions, and one in the Medline search, where one line with MeSH terms was added: Biodegradation, Environmental/and (Plastics/ or Microplastics/).

The search was conducted in October 2025 and captured 178 articles that were evaluated by two researchers.

2.3 Data charting

According to the protocol (VKM et al., 2025), we aimed to determine the extent and characteristic of evidence for environmental effects of biodegradable plastics relevant to Norwegian conditions in published original studies, non-systematic reviews and systematic reviews.

As per protocol for this review we included in the scope of the search all biodegradable, including compostable, materials that are labelled as plastics, nano-, micro- meso- and macroplastics, including also bioplastics since this umbrella term also covers biodegradable plastics from both fossil and biobased sources. The term bioplastics is also often used as a synonym for biodegradable plastics, which is not correct since the term also covers conventional plastics made from renewable sources and other biobased plastics that are not biodegradable (SAPEA, EU policy framework on biobased, biodegradable and compostable plastics). As a preliminary guideline, the current biodegradable plastics were named in the protocol: polylactides (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (biobased and fossil-based PBS), thermoplastic starches (TPS), polyethylene adipate terephthalate (biobased and fossil-based PBAT) as well as fossil-based polycaprolactone (PCL) and polyvinyl alcohol (PVA).

The authors and the members of the VKM Panel discussed and agreed which data should be included in the mapping process and designed uniform charting tables based on this. The data selected for extraction included the main objective(s) of the studies, scientific field(s) included (Material, Microbiology, Ecotoxicology), biodegradable plastic polymer(s) or composites assessed, study design and type of environment targeted, and endpoints included.

It was beyond the aim of this scoping review to discriminate the publications captured in the literature search based on the perceived quality of the studies, which implied that all publications were charted, regardless of their peer review quality. However, aspects related to e.g. study design, methodology and terminology were discussed based on our observations while charting the published data.

3 Selected sources of evidence

The charted data from original research articles were summarized separately for the three categories Material, Microbiology, and Ecotoxicology. However, to acknowledge the

multidisciplinarity of the studies, all the scientific fields involved were recorded for each study across the different categories.

A synthesis of the findings from the data charting is presented in section 3.2, together with an account of articles excluded at this stage due to errors in the sorting and/or inclusion process (tables 1, 2, 3, 4, and 5 in Appendix 6).

The systematic review papers were charted for data without categorization. The number of systematic reviews was limited, and only four out of the six papers obtained from the search were included. They collectively covered a broad focus area (see section 3.2.2). For the systematic reviews we intended, as per protocol, to chart data also from the original studies reviewed, but since the research focus varied significantly across the four papers, we found it appropriate to limit the data charting to the data compiled in the systematic studies.

The included papers that were non-systematic reviews were not charted for data since the methodology for most of these reviews was not stated. However, a summary of each study is provided in Appendix 5.

3.1 Results from the global literature search

The literature search resulted in 2428 publications (see figure 1). The records included book chapters and conference papers in addition to primary studies, non-systematic and systematic reviews. The number of records excluded was 1777, including book chapters, conference papers and studies that were not about biodegradable plastics, but were e.g. about conventional plastics or biopolymers that are not considered plastics.

A total of 639 publications were sought for retrieval, and the original studies were categorised according to their main scientific focus. From each of the categories Material, Microbiology and Ecotoxicology, and the non-systematic reviews, 25 % were randomly selected for data charting. Since only a limited number of systematic reviews were captured, they were all included in the data charting.

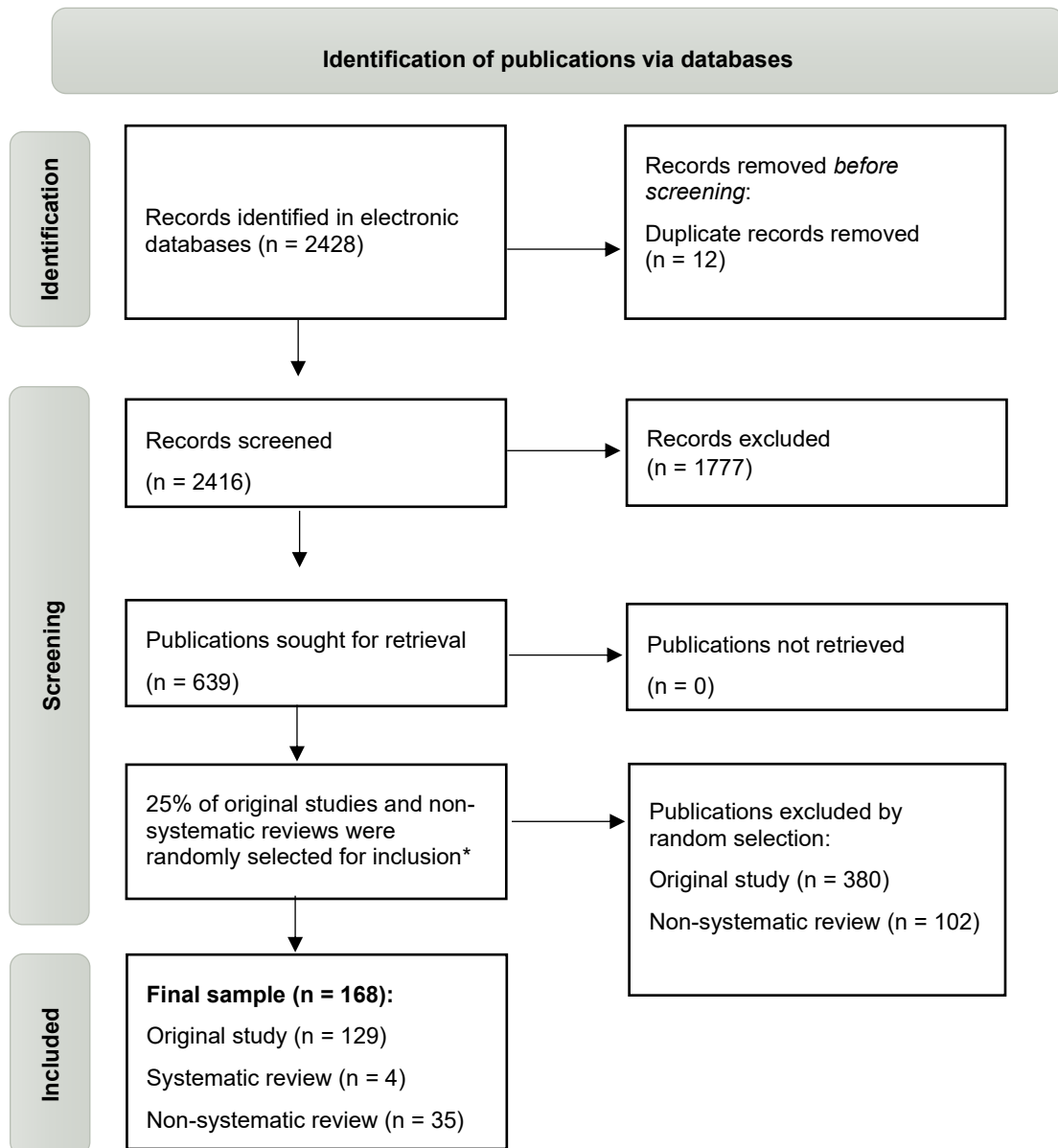


Figure 1. PRISMA 2020 flowchart for the selection of studies (Page et al., 2021).

*Due to random selection of original articles and non-systematic reviews only, the final sample constituted about 26% (materials=36, ecotoxicology=46, and microbiology=47).

3.2 Study characteristics

A general characteristic of the primary studies charted was their high level of multidisciplinary. Typically, experimental studies included several research questions and endpoints approached by various methods. This allowed for a broader view of the studied system but also led to a high degree of variations in the experimental designs and methodology, limiting the opportunity to directly compare studies, a fact that also impacted the charting process.

3.2.1 Primary studies

3.2.1.1 Research topic Material

A random selection of 25 % of the included original papers classified under the research category 'Material' resulted in 36 papers.

Excluded

Out of the 36 papers, ten were excluded after reading the full texts. The reason behind this was that two of them were desk studies and not describing original research (Min et al., 2020; Viera et al., 2021), two were conference papers (Al-Salm, 2020; Potting & van der Harst, 2014), three were not about biodegradable plastics but about other biodegradable polymers (Romero et al., 2023; Sudhakar et al., 2021; Wang et al., 2020), two were non-systematic reviews (Degli-Innocenti et al., 2023; Simó-Cabrera et al., 2021) and one was a perspective paper (Wani et al., 2021).

Papers that may be argued to be classified into another category than Material were not re-classified, as this would distort the a priori approach adopted while sampling among the included papers. However, the scientific focus and/or multidisciplinary profile of all papers is still recorded in the charting tables across all categories, and all studies are eligible as references in the summary and discussions across all relevant scientific topics, as set out in the final discussion section (Chapter 5).

Research focus, objectives and endpoints

Overall, most of the research focused on PLA materials, including their (bio)degradability, environmental impacts and sources or methods of polymer production. The frequency with which the various polymer groups were addressed in original studies on material properties was PLA>PHAs>PBAT>Starch>PBS>PBSA. The second most studied materials were PHAs with focus on polymer production by bacteria including an innovative purification method involving the mealworm *Cupriavidus necator* (Ong et al., 2018). PBAT and starch-based composites were third and fourth most studied, with PBS and PBSA being the least studied of the biodegradable plastics in original studies classified and sampled within the category Material.

The charted studies addressed one or more of the following overarching topics: i) the sustainability of biodegradable plastics (1), ii) greenwashing (1), iii) material/additives source (7), iv) (bio)degradation (14), v) life cycle assessment (1), vi) environmental risk/impact (6) vii) innovative solutions related to material properties and (bio)degradation (9).

It is evident that the main research focus among the randomly selected studies under the category Material was about material degradation and potential for biodegradation. Eleven studies were based on laboratory experiments, one was a marine field study combined with mesocosm in southern European and Southeast Asian climate assessing the material area loss of PHA (Lott et al., 2020), one was a lab-field-mesocosm study conducted in East Asia assessing the fragmentation and weight loss of PBAT and PBSA/PBA in soil after treatment with enzymes from yeast (Kitamoto et al., 2023) and one was a field study where image acquisition was used to calculate the deterioration of cornstarch based mulch film in southern European soil (Moreno et al., 2014).

Material sources were the third largest research focus and included a range of different objectives, including assessing various waste categories as components in starch-based plastics

(Setiawan et al., 2022), and studies on new plastics/products made from starch or chitin, including assessment of their degradability (Triani et al., 2022; Zhou et al., 2022). Four studies were on bioprospecting for bacterial production of PHA polymers and lactic acid for production of PLA (Pessione et al., 2014; Reshma & Singh, 2017; Sumaira et al., 2023), including one study where the purification step of PHA involved the digestive system of mealworm (Ong et al., 2018).

The study by Zhou et al., (2022) also included assessment of the biosafety of a chitin-based plastic, targeting plant growth. The other studies assessed the environmental risk of PBAT and PHB as vectors for herbicides, pesticides or fragrances used in personal care products as compared to conventional plastics (Concha-Graña et al., 2022; Ni et al., 2023), while PLA was assessed for impact on soil carbon, nitrogen content and buffering capacity as compared to LDPE (Iqbal et al., 2024). One lab study assessed the environmental impact of material pre-treatment and bioaugmentation on the biodegradation rate of PLA (Banerjee et al., 2024), while one assessed biomass yield and nitrogen turnover in crop fields treated with biopolymer encapsulated urea made from PHA and PBAT (Redding et al., 2022).

The latter study was also counted under the research focus “Innovation”, as the test materials were modified, forming novel matrix-encapsulated products. Studies involving innovative solutions were the second largest group and included a study of a PLA-composite material assessed for food packaging qualities and biodegradability in the marine environment (Papadopoulou et al., 2019), a study on the application of nanoparticles as antibiotic agents and photocatalysts for the degradation of PLA microplastics exposed to solar radiation (Russo et al., 2024), a study on purification of PHA by mealworm (Ong et al., 2018), and studies on material degradation, including a study assessing a starch-based blend with microbe-independent seawater-responsive dissolution characteristics (Jia et al., 2023), and a polyethylene glycol-PLA composite assessed for seawater biodegradability by measuring oxygen demand (He et al., 2024).

Key findings

PLA, PHAs and PBAT were the most studied biodegradable plastics within the category Material research. Across all studies, the focus on material (bio)degradation was dominant. Among the key findings were improved degradation speed/rate of novel materials based on PLA, starch and chitin, and pre-treatments of PBAT and PHA materials assessed at laboratory conditions (7) and in the field (2). Methods development included a biodegradation test based on oxygen demand, where the authors concluded that commercial compostable plastics are not biodegradable in the marine environment (López-Ibáñez & Beiras, 2022). Another method for assessment of mulch film degradation in field was based on image acquisition, where the authors reported of 50 % degradation of starch-based film (Moreno et al., 2014). Also, the novel recovery approach for PHAs applying mealworms reported on recovery rates >90 % (Ong et al., 2018).

For a detailed overview of the charted studies, we refer to Appendix 6.

3.2.1.2 Research topic Microbiology

The random selection of 25 % out of the included original papers labeled to the research category ‘Microbiology’ resulted in 47 papers.

Excluded

After full-text review of the articles, three were excluded from further analyses as they did not meet the inclusion criteria. Of these, two described pure culture studies (Mukherjee & Chatterjee, 2014; Zhen et al., 2023) and one analysed transport of microplastics by soil fauna (Luo et al., 2023).

Research focus related to microbiology

Of the remaining 44 articles, the majority addressed microbiology in terrestrial environments with the great majority focusing on farmland soil with/without crop plants. Freshwater environments were addressed in six studies and marine environments in ten studies. Other environments that were studied included sand dunes (1), synthetic biowaste (1), and estuaries (1). A few studies investigated more than one type of environment, e.g. soil and freshwater, sea water and sediments or soil and compost.

The two major types of biodegradable plastic material studied were PLA (28/44) and PBAT (18/44). Various starch blends were included in approx. 25 % of studies. The source of the plastic was most often commercial, and materials purchased directly from plastic manufacturer or supplier. Some studies obtained materials directly from stores (e.g. plastic cups, bottles, food containers). A few studies used in-house synthesized material, e.g. PHA films. Many of the agricultural soil studies focused on composting and/or mulch film and effects of their uses in farming practices. Most other studies mimicked various exposure scenarios in the open environment. The study material was often fragmented (grinded) to various degrees.

None of the examined full texts included considerations/effects of the plastic additives and their leachates in the research question. The research questions primarily focused on plastic (bio)degradation (measured as plastic weight loss and surface morphology) and its impacts on microbial and fungal community composition and/or diversity. Some soil exposure studies also considered the effects on exposed organisms (e.g. earthworms) or crop plants, or effects on biogeochemical cycles. Soil studies focusing mainly on the effects of the biodegradable plastic on exposed animals/plants were classified as belonging to the ecotoxicology section. Other research questions covered identifying bacteria and fungi capable of degrading plastics, while some focused on characterizing the biofilm and biofilm formation on the surface of the plastic particles (plastisphere).

Most field studies focused on mimicking a pollution type scenario and investigating accidental or unintended effects of the biodegradable plastic. In contrast, the agriculturally oriented studies focused mainly on the effects of mulch film use under realistic agricultural scenarios.

Experimental design and duration of studies

The experimental design of soil studies mostly involved mixing plastic material with soil, at variable scales and levels of complexity. These ranged from small containers and pots with/without plants to pots placed in the field or samples taken directly from agricultural sites.

Freshwater and marine studies typically relied on biodegradable plastic-containing devices immersed in the water column. Some water-focused studies also utilized micro- or mesocosms, e.g. aquariums. Other studies focused on biofilm development on plastic particles, referred to as the plastisphere.

With few exceptions, the experimental design was based on adding defined amounts of plastic material to the studied system and measuring effects over a limited time span.

Most studies included several research objectives. For instance, to determine both the material aspects of plastic (bio)degradation as well as microbiological aspects including microbial community responses. These studies typically had different durations and sampling intervals. However, some studies presented an experimental design with only one end sampling point.

Most of the studies lacked an experimental design that included repeated treatment/sampling over years. Plastic degradation was often not completed at the end of the sampling period. The rationale for setting the last sampling timepoint was most often not described. One study described repeated sampling over 4 crop growing seasons (Griffin-LaHue et al., 2022) and one study covered 2 years (Li et al., 2024).

The comparator in the experimental design was most often a common, conventionally used plastic, such as PE. In agricultural soil studies with mulch films, the conventional mulch films most often served as the comparator, ensuring representative conditions.

Outcomes of the studies

The studies typically reported on plastic degradation, deterioration, particle characterization, fragmentation, and weight loss, often in combination with analyses of microbial and fungal diversity and community structure. Other studies presented effects of plastic degradation on soil biogeochemistry, plant growth and biomass, and/or the composition of bacterial communities and their genes. A few studies attempted to link environmental factors to microbial community composition and dynamics observed (Li et al., 2025; Miao et al., 2023; Yang et al., 2023; Zhou et al., 2023).

Journals where the work was published

The studies were published in established field specific journals such as Science of the Total Environment (8) and Journal of Hazardous Materials (10). Five were published in typical microbiology journals (Microbes and Environment, Environmental Microbiology, Microorganisms, Frontiers in Microbiology, and Archives of Microbiology). None of the studies were published in more general journals with broader visibility/readership.

3.2.1.3 Research topic Ecotoxicology

The random selection of 25 % out of the included original papers labeled to the research category 'Ecotoxicology' resulted in 46 papers.

Excluded

One article written in Chinese and one fraudulent article plagiarizing another scientific article were excluded.

Research focus of the selected papers

Out of the 44 remaining papers, 33 were quite unequivocally dealing with 'Ecotoxicology', while 11 articles lacked a clear focus on toxic effects to organisms, rather covering topics closer to 'Material' (e.g., adsorption mechanisms and kinetics of metals, antibiotics, and pesticides on biodegradable plastic materials; release of phthalate DEHP; abrasion properties of various materials) and 'Microbiology' (one article on conidial splash dispersal of molds on mulch surfaces). This is not entirely unexpected, as categorization was done based on titles and abstracts, which in some cases fail to convey the primary focus of studies that are

multidisciplinary and at the interface between several research topics. In addition, while peripheral to 'Ecotoxicology', studies on adsorption dynamics of metals and xenobiotics are important at documenting how biodegradable plastics may modulate exposure levels of xenobiotics in the environment.

Biodegradable polymer types and exposure characteristics

Poly(lactic acid) (PLA, on its own or in blends with other polymers) was covered in 20 articles (60 %), followed by poly(butylene adipate terephthalate) (PBAT, on its own or in blends with other polymers) in 13 articles (40 %). Poly(hydroxyalkanoates) (PHA and associated, such as P3HB and P(2HB-co-3HV)) were studied in 6 articles, starch-based polymers in 5 articles, and polycaprolactone (PCL) in 4 articles. Other polymers, such as poly(butylene succinate) (PBS) and poly(propylene caprolactone) (PPC) were only covered by a single article each. Three studies did not include any physical plastic particles, but only organic additives typically found in biodegradable plastics or leachates from biodegradable plastics (Gao et al., 2022a; Li et al., 2023; López-Ibáñez et al., 2024). Two studies tested both biodegradable plastic and their leachates (Barbir et al., 2023; Zimmermann et al., 2020).

Comparison to conventional plastic was made in 76 % of the studies, mostly using PE (and less frequently to PET, PS, PVC) with similar dimensions as the biodegradable plastic material tested, while other types of control, such as cellulose, kaolin particles and tree leaves were also employed, albeit less frequently. Control treatments without plastic were included in 70 % of the studies.

Type of environment and geographical regions covered

The soil environment was covered in 17 out of 33 articles, the marine environment in 12 articles, and the freshwater environment by 7 articles, with two articles covering more than one type of environment.

Only 6 studies were conducted under field conditions, while the rest were experiments conducted in the laboratory or in greenhouses. Field studies were all performed in soil and, apart from one study on PLA-based tea bags, all focusing on PLA or PBAT-based agricultural mulch films. Four of these 6 field studies came from China, and featured one arid oasis region (Fan et al., 2019), one continental temperate arid climate (Deng et al., 2019), two mountainous regions at 1620 m (Uzamurera et al., 2023a) and 2400 m (Uzamurera et al., 2023a), respectively, where the latter could be relevant to Nordic climate (average annual air temperature 6 °C, January -8 °C, July 19 °C). The two other field studies came from UK (Courtene-Jones et al., 2024) and USA (Tennessee, Texas, Washington State, Li et al., 2014), respectively.

In the marine environment, 5 studies were conducted in mesocosms, all of which in EU countries: two in Spain (López-Ibáñez et al., 2024; Quade et al., 2022), two in Northern Ireland (Green, 2016a; Green et al., 2016b), one in Italy (Gulf of Naples) (Viel et al., 2024).

Objectives and endpoints

The ecotoxicological effects on soil organisms were investigated in plants (13 articles, 10+ species), invertebrates (4 articles, of which 2 on nematodes and 2 on earthworms), microorganisms (4 articles), with endpoints ranging from subcellular (e.g. enzymatic activity) to individual (e.g. growth) and population (reproduction) levels. Similar ecotoxicological endpoints were investigated in freshwater and marine organisms. The ecotoxicological effects

on marine organisms were mostly investigated in invertebrates (8 studies, multiple species), and to a lesser extent in microalgae (3 studies) and vertebrates (2 studies on one fish species). Comparatively fewer studies dealt with the freshwater environment (7 articles), covering invertebrates (4 articles), cyanobacteria (2 articles), microalgae (1 article) and plant (1 article).

Key findings

Generally, toxic effects were low or observed at high concentrations (24 articles). Among articles that included a conventional plastic control, toxicity of biodegradable plastics was generally lower or like conventional plastic (14 articles). Some studies, however, reported higher toxicity of biodegradable than conventional plastic (5 articles). Field and UV weathering of biodegradable plastic was shown to trigger toxicity (Luangrath et al., 2024; Quade et al., 2022; Serrano-Ruiz et al., 2023).

3.2.2 Systematic reviews

There were only six papers sorted under this category, and after full text analysis, one was excluded for lacking methods description (Kumar et al., 2024), and one was excluded being a non-systematic review (Briassoulis, 2023).

The four papers included addressed different perspectives of biodegradable plastics ranging from biodegradability, degradation in waste systems and the open environment, and environmental impacts with a dedicated focus on the soil environment. One of the papers addressed the recycling of plastic waste, where biodegradable plastics were part of the data analysed (Tsuchimoto & Kajikawa, 2022).

The systematic review on biodegradability addressed and discussed biodegradability tests applied within the scientific community to assess biodegradation in freshwater and seawater environments (Lavagnolo et al., 2024). One of their key findings is that there is a large variety of methods applied to verify biodegradability. They also stated that the test methods endorsed by existing standards fail to establish a value of parameters to be met to clearly define a substance as biodegradable. They pointed at test duration, incubation temperature and the shape of test materials as variables that significantly influence the results obtained, which makes it challenging to compare results across different studies. The authors also suggested including ecotoxicological assessment of by-products in case of incomplete biodegradation.

One study focused on the state of research on 'bioplastics' in soil, including effects of material residues (Chah et al., 2022). Among the key findings was a domination of short-term studies and the fact that lab and field studies often gave inconsistent results, with seasonal, climatic and biogeographical factors strongly influencing field results. Furthermore, most studies reported significant environmental effects from microplastics in soil at concentrations ≥ 1 % w/w. 'Bioplastic' residues were found to affect soils' physical structure and C/N ratio, and impact soil microbial diversity and composition. At higher concentrations, plant health and germination were negatively affected.

One study explored the current level of knowledge about the environmental fate and consequences of biodegradable plastics to substantiate the discussions about their future role in society (Afshar et al., 2024). The study included both waste management environments (e.g. compost, sludge and landfills) and the open environment (seawater, freshwater and soil). The comparison and quantitative analysis of data was challenged by methodological variations in the original studies (testing methods, test materials, and mode of quantification). The authors

identified several research gaps, including the need to: i) intensify the research on PHAs, PBAT and PBS to match the level of PLA and starch-based plastics, ii) develop standard test methods for field conditions, and iii) couple degradation testing with ecotoxicological tests.

The last study was about recycling of plastic waste in general where the literature was classified into six clusters, where the largest cluster on general issues of plastic recycling included one subcluster on 'bioplastics' and one on 'biodegradation of plastics' (Tsuchimoto & Kajikawa, 2022). The authors' findings showed that the cluster 'biodegradation of plastics' was the youngest cluster, with high citation ratio and increasing publication activity. The subcluster 'bioplastic' was the second youngest subcluster with a rapidly increasing number of papers. The authors identified three different definitions of bioplastics used across studies and stated that their own definition of bioplastics was 'polymers derived from renewable resources and material synthesised by microbial metabolism'.

3.2.3 Non-systematic reviews

A total of 25 % of the non-systematic reviews included were randomly selected resulting in 35 papers that were subjected to full text studies (Appendix 5). Five papers were excluded after reading the full texts. One paper did not address biodegradable plastics but conventional micro- and nanoplastics (Junaid & Wang, 2022). Another (Napper & Thompson, 2023) addressed plastics in the environment, where biodegradable plastics were mentioned but not specifically addressed. The papers by (Prieto, 2016) and (Liu et al., 2023) were excluded as they were commentary and opinion, respectively, rather than a literature review. Finally, one paper (Narancic et al., 2018) was not a review.

Out of the remaining 30 papers included, three addressed the sustainability of biodegradable plastics from a perspective of production and environmental impacts on natural terrestrial and aquatic environments and agricultural soils. Eighteen papers addressed their (bio)degradation and/or environmental presence and impact, including photodegradation, conversion to microplastics, bioremediation, interactions with other environmental stressors, and effects on microbiomes, plants and animals. Four papers addressed the sources and methods of production. Three papers addressed waste management, socioeconomic impact, policy, regulation and LCA. Two papers addressed packaging and single-use plastics.

The order of frequency that specific biodegradable plastic polymers addressed were as follows: PHAs > PLA > starch-blends > PBS > PBAT > PCL > cellulose based > PVA. Two studies did not specify the polymers of biodegradable plastics.

3.3 Results from the Nordic literature search

The literature search targeting studies relevant to Nordic conditions resulted in 178 papers, whereof 19 were included. One of the papers included was a non-systematic review on recycling strategies for PHAs, where the aim was to provide an overview of the potential recycling routes for these polymers considering also the production of PHA from waste materials (Vu et al., 2020). Relevant to this was another study on the bioconversion of pyrolysis wax to PHA, and two studies bioprospecting PHA production from algae isolated from wastewater in Sweden and halophilic psychrophilic bacteria isolated from Southern Ocean sea-ice (Eronen-Rasimus et al., 2021; Lomwongsopon et al., 2024; Nzayisenga & Sellstedt, 2021). PHAs were also studied regarding their potential for degradation in the marine environment alongside PLA, plasticized starch and cellulose acetate, and their impact on marine animals,

specifically oxidative stress in blue mussels from exposure to PHB-microplastics (Eronen-Rasmus et al., 2022; Magara et al., 2019).

Overall, PHAs was the second most studied biodegradable plastic polymer (6 studies) among the Nordic studies after PB(S)AT composites (9 studies). Among the most recent are papers addressing biodegradable fishing gear (4 studies). One assessed the material characteristics of PBSAT and PBSA, and based on lab-generated data they simulated their degradation timespan under Nordic marine conditions (from 2 °C) compared to the conventional polymer PA (Wataniyakun et al., 2025). Another study compared the degradation behavior of PBSAT and PA exposed to accelerated aging, considering replacing PA with PBSAT for the production of gill nets (Karl et al., 2025). PB(S)AT was also, based on controlled weathering simulation, considered as alternative material in Dolly ropes as replacement for conventional PP, PE, PET and PA, and for snoods in longlines used in fisheries of cod and haddock as replacement for PA (Cerbule et al., 2022; Grimaldo et al., 2023).

The remaining five studies addressed the environmental fate and ecotoxicological effects of PBAT in agricultural soils related to mulch film application. PBAT-microplastics were assessed as potential stressors to earthworms, springtails, lettuce, and soil microbiome in lab and mesocosm studies (Kim et al., 2025). One large field-study addressed the accumulation of phthalates and other organic chemicals in agricultural soils from the application of mulch films made of PBAT composites compared to PE, PP or no mulch applied, with a timeline of exposure between 0 and 30 years (Scopetani et al., 2024). Only one study assessed the in-situ degradation of PBAT films in agricultural soils, comparing the degradation of a PBAT-starch composite with a PBAT-PLA composite over the course of two years (Coutris et al., 2025b).

PLAs were included in a total of five studies. Besides the two already mentioned above, one assessed the degradation of single-use plastics in natural environments, another focused on the environmental effects of PL(G)A-microplastics on marine microbial communities, and one on the sorption capacity of organic pollutants and bacterial composition on PLA material incubated in marine coastal sediments compared to cellulose acetate, PA and PS (Lora et al., 2024; Näkki et al., 2021; Shashoua et al., 2024).

PCL was included in one study on polymer blends of biodegradable-conventional polymers, assessing the risk of release of nano- and microplastics in relation to their (enzymatic) degradation (Wei et al., 2022). Cellulose acetate, already mentioned above (2 studies), was assessed combined with PLA, PHB, plasticized starch, and PLA.

Funding sources

Sixteen out of the nineteen studies were financed through state funding programs, while two received a combination of state and private/personal funding. Only one study was fully funded by a private foundation.

Experimental design and duration of studies

Five studies were conducted in field, one of these in combination with a lab study. Two were mesocosm studies, one was a desk study (review), and the rest were lab-based studies (11).

Studies relevant to Norwegian and Nordic marine environments

Lab data generated on the pure water hydrolysis of PBSAT, PBSA and PA at high temperatures (40-80°C) were applied to predict the lifespan of fishing gear made of biodegradable polymers

compared to conventional polymers at temperatures relevant to Nordic conditions and also warmer geographical areas (2°C, 10°C, 15°C, 20°C and 30°C) (Wataniyakun et al., 2025). Lab-based material aging followed by assessment of material strength was the basis in studies where the durability and applicability of biodegradable plastic polymer PBSAT was considered as alternative material to PA for fishing gear (Grimaldo et al., 2023; Karl et al., 2025). There was only one study conducted under realistic use in Norwegian marine conditions. That study compared both catch efficiency and risk of snood loss from longline fishery in the Barents Sea applying snood material made of PBSAT and PA (nylon) (Cerbule et al., 2022).

The impacts of PL(G)A-microplastics, PS microplastics, and a combination of the two on native bacterial phyla, and the enrichment of bacterial community on and (bio)degradation rate of PLA, PHB, plasticized starch and cellulose acetate was assessed in brackish seawater of the Baltic Sea (Eronen-Rasimus et al., 2022; Lora et al., 2024).

The toxicological effects of microplastic exposure on blue mussels were assessed comparing the polymers PHB and PE, as single contaminants, and as potential vectors for PAHs (Magara et al., 2019).

There was one study that assessed the material degradation of biodegradable single-use plastics (PLA) compared to conventional plastics (PE, PS, PET, PP) (Shashoua et al., 2024).

Studies relevant to the terrestrial environment

Most of the studies relevant to the terrestrial environment addressed agricultural soils and exposure from mulch film, their additives or microplastics derived from these products because of their use. A recent study assessed the in-situ degradation of two different PBAT-composite mulch films in Nordic agricultural soils over the course of two years (Coutris et al., 2025b). They assessed material degradation by mass loss and FTIR chemical analysis, and assessed growth observed on the material surfaces by DNA sequencing. A recent mesocosm study using standard natural soil assessed the effects of PBAT-microplastics on soil invertebrates and microbial community and activity at soil temperature relevant to Nordic summer conditions (15 °C) (Kim et al., 2025). A study in Finland involved 16 different farms and 38 fields where mulch films and covers made of biodegradable (PBAT) or conventional plastics (PE, PP) had been used for up to 30 years. The study compared the content of phthalates and organic chemicals in these soils to those in fields where mulch films and covers had not been applied (Scopetani et al., 2024).

Studies relevant to the production and waste handling of biodegradable plastics

Two studies are related to the bioprospecting of microorganisms able to produce PHAs, including bacteria that grow at high salinity and low temperatures, which are characters that may be utilized for more cost-efficient industrial production of PHAs (Eronen-Rasimus et al., 2021; Nzayisenga & Sellstedt, 2021). Relevant to this is a desk study on recycling strategies for PHAs and one assessing the use of pyrolysis wax as a substrate for the biological production of PHAs and highlighting this as one possible circular value chain upcycling opportunity for this type of waste product (Lomwongsopon et al., 2024).

4 Discussion

To better understand the current knowledge base and forecast the potential environmental consequences of biodegradable plastic materials, we conducted a scoping review of the scientific literature addressing biodegradable plastics and their effects on the environment. Based on the developed protocol, the first literature search, without geographical constraint, gave a total of 2428 studies (2014-2024), including original papers, and systematic and non-systematic reviews. After screening abstracts and categorizing according to main scientific field, 613 papers were retrieved. Due to the large number of original research and non-systematic reviews, we selected a random sample of 25 % from both these categories for full text analysis and charting, while all the systematic reviews were charted. The final sample that was analysed consisted of 168 papers, 129 original studies, 35 non-systematic reviews and 4 systematic reviews.

The risk of missing key original studies using this approach is significant, but this was justified by that they would likely be included through the systematic reviews. Furthermore, the random selection of studies would not impact the statistical overview of research topics and objectives addressed within this research field or the fraction of studies that may be relevant to Nordic conditions. Given that the main objective of this scoping review was to capture the literature on biodegradable plastics relevant to Norwegian and Nordic conditions, including environmental conditions and current and future applications, we delivered specifically on that by the additional targeted geographical search conducted. The global literature search was to establish an overview of the international status of research on biodegradable plastics, focusing on the distribution between the research fields Material, Microbiology and Ecotoxicology, including the types of polymers studied, main objectives addressed, methodology and study designs, types of exposure, and environmental conditions included.

The systematic reviews written on the topic of biodegradable plastics were, as expected, limited. Therefore, we also included non-systematic reviews. However, there were concerns about the varying methodology of non-systematic reviews, hence a systematic data charting of the randomly selected articles was replaced by a summary based on individual evaluation of the papers addressing methodology, literature reviewed and the main findings and conclusions.

Besides providing a general overview, the compilation of data extracted from the global search also provided a basis for discussing the status of research relevant to Norwegian conditions. The literature search targeting Norwegian and Nordic conditions (2014-2025) was, as expected, limited in comparison, giving 174 papers, whereof 19 papers were found relevant and included in the data charting.

The targeted search for Norwegian/Nordic studies indicated that the current literature was mostly focused on marine environments and agricultural soil, with primary applications being mulch films and fishing gear. A significant portion of these studies had an applied focus, including field and mesocosm studies, as well as simulations of environmental scenarios based on laboratory-data. This research was primarily funded by state funding programs and targeted conditions relevant for Norwegian and Nordic conditions, including temperature range, light/dark cycles and levels of irradiance. Although some of the lab-based studies charted from the global search may also be relevant to Norwegian/Nordic conditions, they lacked the holistic relevance to risk assessment that is provided by field studies conducted in the environment of intended use, including types of application and exposure characteristics.

4.1 Categorization

The sorting of literature into the categories Material, Microbiology and Ecotoxicology was motivated by the opportunity to gain knowledge about the distribution of research efforts invested into the topic of biodegradable plastics from different scientific disciplines. Appreciating the cross- and multidisciplinary profile of the research topic, it was expected that many of the studies included more than one research discipline. This was also evident from the initial sorting of selected papers into the respective categories. For this sorting to be efficient and statistically manageable, it was conducted by labelling the studies according to the main scientific field in terms of analytical approach. This approach is not without challenges, as the sorting process may have been subjected to partiality from the authors of this report. This was also evident when the data-charting was reviewed across the working groups, where e.g. adsorption studies of environmental toxins on plastic surfaces was placed in the Material category by some and in Ecotoxicology by others. This also illustrates the multifaceted aspect of the topic biodegradable plastics, and plastics in general. The adsorption and desorption of environmental toxins on plastic surfaces are not only relevant in terms of material properties, but also in an ecotoxicological perspective when materials act as vectors of environmental stressors and amplify their relative concentrations and risk of exposure through e.g. ingestion. The sorting exercise gave a deeper insight into the complexity and multidisciplinary aspects of this research topic and the potential for utilising data across different scientific fields in mathematical modelling of the overall impacts of biodegradable plastics in different types of environments.

Due to the multidisciplinary profile of many of the original studies, the sorting approach did not result in a clear categorization for any of the categories established. This means that original papers that some would argue to be placed in the Material category, were placed in the category Microbiology or Ecotoxicology, or vice versa. For transparency, we have in such cases not moved papers between categories. And in cases where non-systematic reviews had been mistaken for original studies, they were excluded and not moved to the sample of non-systematic reviews, so not interfering with the a priori approach.

4.2 Material properties and fate in the environment

The objectives of most studies categorized within the category Material were linked to material properties of commercial or innovative materials, focusing on their (bio)degradability when exposed to microorganisms and/or environmental factors. The biodegradability of biodegradable plastic products is the core characteristic for their intended applications and waste handling, so a focus on material (bio)degradability in different environmental conditions was expected.

The most frequently studied polymeric material was PLA, which requires high temperatures for efficient biodegradation and therefore is intended for waste handling by industrial composting. Still, all the original studies sorted under the category Material assessed their biodegradability under environmental conditions. Also, some studies were on PLA-composites designed for improved biodegradability under environmental conditions (Banerjee et al., 2024; He et al., 2024; Russo et al., 2024). Overall, this trend indicates a focus on knowledge building about the environmental fate and consequences of PLA released to the environment, with littering of compostable products such as single-use packaging or other inappropriate waste handling as examples of release points to the environment. The efforts put into developing PLA-based products that are more easily biodegraded at environmental conditions indicate

efforts to mitigate their environmental impact in terms of material persistence and pave the way for their application and waste handling by biodegradation in the open environment.

One study from the Nordic search compared the degradation of mulch films made from PBAT-starch and PBAT-PLA composite at Nordic conditions, buried in Norwegian agricultural soils at 10 and 30 cm below the surface over the course two years (Coutris et al., 2025b). These biodegradable mulch films are marketed as compostable, suggesting another end-of-life option than direct incorporation into soil, but recovery for composting is not likely to be done by farmers, who would lose the economic benefit due to the absence of mulch recovery (Coutris et al., 2025b) Furthermore, autumn ploughing is not always possible due to weather conditions or even allowed in some regions due to risk of increased soil erosion. In such cases the mulch will stay on the soil surface until spring with risk of spreading to other environments by wind or interactions with animals. The study by Coutris et al. reported on residual mulch materials ranging between 52 % and 93 % after two years, suggesting significant risk of accumulation of plastic materials with repeated use of both mulch composites studied.

PHAs, being produced and extracted from microbial cells is on the other hand instinctively eligible for biodegradation at environmental conditions. However, the biodegradability of biodegradable plastic products may vary compared to the biodegradability of the pure polymeric materials (SAPEA, 2020). This is because the material properties are modified through the production process, from temperature exposure and from the additives that shape the final products. Hence, the properties of biodegradable plastic products and their environmental impact also include the chemical profile of the products. This fact speaks for certification and risk assessment of biodegradable plastic products rather than pure polymeric materials (SAPEA, 2020).

The Nordic studies included a comprehensive mapping of chemicals in agricultural soils in Finland treated with biodegradable plastic mulch and covers as compared to conventional plastic mulch and no treatment (Scopetani et al., 2024). Among the findings was a positive correlation between the concentration of organic pollutants in soil and the number of years during which conventional or biodegradable mulch films had been applied. The authors stressed that the leakage of plastic additives from biodegradable mulch raises concerns regarding their environmental impact, especially considering that biodegradable mulch films are left in the soil after use, allowing for continued chemical release.

Several studies also addressed biodegradable microplastics as vectors for (and amplifiers of) environmental toxins and chemicals in personal care products (Concha-Graña et al., 2022), posing a risk of chemical stress to organisms via ingestion or from external exposure. Other studies assessed the toxicity of biodegradable microplastics with or without organic pollutant adsorbed, as compared to conventional microplastics (Magara et al., 2019). See more discussion points on the literature about the ecotoxicity of biodegradable plastics in section 5.4.

Besides agricultural applications, the applicability of biodegradable plastics to produce fishing gear or product elements used in fisheries was extensively covered among Nordic studies compared to the studies charted from the global research. All the studies related to fishing gear sprung out from research institutions in Northern Norway and research partners associated to the Centre for research-based innovation Dsolve, led by the Arctic University in Tromsø, Norway. As many as four out of nineteen studies addressed biodegradable plastics' material properties and stability at Nordic conditions, including a comprehensive field study testing the application of PBSAT in longline fisheries (Cerbule et al., 2022). The primary

biodegradable plastic polymer tested for fisheries applications was also PB(S)AT. The only non-fishery related material study focusing on marine Nordic conditions assessed degradation rates of PLA, PHB, starch- and cellulose-based plastic and bacteria enriched on their surfaces in coastal brackish water in Finland (Eronen-Rasimus et al., 2021).

LCA studies from the global research compared the environmental performance of biodegradable mulch film with conventional mulch with mixed results across indicators assessed (Razza et al., 2019; Tan et al., 2023). The need for upgraded LCA methods that includes improved international standards for biodegradation tests, unambiguous definitions and terminology of biodegradation, biodegradable materials and recycling technologies was stressed by others (García-Depraect et al., 2021). There is also a need to address the open environment as end of life alternative for biodegradable plastic materials and the implications this may have on the environment and ecosystem services. To reach these goals will require improved communication and transparency across industry, regulation, consumers and the scientific community.

4.3 Impacts on microbial activity and ecology

The charted studies generally indicated that biodegradable plastics influenced microbial community structure and diversity. However, some evidence suggested that microplastics in marine environments primarily served as physical surfaces for microbial attachment rather than being consumed for growth, with minimal impact on microbial composition. Most studies analyzed changes in bacterial community structure and diversity using 16S rRNA gene sequencing or metagenomics, while fewer studies investigated the fungal components of microbial communities. Overall, the results showed greater effects on bacterial than fungal community composition. Bacterial diversity generally increased when exposed to moderate amounts of biodegradable plastics, whereas fungal diversity tended to decrease.

Analyses of microbial communities exposed to biodegradable plastics identified various bacterial groups (and, in some cases, fungi) that increased in abundance, suggesting growth driven by plastic biodegradation. Different studies identified different microbial taxa as key organisms for degradation, even when the same plastic material was used. The immense taxonomic diversity of microorganisms in the environment—particularly in soil—indicates a high functional diversity, making it likely that different microbial groups may benefit from using biodegradable plastic as a source of carbon and energy, or surface colonization, depending on a range of biotic and abiotic factors.

None of the studies tracked the systems long enough to determine whether changes in microbial composition persisted after the complete degradation of plastic. However, the general expectation is that microbial communities are likely to revert to their original composition once the added nutrient source is depleted (Allison & Treseder, 2008). In environments where biodegradable plastics are repeatedly added, like the case of mulch films in agriculture, this general expectation is no longer valid and points to a need for studies addressing the long-term impacts on microbial ecology and the risk of material and chemical accumulation in agricultural soils (Coutris et al., 2025a; Coutris et al., 2025b; Scopetani et al., 2024).

Studies focusing on soil typically showed an increase in dissolved organic carbon and a decrease in available nitrogen (NO_3^- and NH_4^+) and phosphorus. Along with this, some results

showed increased enzymatic activities of both urease and phosphatase (Li et al., 2023; Wang et al., 2022a; Zhou et al., 2024).

Some studies investigated the effect of biodegradable plastics on the prevalence of antibiotic resistance genes and virulence factors in the associated microbial community. Antibiotics and other chemicals may adsorb to microplastic surfaces, selecting for an increase in antibiotic resistance genes in microbes attached to/or living in the vicinity of the particles (Wang et al., 2022b). Moreover, antibiotic resistance genes were present on plasmids that also carry virulence traits (Li et al., 2024). Thus, selection of resistance can simultaneously select linked genes such as those expressing virulence factors. These findings imply that the plastsphere may act as a reservoir for an antibiotic resistome as well as for traits present in pathogenic bacteria.

A clear gap in knowledge is caused by the relatively few studies (Li et al., 2025; Yang et al., 2023; Zhen et al., 2023) focused on comparative aspects or aimed at determining the relative importance of the various environmental factors. Temperature is one of the most critical environmental factors influencing the activity of microorganisms responsible for biodegradation of plastics. However, it is important to note that temperature interacts with other factors, such as moisture, oxygen, pH, and nutrient availability, which can also significantly influence biodegradation rates.

Most environments harbor a vast microbial diversity with a high degree of functional redundancy, meaning that many groups of organisms can perform the same “broad-scale” functions, such as degradation of polymeric compounds. Consequently, microbial communities from different locations are likely to exhibit similar, temperature-dependent degradation profiles. This suggests that studies from other parts of the world included in this scoping review are relevant to Nordic conditions, provided the temperature ranges of the microbiomes and test conditions align with those of the Nordic region.

The following key factors of importance for microbial degradation across the studies included: temperature, soil moisture, pH, soil organic matter, fragmentation and dispersal of the plastics material, microbial diversity, presence of degraders, agricultural soil versus the marine environment. These are all considered factors of importance as they generally govern biological activity levels. However, the value of comparisons between studies is limited by non-standard methods, models, reporting format, various scopes, types of polymeric material and composites tested, inconsistent focus on the impacts of additives/leachates when assessing effects, and various focus on the (combination of) environmental factors that may impact the endpoints assessed. Furthermore, the primary studies generally included very few time series and/or longitudinal designs.

4.4 Ecotoxicological effects

Concentrations at which ecotoxicity effects were observed were not always clearly reported or only observed at concentrations by far exceeding what can be expected in the open environment, e.g. above 1 % w/w (Celletti et al., 2023; Forsell et al., 2024; Xie et al., 2023). In soil, toxic effects of biodegradable plastics were seen at high concentrations, possibly mediated by effects on physicochemical soil properties, e.g. changes in hydrophobicity, oxygen availability, soil structure, water content (Celletti et al., 2023; Uzamurera et al., 2023a). Likewise, in aquatic environments, effects seen at high concentrations were indirect, due to

nutrient sequestration on biofilms formed on biodegradable microplastics (Procházková et al., 2023).

Generally, effects of biodegradable (micro)plastics were comparable to those of conventional (micro)plastics in both soil and aquatic ecosystems (Anderson & Shenkar, 2021; Courtene-Jones et al., 2024; Green et al., 2016b; Sai et al., 2022). In an 18-month field study, Li et al. (2014) showed that PBAT-based mulch films had minor effects on several biological (microbial biomass and β -glucosidase) and physicochemical (electrical conductivity, total organic carbon and pH) soil properties.

Exceptions were however reported, e.g. in a study by Luangrath et al. (2024), where PLA microplastics were more toxic to freshwater organism *Daphnia magna* than PE microplastics. The authors found that UV-aging enhanced toxicity, a phenomenon also observed by (Quade et al., 2022) for other biodegradable plastics (starch-based and PLA/PBAT) in the marine environment where UV-aged plastics exhibited higher toxicity to sea urchins. Similarly in soil, Serrano-Ruiz et al. (2023) showed that biodegradable mulch was more toxic to plants than PE mulch, and that field-weathered biodegradable mulch caused stronger effects than their pristine (non-aged) counterparts. In freshwater, Kim et al. (2024) showed that PLA and PCL (but not PS) microplastics stimulated algal growth, which could lead to unwanted harmful algal bloom. The production of cyanotoxin was, however, equally triggered by biodegradable and conventional microplastics.

Contrary to ecotoxicity testing of chemicals, testing of commercial biodegradable plastic materials is complicated by the lack of transparency on their chemical composition, which is commercially protected. Efforts have been made to qualitatively characterize additives and plastic associated chemicals leaching from commercial biodegradable plastic materials (Zimmermann et al., 2020). A minority of studies have specifically tested the ecotoxicity of leachates (Barbir et al., 2023; López-Ibáñez et al., 2024), and this aspect deserves further scrutiny, as results from the present literature are equivocal. Zimmermann et al. (2020) aimed at elucidating the drivers of microplastic toxicity and showed that while plastic chemicals (leachates) were the main driver of toxicity for PVC, it was not the case for PLA. In contrast, leachates from eight PBAT-based compostable plastic bags, but not from PE bags, were (moderately and transiently) toxic to sea-urchin (López-Ibáñez et al., 2024). In a 2-year long field study, Uzamurera et al. (2023a), showed higher concentrations of phthalates acid esters (PAE, plasticizers) in soil in presence of PLA mulch, compared to PE mulch. In a shorter (8 weeks) lab experiment using PPC/PBAT mulch microplastics, the opposite was observed, namely higher PAE concentrations in presence of PE mulch microplastics than with their biodegradable counterparts (Zhang et al., 2024; Zhou et al., 2024). In freshwater tests, leachates of PPDO were less toxic than those from PE and PS (Gao et al., 2022b) .

Another challenge in ecotoxicity testing of biodegradable plastics (but also valid for conventional plastics) is their dual physical and chemical influence on ecosystems. The reviewed literature presented several studies on adsorption mechanisms and kinetics of metals, antibiotics, and pesticides on biodegradable plastic materials (Li et al., 2020; Sahai et al., 2024; M. Sun et al., 2022; Sun et al., 2021; Y. Sun et al., 2022), underlining the potential for biodegradable plastics to act as vectors of xenobiotics in the environment.

The vast majority of ecotoxicity studies (82 %) were conducted under laboratory or greenhouse conditions, using standard conditions of e.g. temperature, moisture, oxygenation and photoperiod, and standard test species (i.e. ubiquitous organisms or of widespread commercial interest), without Nordic specificities. With the exception of the study by Näkki et

al. (2021) which used native sediments collected around Helsinki, Finland, incubated at 9.5 °C, the absence of Nordic specificity applies to the few ecotoxicity studies recovered in the Nordic search. Forsell et al. (2024) used a standard soil from Germany (Lufa 2.2), the compost earthworm *Eisenia andrei* and conducted the test at constant 20 °C, following international test guidelines. The same standard soil Lufa 2.2 was used in (Adamczyk et al., 2024), in multispecies columns maintained at 18 °C (day)/15 °C (night) and featuring standard test species (lettuce, earthworms, springtails). It is common practice in ecotoxicology to follow international standards, so that ecotoxicity data on test chemicals/materials can be generated anywhere in the world and still be valid and comparable. This is regarded as beneficial and applies to ecotoxicity testing of biodegradable plastics as well. This advocates for the general relevance of the body of evidence on mechanisms of toxicity of biodegradable plastics (and associated chemicals) generated in laboratory studies, regardless of the country of origin.

Finally, a general improvement in material and exposure characterization from early 2010s to present was observed, except for papers published in low-quality journals. Thorough description of test materials and test concentrations is crucial for meta-analysis of literature.

4.5 Relevance to Norwegian and Nordic conditions

Nordic conditions refer to climate characteristics of Norway, Sweden, Finland, Denmark, and Iceland. The climate of these countries spans from temperate/cold to subarctic. In general, Norway experiences long winters with snowfall, and mild short summers. There are large seasonal variations due to latitude and proximity to the coastline and the North Atlantic Current. Light conditions vary with low sunlight exposure in winter to continuous daylight in summer north of the polar circle. The weather pattern is changeable, particularly in mountainous and coastal areas. Low-pressure systems coming in from the Atlantic bring frequent wind and precipitation.

Major soil types in Norway are marine clay soils, peat soils, gleysols and podzols. These soils are generally acidic, with slow organic matter decomposition and limited biological activity due to the cold climate and long winters. However, there is considerable regional variation across terrestrial areas, including differences in annual temperature range, irradiance levels, precipitation and length of growth season.

The marine environments of Norway are characterized by a large degree of specificity and variations across longitude, even compared to its Nordic neighbour countries. The marine waters along the lengthy coast can generally be characterised as cold and with high salinity but with significant variations in surface temperatures especially during the summer/autumn season. The fishing industry is particularly rich and active in the Northern parts and aquaculture in the southern part of the country. Other distinctive features are the fjord systems and associated terrestrial terrain, with characteristic geography and temperature conditions that differ significantly from both the exposed shorelines and inland environments.

These conditions imply that the temperature-dependent activity of Nordic microbiomes to a larger degree vary through the yearly cycle compared to geographical regions with more even temperatures throughout the year (smaller annual temperature span). Considering also the variation in climatic conditions from south to north in most Nordic countries, there are also significant temperature differences across Norway, Sweden and Finland.

Both the general environmental characteristics of Nordic countries and the specific characteristics of Norway are of high relevance when considering the application of biodegradable plastics for use and waste handling in the open environment. The recent study by Coutris et al. (2025b) illustrates how even sites in the southern part of Norway vary significantly in air temperature span through a yearly cycle, although the annual mean air temperature is similar. The difference in temperature span impacts not only the length of growing seasons but also the annual window for efficient biodegradation of organic matter, including biodegradable plastics. This is also shown by the results from the study, where the fields with the lowest annual air temperature had the highest remaining mass of biodegradable mulch after two years. The fields where the annual air temperature did not fall below zero had the overall lowest residual mass of biodegradable mulch in the soil at the end of experiment. These results point not only to the relevance of mean annual temperature levels, but also to the temperature span and how that impacts microbial activity and turnover of organic matter.

On a general basis, the same variability in temperature ranges applies to the surface waters of marine environments across the Nordic countries, with supposed similar impacts on (bio)degradation rates at marine conditions across the same geographical area. A study assessing the degradation of PBSAT and PBSA compared to PA in ageing experiments performed in pure water, predicted that fishing gear made from biodegradable polymers laying on the seabed ($\sim 2\text{ }^{\circ}\text{C}$) would lose their ability to ghost fish after 10 years (PBSAT) and 20 years (PBSA) compared to 1500 years for fishing gears made from PA (Wataniyakun et al., 2025). The actual degradation time may be shorter when also considering the impact of *in situ* mechanical stress and biodegradation.

None of the studies addressing the potential use of biodegradable plastic polymers in fishing gear assessed the environmental impacts of material fragmentation and release of additives during use or loss entailing degradation in the open environment. The toxicological effects of microplastic exposure on blue mussels were assessed in a study comparing microplastics PHB and PE as single contaminants and as potential vectors for PAHs (Magara et al., 2019). The study demonstrated ecotoxicological impacts from both types of microplastic materials but an apparent absence of combined effects with the pollutant.

One study assessed the material degradation of biodegradable single-use plastics (PLA) compared to conventional plastics (PE, PS, PET, and PP), which is a relevant scenario of unintended release or littering to the environment with exposure to atmospheric and urban marine conditions over the course of 3 years (Shashoua et al., 2024).

When comparing the overall test temperatures versus incubation time, it was evident that most studies were conducted at mesophilic conditions, and few $<10\text{ }^{\circ}\text{C}$ or $>40\text{ }^{\circ}\text{C}$. The Nordic sample contained studies conducted under a broad range of temperatures, although most were conducted $<20\text{ }^{\circ}\text{C}$. Most studies had a duration <100 days, but many long-term studies were also recorded (figure 2).

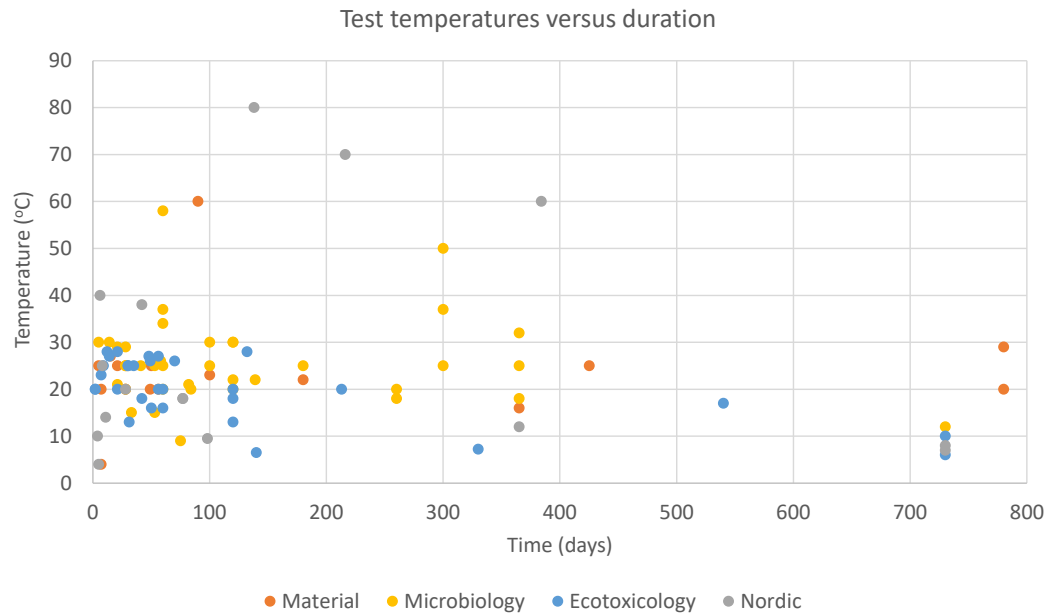


Figure 2. Test temperature versus incubation time of all studies charted (in cases where the data was given). In addition, there were 3 studies with longer incubation time, not included in the figure (1095d, 12 °C; 1460 d, 10 °C and 2808 d, 40 °C).

4.6 Terminology

Bioplastic is a commonly used term, but it is sometimes mistakenly applied as a synonym for biodegradable plastics. A review of the literature on recycling of plastics showed that there are at least three different definitions of bioplastics used across studies in plastic research (Tsuchimoto & Kajikawa, 2022). The authors of the review stated their own definition of bioplastics, as “polymers derived from renewable resources and material synthesised by microbial metabolism”. Their definition deviates from that adopted by EU in 2022, which includes biodegradable plastics made from fossil-based building blocks under the umbrella term bioplastics (Biobased, biodegradable and compostable plastics).

A common understanding of definitions and terms is a prerequisite for a sound scientific analysis, reasoning and discussion. The challenge around the understanding about biobased, biodegradable and compostable plastic is hence not only a challenge among consumers, but is evidently also an issue within the scientific community. This is concerning and may delay the efforts to achieve a common and holistic understanding on the sourcing, labelling and use of biobased, biodegradable and compostable plastics as set out by the EU policy framework about these plastics.

5 Uncertainties

Various sources and types of uncertainties will be inherent to a scoping review approach. This is caused by the process itself including choices made in the search, interpretation, and presentation of the identified scientific literature as well as by the nature of the assessed scientific literature itself. Sources of uncertainty in the literature examined include methodological aspects of the single published studies, to what extent the study design is

relevant to the research question of the scoping review, and to what extent study design and data reporting allows comparison between studies and meta-analyses.

European Food Safety Authority's guidance on uncertainty in scientific assessments provides a useful resource to understand various types of uncertainties (EFSA, 2018).

Some sources of uncertainty of our approach included limited full text analyses (25% of the retrieved studies) due to time constraints, and the limited time to assess the included literature. Moreover, there is inconsistent use of terminology between studies that may have led to missed studies. For instance, the term biodegradable plastic is inconsistently defined across studies. Some use it for bio-based or oxo-degradable plastics. Moreover, it is unclear to what extent the limited number of studies on additives and leachates is due to non-exhaustive literature search, a knowledge gap caused by missing studies, or a lack of transparent product declarations available for the studied material.

Other sources of uncertainty include the primary studies retrieved. The experimental design of many studies was often limited in scope. This was due to choices made in experimental setup and sampling design that limited the duration of studies. Most often, the last sampling point was set before degradation of the studied plastic material was completed. Many experimental designs mimicked a pollution scenario of limited scale and duration, and the distinction between degradation understood as removal (i.e. mineralization) versus fragmentation was not always clear. It should also be noted that the primary study aim/objective differed between studies and were not always focused on the research question of the scoping review.

Few studies could deliver insight into longitudinal or accumulative effects. This, combined with variable and non-standardized experimental designs, creates uncertainty in our understanding of the effects of biodegradable plastic exposure to the environment. Such exposure is continual, occurs as plastic mixtures and over timespans not reflected in the published studies.

A key limitation and source of uncertainty observed when assessing current studies is the limited ability to extrapolate between studies, environments, and time. Moreover, non-standardized study designs limit the ability to compare studies between different environments/geographies, and hence, the ability to identify single factors of importance. For instance, temperature is considered a key determinant for biodegradation of plastics. However, many experimental studies do not explicitly consider temperature in the study design or seek to determine the effect thereof. Micro- and mesocosms were rarely experimentally designed to disentangle the effects of single factors.

Summarized, some key limitations and hence sources of uncertainty include:

- Lack of standardized experimental designs and reporting formats makes it difficult to compare findings or aggregate data across papers.
- Studies vary widely in scope, materials tested (PLA, PHA, PBS, etc.), and methods. Variable aims and objectives make it hard to synthesize results systematically.
- Laboratory biodegradation tests (e.g., ASTM, ISO standards) differ from real-world conditions (marine, soil, landfill, freshwater).
- Limited long-term field studies on degradation rates, microplastic formation, or ecotoxicity. Some biodegradable plastics may still fragment rather than fully degrade.

- Inconsistent or incomplete Life Cycle Assessment (LCAs) on energy use, carbon footprint, and end-of-life impacts.
- Limited data on by-products of biodegradation and their ecotoxicological effects on soil and aquatic organisms.
- The role of additives in biodegradable plastics is seldom considered in the plastic material used (assessed) in primary studies.
- Possible publication bias toward studies showing positive degradation outcomes. It may overestimate the performance and environmental friendliness of biodegradable plastics.
- Incomplete mapping of the literature or overrepresentation of specific viewpoints. Balance between reviews and primary articles, and uncertainties of the added value of non-systematic reviews considering their lack of a methodological description and possible subjectivity.

6 Conclusions (with answers to the terms of reference)

The objectives were to 1) determine the extent of evidence summarized in reviews and original research papers within this emerging research area, and 2) map the evidence according to the materials and chemicals studied, types of environments and geographical regions covered, the research questions addressed, the type of endpoints measured, and a summary of the reported key findings.

There is a general probability for **accumulation of plastics material and plastic chemicals** in agricultural soil from the repeated use of biodegradable mulch film. For Norwegian conditions this probability is reinforced by: i) the practise of using compostable mulch that is tilled into soil after use, ii) the general narrow growth season in Norway, and iii) significant variations in conditions with longitude.

Toxic responses from the exposure to biodegradable microplastics have been shown for a wide variety of organisms, but often at concentrations unrealistic for the open environment. However, for most studies it is not clear whether the response is caused by the polymeric material or additives leaching from the plastic matrix.

There are **uncertainties about the environmental relevance** of many ecotoxicological studies due to the use of high exposure concentration and varying levels of toxicity observed between studies. Some studies suggests that weathering of biodegradable plastic materials, both under laboratory (UV radiation) and field conditions, trigger toxicity.

The **degradation of biodegradable plastics** is most often measured by weight loss, which does not distinguish between material loss by fragmentation and mineralization by biodegradation.

There is a **lack of knowledge about the environmental fate** of biodegradable plastics due to the lack of appropriate methodology for field assessment of their mineralization.

For most cases, (bio)degradation studies report **incomplete degradation** within the test period, with likely formation of microplastics.

Biodegradable plastic polymers may be **produced by microorganisms** such as bacteria when growing on substrates derived from organic waste, including different fats and pyrolysis wax.

Most primary studies were enabled through **state/governmental funding** sources such as national research councils. A few declared other sources of financial support such as personal. Funding from commercial sources was identified. The systematic reviews were mostly funded by state or not reported.

7 Data gaps

The scoping review revealed a number of key knowledge gaps that can be addressed in further studies. We recommend further studies focus on:

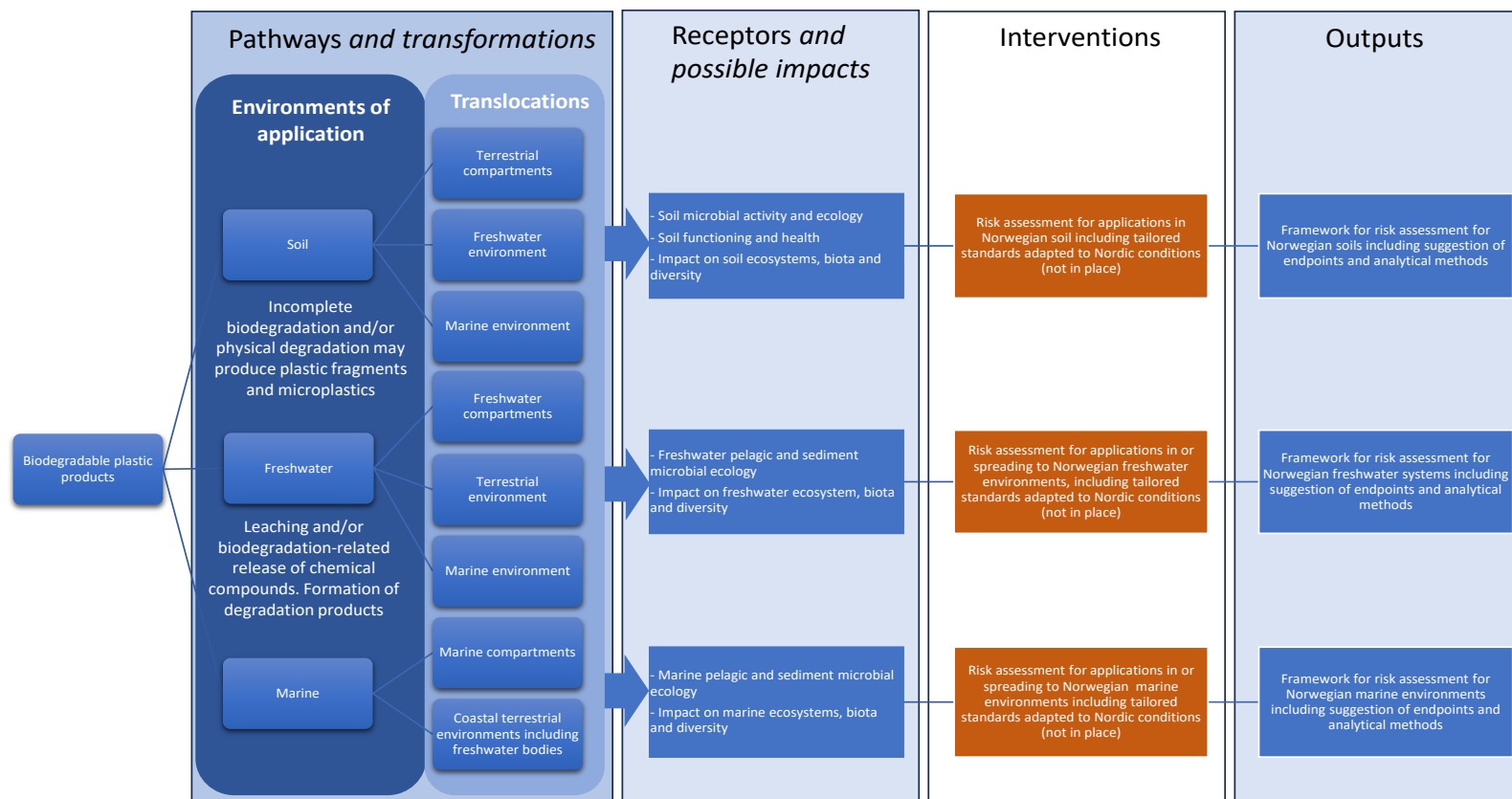
- Designing studies that examine a broader range of representative field conditions and that allow for comparison between sites/factors.
- Standardization of study designs so that study outcomes can be compared across studies and meta-analyzed.
- Adopting study designs that collect long-term field data from marine, freshwater, soil, and landfill environments (months to years). This to build understanding of final degradation endpoints and mineralization rates.
- Providing clarity on the mechanisms behind the observed plastic degradation processes, i.e. plastic removal versus fragmentation.
- Increasing the focus on the degradation products from biodegradable plastics and collect quantitative data on microplastics and nanoplastics formed during degradation.
- Developing consistent test methods (e.g., varying ASTM/ISO standards) and harmonize units and endpoints. This to allow comparable, reproducible biodegradation metrics (e.g., CO₂, mass loss).
- Including a characterization of polymer composition, additives, and molecular weight of the study material (e.g. assessing for unspecific chemical substances in plastic products and/or degradation products from their biodegradation). This will allow linking chemical structure to biodegradation behavior.
- Placing the presented study in a holistic perspective on how biodegradation affects soil, water, and microbial ecosystems including effects of toxic residues, nutrient cycling impacts, and effects of bioaccumulation.
- Establishing environmental safety profiles of degradation products.
- Increasing the geographic scope of studies to ensure regional/global representativeness.
- Including explicit considerations on how studies can support extrapolation between sites and regions.
- Developing predictive models that can support hypothesis formation and study design. E.g., factors governing degradation of biodegradable plastics used or considered to be used under Nordic conditions.

- Establishing terms, conditions and effects of practical uses of biodegradable plastics in aquaculture and agriculture in Norway and other Nordic countries.
- Developing and using consistent terminology that is harmonized across studies, countries and geographical regions.
- How laboratory biodegradation tests (e.g., ASTM, ISO standards) differ from real-world conditions (marine, soil, landfill, freshwater). They are, however, important for standardizing basic test conditions and resolving the effect of single factors.
- Addressing the limited number of long-term field studies on degradation rates, microplastic formation, or ecotoxicity. Some biodegradable plastics may still fragment rather than fully degrade.
- Resolve how study design that vary widely in scope, materials tested (PLA, PHA, PBS, etc.), and methods can inform risk assessment.
- Resolving inconsistent or incomplete Life Cycle Assessment (LCAs) on energy use, carbon footprint, and end-of-life impacts.
- Addressing the limited data on by-products of biodegradation (e.g. metabolites formed, particles and chemical substances released) and their ecotoxicological effects on soil and aquatic organisms.
- Focus on possible publication bias toward studies showing positive degradation or sustainability outcomes. It may overestimate the performance and environmental friendliness of biodegradable plastics.
- Develop research design and methods that can disentangle the effects of additives in biodegradable plastics.

Appendix 1. Assessment Questions and Problem Formulation

The assessment questions and sub-questions developed as basis for the project's problem formulation.

AQ(s) and SQs generically defined	Agent (A)	Pathway (P)	Receptor (R)	Intervention (I)	Output (O)	AQ(s) and SQs formulated using APRIO
AQ 1: Impact of biodegradable plastics on the environment at Nordic/Norwegian conditions.	All products of/containing biodegradable plastics intended for biodegradation in the open environment	Environments of intended application and risk of spreading to other environments	Terrestrial environment, soil, riverine, freshwater, and marine environment	Control measures based on appropriate risk assessment (complete/sufficient regulatory frameworks are not in place)	Identify and describe potential environmental risks associated with intended applications and establish a framework for risk assessment	What is the status of knowledge about biodegradable plastics applied in Norway, within which regulatory frames and/or best practices are they applied, and to what extent is knowledge in place and/or currently produced aimed at/useful for forming the basis for appropriate risk assessment of these plastics for application in Norway?
Tier-1 SQ 1.1: When applied in soil (e.g., agriculture)	All products of/containing biodegradable plastics intended for biodegradation in soil	From the soil of intended application to surrounding environment(s)	Terrestrial environment, soil, riverine, freshwater, and marine environment	Assess existing regulatory framework for soil applications	Probable environmental risks and possible environmental benefits	What is the knowledge status about the effects of biodegradable plastic applications in Norwegian soils, what regulatory frames and/or best practices are applied, and to what extent is knowledge in place and/or currently produced aimed at/useful for forming the basis for appropriate risk assessment of these plastics for their future applications in Norwegian soils?
Tier-2 SQ 1.1.1: List of relevant scientific knowledge and analytical data	Types of biodegradable plastic polymers and polymer + chemical composition of biodegradable plastic products	Potential for secondary pollution by spreading to surrounding environments, including in the form of microplastics and chemical leachates	Impacts on organisms (physical, ecotoxicological), their habitats and ecosystem functioning (structural, physicochemical, biodiversity)	Endpoints applied in current risk assessments and regulatory frameworks of biodegradable plastics in soil	Probable environmental risks and possible environmental benefits	Same as above
Tier-1 SQ 1.2: When applied in the marine environment	All products of/containing biodegradable plastics intended for biodegradation in the marine environment	Within and from the marine environmental compartment of intended application to other marine environmental compartments or costal terrestrial environments (e.g., from water column to marine sediments or costal terrestrial environment)	Marine environmental compartments, costal terrestrial environments including soil and freshwater	Assess existing regulatory framework for marine applications	Probable environmental risks and possible environmental benefits	What is the knowledge status about the effects of biodegradable plastic applications in Norwegian marine environments, what regulatory frames and/or best practices are applied, and to what extent is knowledge in place and/or currently produced aimed at/useful for forming the basis for appropriate risk assessment of these plastics for their future applications in Norwegian marine environments?
Tier-2 SQ 1.2.1: List of relevant scientific knowledge and analytical data	Types of biodegradable plastic polymers and polymer + chemical composition of biodegradable plastic products	Potential for secondary pollution by spreading to surrounding environments, including in the form of microplastics and chemical leachates	Impacts on organisms (physical, ecotoxicological), their habitats and ecosystem functioning (structural, physicochemical, biodiversity)	Endpoints applied in current risk assessments and regulatory frameworks of biodegradable plastics in the marine environment	Probable environmental risks and possible environmental benefits	Same as above
Tier-1 SQ 1.3: When applied in freshwater environments	All products of/containing biodegradable plastics intended for biodegradation in freshwater environments	Within and from freshwater environments of intended application to other freshwater environmental compartments, terrestrial and marine environments	Freshwater environmental compartments, terrestrial environments including soil and marine environments	Assess existing regulatory framework for applications in freshwater	Probable environmental risks and possible environmental benefits	What is the knowledge status about the effects of biodegradable plastic applications in Norwegian freshwater environments, what regulatory frames and/or best practices are applied, and to what extent is knowledge in place and/or currently produced aimed at/useful for forming the basis for appropriate risk assessment of these plastics for their future applications in Norwegian freshwater environments?
Tier-2 SQ 1.3.1: List of relevant scientific knowledge and analytical data	Types of biodegradable plastic polymers and polymer + chemical composition of biodegradable plastic products	Potential for secondary pollution by spreading to surrounding environments, including in the form of microplastics and chemical leachates	Impacts on organisms (physical, ecotoxicological), their habitats and ecosystem functioning (structural, physicochemical, biodiversity)	Endpoints applied in current risk assessments and regulatory frameworks of biodegradable plastics in freshwater environments	Probable environmental risks and possible environmental benefits	Same as above



Problem formulation model showing the pathways from application, release and environmental transformation of biodegradable plastics to potential environmental effects and harms. Note that interventions are not in place for risk assessment that account for the multifaceted environmental risks associated with materials and additives fates in different types of environments.

Appendix 2. Literature Search

Basic search (June 2024)

1	biodegradable plastics/
2	(biodegradable materials/ or biodegradation/ or biodeterioration/) and (plastics/ or microplastics/)
3	((((biodegrada* or compostable or degrada* or biodeteriora* or deteriora*) adj4 (plastic? or microplastic? or mesoplastic? or nanoplastic? or macroplastic?)) or ((biodegrada* or compostable or degrada* or biodeteriora* or deteriora*) adj4 ("micro plastic?" or "meso plastic?" or "nano plastic?" or "macro plastic?")))).tw.
4	or/1-3
5	environment/ or exp aquatic environment/ or exp ecosystems/ or freshwater ecology/ or marine ecology/ or exp aquatic organisms/ or exp aquatic communities/ or peat soils/ or peat/ or exp humus/ or clay soils/ or clay/ or halloysite/ or permafrost/ or exp sand/
6	(environment* or ecosystem? or "eco system?" or ecological or ecologic or habitat? or biome? or biodiversity or diversity or biota or biotic or biocenose? or "biological communit*" or freshwater? or lake? or pond? or river? or stream? or seawater? or ocean? or sea? or wetlands or boglands or bogs or fens or marshes or marshland? or swamp? or brackishwater? or soil? or peat or humus or clay? or halloysite? or permafrost? or sand? or aquatic or marine or benthos or "coral reef?" or periphyton? or seston or nekton or plankton or phytoplankton or Microalga? or Microphytes or zooplankton or krill or seagrass* or eelgrass* or seaweed? or kelp or algae or alga or Macroalgae or Gracilaria or Porphyra).tw.
7	((fresh or saline or brackish or sea or coastal) adj water?).tw.
8	or/5-7
9	4 and 8
10	limit 9 to yr="2014 -Current"

Literature search- Nordic countries

(October 2025)

There are two differences in this search, compared with the primary search (June 2024). In addition to the limitation to Nordic conditions, the second difference is in Medline, where one line with MeSH terms has been added: Biodegradation, Environmental/ and (Plastics/ or Microplastics/)

Appendix 3. Title and Abstract Screening Results

The criteria for inclusion in the scoping review stated that the studies should address the open environment in terms of (bio)degradation rates and environmental impacts including: 1) microorganisms (microbial ecotoxicology) and other organisms, 2) environments (ecotoxicology), and 3) material properties.

In terms of material properties and sources, the criteria were broader, including material properties of biodegradable plastics, biodegradable plastic products and their additives, plastic materials derived from biodegradable and compostable products including microplastics, associated sorbed environmental toxins and/or organisms, studies on bioprospecting and polymer sources for the production of biodegradable plastics. The publication types to be included were limited to original papers and systematic and non-systematic reviews.

The articles were assigned to groups of reviewers randomly (the literature search results were split into three sets alphabetically). Hence, we expected to get similar results from the three groups. The actual results are summarized in Table 1 below.

Table 1: Results of Title-Abstract Reviews

Decision	Group 1	Group 2	Group 3	Sum
Total	954	733	741	2,428
Exclude	613	604	559	1,776
Include	341	129	182	652
Sys.Review	1	3	2	6
Review	63	24	50	137
Ecotoxicology	96	40	47	183
Materials	78	35	28	141
Microbiology	103	27	55	185

Table 1 suggests that reviewers across groups made their decisions somewhat differently. To formally quantify degree of dissimilarity, we used two types of statistical analysis. First, we computed pairwise values of the Fisher's exact test, the test to compute likelihood that decisions made by Group i and j come from the same binomial distribution. In other words, we estimated the probability that the likelihood of making, for example, an 'include' decision is the same across the two groups. Second, we computed confidence intervals for the implied probability of 'include' decisions for each group. We combined both results for 'include'/'exclude' decisions in Table 2 below. The diagonal elements in the table are 95%-confidence intervals for the 'include' probability for each group. The off-diagonal elements are p-values for Fisher statistics (the null hypothesis was that the probabilities were equal across group pairs).

Table 2: Similarity of Accept/Reject Decisions Across Groups

	Group 1	Group 2	Group 3
Group 1	(0.33, 0.39)		
Group 2	8.08e-17	(0.15, 0.21)	
Group 3	7.87e-07	1.12e-03	(0.22, 0.28)

While we cannot rule out that the three pools of abstracts were systematically different, the results in Table 2 strongly suggest that the reviewer groups applied inclusion criteria heterogeneously, with Group 1 exhibiting the least strict selection and Group 2—the most strict selection. All groups made selections statistically significantly different from each other, when using the general inclusion decision frequency as the criterion. To find out if these discrepancies were driven by particular article classes, we repeated the same (dis)similarity analysis for all inclusion classes except systematic reviews. Systematic reviews were so few and far between that their inclusion frequencies across groups cannot be used to form any meaningful statistical conclusions. Results for (non-systematic) Reviews, Ecotoxicology, Materials, and Microbiology are presented in Tables 3–6.

Table 3: Similarity of Review Assignments Across Groups

	Group 1	Group 2	Group 3
Group 1	(0.05, 0.08)		
Group 2	2.53e-03	(0.02, 0.05)	
Group 3	9.22e-01	2.67e-03	(0.05, 0.09)

As evident from Table 3, and perhaps not surprisingly, Review class was associated with most homogeneous decisions across groups. Still, Group 2 was significantly different from both other groups at all conventional significance levels (p-value is below 1%).

Group 2 and 3 had statistically indistinguishable propensity to include Ecotoxicology and Material abstracts (see Tables 4 and 5), while Group 1 was significantly more lenient. When it comes to abstracts in Microbiology, Group 1 and 3 were insignificantly different but only at very low levels of significance below 2% (p-value is 1.84 %). At the conventionally chosen significance level of 5%, the two groups were significantly different. All other group pairs were significantly different at all reasonable levels of significance, with the same relative lenience ranking as for the overall inclusion decisions.

Table 4: Similarity of Ecotoxicology Assignments Across Groups

	Group 1	Group 2	Group 3
Group 1	(0.08, 0.12)		
Group 2	5.72e-04	(0.04, 0.07)	

	Group 1	Group 2	Group 3
Group 3	6.28e-03	5.08e-01	(0.05, 0.08)

Table 5: Similarity of Materials Assignments Across Groups

	Group 1	Group 2	Group 3
Group 1	(0.07, 0.1)		
Group 2	5.82e-03	(0.03, 0.07)	
Group 3	1.69e-04	3.69e-01	(0.03, 0.05)

Table 6: Similarity of Microbiology Assignments Across Groups

	Group 1	Group 2	Group 3
Group 1	(0.09, 0.13)		
Group 2	2.12e-08	(0.02, 0.05)	
Group 3	1.84e-02	2.01e-03	(0.06, 0.1)

We conclude that reaching homogeneity in understanding of criteria for assignment of one subject-matter field to abstracts as well as the overall abstract relevance threshold were a challenge. This highlights methodological problems associated with using multiple sets of reviewers at the abstract screening step of systematic and scoping literature reviews. In systematic literature reviews, too lenient inclusion results in extra burden at the full-text stage, while too strict exclusion results in an increased risk for omission of relevant articles. In scoping reviews, too lenient inclusion is not as benign. While it still increases the work burden at the full-text stage, it also dilutes the set of relevant articles with superfluous irrelevant articles, thus reducing the share of relevant literature reviewed at the full-text stage.

This discussion may suggest that a better use of limited resources is having multiple (more than 2) reviewers assess a share of abstracts and using one of the widely available machine learning tools for inclusion and classification decisions for the remaining abstracts.

Random sampling of articles from the basic search

A subset of the articles that passed the abstract and title screening stage was selected for the full-text stage. The rationale for performing full-text analysis on only a share of these articles was that otherwise the number of articles was too large.

Since the topic of biodegradable plastics is multi- and cross-disciplinary, a random selection from the included documents may result over- and/or underrepresenting some of the relevant scientific disciplines and hence their representativeness in the data charted. Cross-disciplinary studies were classified according to what was perceived as the main scientific focus. For review articles, there were clearly more non-systematic reviews. Hence, the same approach of random selection was performed on non-systematic reviews.

All systematic reviews were retained for full-text analysis, while all other groups of articles were sampled, selecting 25% from each group. As all articles selected to be in the pool of articles for full-text review were assigned to one main scientific field (or identified as a review article), each article had only “one chance” of being randomly picked for a full-text review. The total number of abstracts screened was 2,428. Of these, six were identified as systematic reviews. There were 137 non-systematic reviews and 183, 141, and 185 articles in Ecotoxicology, Materials, and Microbiology, respectively.

In order to have an objective and reproducible sampling of articles for full-text review, the process was implemented in the programming language R, version 4.2.0. For technical details, please see Appendix 4, Section “Sampling of Articles in R”.

The final sample of full-text articles is 170 articles consisting of all 6 systematic reviews, 35 non-systematic reviews and 46, 36, and 47 of articles in Ecotoxicology, Materials, and Microbiology, respectively.

Appendix 4. Sampling of Articles in R

The complete abstract screening results were exported from Rayyan in the csv format.

The sampling of articles relied on the base R function *sample*. Library *data.table*, version 1.14.8, was used to handle data.

```
share<-.25
set.seed(1234)

classes<-c("Sys.Review", "Review", "Ecotoxicology", "Material", "Microbiology")
article.sample<-list()

for (cl in classes){
  if (cl!="Sys.Review"){
    N.r<-nrow(article.list[get(cl)==TRUE])
    N.c<-ceiling(N.r*share)
    article.sample[[cl]]<-article.list[get(cl)==TRUE][sample(1:N.r,N.c)]
  }u else {
    article.sample[[cl]]<-article.list[get(cl)==TRUE]
  }
}
```

The files with the full list of articles, *article.list*, and the sampled articles, *article.sample*, are available on the project webpage. Setting the seed in R provides the same pseudo-randomly drawn subset of articles when applied to the original table with all articles (*article.list*).

Appendix 5. Summary of Non-systematic reviews

Author	Reference	Title	Polymers	Summary
Ahsan et al., 2024	doi.org/10.1007/s10661-024-12721-z	Sustainable struggling: decoding microplastic released from bioplastics—a critical review	PLA, PHA, PBAT, cellulose based, starch based.	Address biodegradable plastics as alternative to conventional plastics with focus on environmental consequences in natural soils and aquatic environments. Targets their content of additives, microplastics formed and environmental effects, including for different species, and their adsorption capacities for organic and inorganic pollutants. Their review methodology was systematic and without filters.
Ali et al., 2024	doi.org/10.1007/s10311-024-01703-9	Biodegradable microplastics interaction with pollutants and their potential toxicity for aquatic biota: a review	PLA, PHA, PBS, PBAT, PCL.	Review of biodegradable plastics with focus on their conversion into microplastics, their interaction with other pollutants, and their combined toxicity for aquatic biota and the impact of biofilm formation on their degradation and pollutant interactions.
Cinar et al., 2020	doi:10.3390/ijerph17113842	Bioplastic Production from Microalgae: A Review	PHA, PHB, PBAT, PBS, PVA (polyvinyl alcohol)	Address the production of biobased plastics from microalgae, targeting production technologies and methods, species used and possible optimization opportunities and application areas. Emphasize restrictions for use in health care and food packaging due to various additives used and the need for innovative design to address this issue.

				Search in Scopus included the key words “bioplastic microalgae”.
Cucina et al., 2021	doi.org/10.1016/j.biortech.2021.125459	The role of waste management in reducing bioplastics’ leakage into the environment: A review	PHA, PLA, starch blends	Review of literature on biodegradation at industrial (anaerobic digestion and composting) and natural (soil and water) environments, and link to potential leakage to the environment. Assessed the potential role of waste management processes to decrease leakage to the environment.
Degli-Innocenti et al., 2023	doi.org/10.1007/s10532-023-10031-8	Microorganisms that produce enzymes active on biodegradable polyesters are ubiquitous	PLA, PBS, PHA, PCL, PBAT, starch blends, PVOH (polyvinyl alcohol) (PVA)	Address the intrinsic biodegradability of plastics (xenobiotics) at natural conditions but does not consider the environmental fate. Consider i) the chemical nature of biodegradable plastics, ii) the diffusion of ester bonds in nature, iii) the diffusion of decomposers capable of producing enzymes (esterases), iv) evidence showing that synthetic polyesters can be depolymerized by esterases, v) evidence showing that these esterases are ubiquitous.
Emadian et al., 2016	doi.org/10.1016/j.wasman.2016.10.006	Biodegradation of bioplastics in natural environments	PLA, PHA, PHB, PHBV, starch based, including Mater-Bi, cellulose based, PBS, PBSA, PCL,	This review highlights the recent findings attributed to the biodegradation of bioplastics in various environment, environmental conditions, degree of biodegradation including the identified bioplastic. Degrading microorganisms from different microbial communities.

Filicott o & Rothen berg., 2021	doi.org/10.1002/cssc.20 2002044	Biodegradable Plastics: Standards, Policies, and Impacts	PHA, PHB, PBAT, PLA	This review covers the environmental and socioeconomic impact of plastics, government policies, and analytical techniques. The authors present a subjective o utlook on the future of bioplastics (bio-based and/or biodegradable) based on their experience with their development and commercialization.
Garcia- Deprae ct et al., 202 1	doi.org/10.1016/j.biotec hadv.2021.107772	Inspired by nature: Microbial production, degradatio n and valorization of biodegradable bioplastics for life- cycle-engineered products	PLA, PHA, starch blends, PBAT, PBS, PBSA, PCL	This review aims at providing an overarching and updated survey of key aspects related to the biobased and biodegradable plastic (bioplastic) value chain with focus on its microbial production, degradation and v alorization. Includes examination of the key factors and mechanisms involved in the biodegradation of bioplastics and their biodegradation standards.
Hernán dez- García, et al., 202 1	doi.org/10.3390/foods10 061256	Biodegradable Antimicrobial Films for Food Packaging: Effect of Antimicrobials on Degradation	PLA, PBAT, PBS, starch, PVA, PCL, PHA, PHB, PHBV	The aim of this review was to analyze different studies developing antimicrobial materials based on biodegradable polymers (including fossil- and biobased plastics). They also analyzed the biodegradat ion behavior of the active materials.
Huang et al., 2023	doi.org/10.1016/j.jhazm at.2023.132024	Are biodegradable mulch films a sustainable solution to microplastic mulch film pollution? A biogeochemical perspective	PLA, PHBV, PBAT, PBS, PHB, PHA, PCL, starch	This review discusses the destination and consequences of biodegradable plastic mulch (BDM) in soil and the impacts of microplastics f ormed on soil C sequestration, nutrient cycling, primary productivity, greenhouse gas emissions, and soil biodiversity.

Ildris et al., 2023	doi.org/10.1016/j.envres.2023.115988	The degradation of single-use plastics and commercially viable bioplastics in the environment: A review	PLA, cellulose-based, starch-based, PHA, PHB, PBS	This review is about different types of plastics, with focus on single-used products like packaging, food-containers and disposable toiletries. They discuss their degradation process and the role of microorganisms. The review also briefly elaborates the background of plastic pollution, the biodegradation of plastics in different environments, and the fate of plastics in their microplastic forms. They also discuss advantages, disadvantages and environmental impacts of conventional and emerging plastics.
Kaing et al., 2024	doi.org/10.1016/j.scitotenv.2023.1	Photodegradation of biodegradable plastics in aquatic environment: Current understanding and challenges	PCL, (PEA), PBS, (PPL), (PU), PHA, PHB, PBAT, (protein-based), Starch, cellulose-based, (Nylon), PCL	Review on the chemical properties, distribution and photochemical reactivity and related processes of biodegradable plastics in aquatic environments. Search method given, 19 out of 320 papers described the photodegradation of biodegradable plastics.
Karalija et al., 2022	doi.org/10.1016/j.jhazmat.2022.1	Interplay of plastic pollution with algae and plants: hidden danger or a blessing	Not specified	The objective of this review was to shed light on how algae in marine environments and plants in terrestrial ecosystems are impacted by plastic pollution and future frontiers of exploitation of plants and algae in solving the plastic pollution problem.
Kingsley et al., 2023	DOI:10.1134/S106193482309006X	Environmental Microplastics Distribution, Impact, and Determination Methods: a Review	Not specified but refer to microplastics from biodegradable plastics as source of	Review on the global distribution of microplastics, their impact and analytical tools applied.

			environmental pollution.	
Lara-Topete et al., 2024	doi.org/10.1016/j.scitotenv.2024.173735	Compounding one problem with another? A look at biodegradable microplastics	PLA, PHA, PHB starch-based, cellulose-based, PBAT, PBS, TPS	This review aims to assess the risks of unintended consequences associated with the introduction of biodegradable plastics into the environment, namely, whether the incomplete mineralization of biodegradable plastics could enhance the risk of microplastic formation and thus, exacerbate the problem of their environmental dispersion, representing a potentially additional environmental hazard due to their presumed ecotoxicity.
Li et al., 2023	doi.org/10.1016/j.chemosphere.2022.137637	A discussion of microplastics in soil and risks for ecosystems and food chains	PLA	Review of the sources of microplastics and its effects on soil physical and chemical properties, including water holding capacity, bulk density and pH, as well as the potential effects on microorganisms and animals.
Lin et al., 2022		Current progress on plastic/microplastic degradation: Fact influences and mechanism	Enzymes that hydrolyze PHB, PHBV, PHA, PLA, PBSA, PCL	This review provides a summary of current plastic degradation research, thus establishing a robust theoretical basis for future studies on plastic remediation.
Liu et al., 2022	doi.org/10.1016/j.scitotenv.2021.151312	On the degradation of (micro)plastics: Degradation methods, influencing factors, environmental impacts	PLA, starch-based, PHA, PBS, TPS, cellulose-based	The paper mainly summarizes the following aspects: (1) The relationship between degradation of plastic and microplastics is explored; (2) The main degradation methods of (micro)plastics are

				<p>summarized; (3) The intrinsic properties and environmental factors</p> <p>that affect the degradation of (micro)plastics; (4) The impact of the degradation</p> <p>products of (micro)plastics on the environment; (5) The problems</p> <p>existing in current research are summarized and prospected.</p>
Manfra et al., 2021	doi.org/10.1016/j.jhazmat.2021.125763	Biodegradable polymers: A real opportunity to solve marine plastic pollution?	PLA, PCL, PHA, PHB, PHBV, PBS., starch-based, PBSA,	This paper reviewed the scientific literature about biodegradable plastics in the marine ecosystem, focusing on three key-aspects: (i) definition and type of BPs; (ii) degradation of BPs in the marine environment; and (iii) ecotoxicity of BPs.
Okeke et al., 2022	doi.org/10.1016/j.ceja.2022.100402	Microplastic burden in Africa: A review of occurrence, impacts, and sustainability potential of bioplastics	PHA, PHB, PLA, starch-based, cellulose-based, Chitosan	This review gives a comprehensive overview of microplastics and their impact on Africa's environment. The study highlights the mismanagement of plastic waste at its peak in Africa and proposes bioplastics as a biodegradable and environmentally friendly alternative that can be crucial in expanding Africa's plastic industry.
Oliveira et al., 2020	doi: 10.3389/fmars.2020.567126	Marine Environmental Plastic Pollution: Mitigation by Microorganism Degradation and Recycling Valorization	PLA, PHA, PBS, starch-based, PCL, PBAT	This review compiles the data spread across disciplines and aim to fill the existing knowledge gaps in this area, helping researchers to set experimental methodologies

				in their search for solutions to mitigate the problem caused by plastic pollution.
Rani et al., 2024	doi.org/10.1016/j.scp.2024.101595	Advances in the role of microorganisms, waste management strategies and policies on microplastic abatement in the era of biocircular economy	PLA, PHA, PBS, PCL, starch-based, cellulose-based	This article reviews different studies employed for the biodegradation of microplastics through microorganisms, their related products and the approaches used to improve their disposal issues with alternatives and better policy measures in the context of the bio-circular economy and the benefits and challenges of biotechnological methods. The literature of the last seven years has been reviewed to target the microplastic research in the area.
Sayantani et al., 2023	doi.org/10.1080/03067319.2021.1983552	Incarnation of bioplastics: recuperation of plastic pollution	PBAT, PVA, starch-based, PBAF, PHA, PHB, PBS, PLA, PCL	This work reviewed how bio-derived plastics achieve such interest and how it becomes the most acceptable substitute to beat plastic pollution.
Tan et al., 2022	doi: 10.3389/fbioe.2022.879476	Microalgal Biomass as Feedstock for Bacterial Production of PHA: Advances and Future Prospects	PHA	This work discusses the recent advancement in refining PHA synthesis from microalgal biomass as an industry-scale production that holds economic competitiveness against conventional plastics as well as non-microalgae production systems.
Tang et al., 2022	DOI 10.3389/fbioe.2022.1057067	A review on poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)	PHA	This paper reviews the properties, metabolic pathways of P(3HB-co-3HHx) production, factors affecting the 3HHx molar composition in P(3HB-co-3HHx) copolymer,

		[P(3HB-co-3HHx)] and genetic modifications that affect its production		and potential applications of P(3HB-co-3HHx).
Van Rossum, 2021	doi.org/10.1016/j.watcy.2021.06.001	Marine biodegradability review of plastics	PLA, PHA, PCL, PLGA	Discuss the biodegradability of plastics in marine environment in light of environmental conditions and impacts.
Venâncio et al., 2022		Available online 10 October 2022 0045-6535/© 2022 Elsevier Ltd. All rights reserved. Bioplastics: known effects and potential consequences to marine and estuarine ecosystem services	PLA, PHB, PHA, starch-based, PBAT, labelled biodegradable/compostable	This review analyzes bioplastics as alternatives to conventional petroleum-based plastics, considering sustainability of production as well as reported ecotoxicological effects to marine/estuarine biota and, degradability under realistic exposure scenarios.
Wu et al., 2021	doi.org/10.1016/j.scitotenv.2021.148337	Particulate plastics-plant interaction in soil and its implications: A review	PLA, 'biodegradable plastic'	This review comprehensively examines the pollution characteristics and exposure pathways of particulate plastics in agricultural soils, highlighting plastic uptake process, and mechanisms in plants, and effects of particulate plastics, biodegradable particulate plastics and combined pollution of plastics with other environmental pollutants on plant performances.
Zhang et	doi.org/10.1016/j.biortech.2019.121700	Progress and perspective on algal	PHA, PHB, starch-based, cellulose-based, PBS-	This review discusses the current status and

al., 2019		plastics – A critical review	composites, PBAT-composites, PVA-composites	progress in using seaweed polysaccharides (alginate and carrageenan) for bio-based plastics.
Ali et al., 2023	doi.org/10.3390/pr11123445	Ecotoxicological impact of bioplastics biodegradation: a comprehensive review.	PHA, PLA, PBS, PHB, cellulose-based, starch-based, PBAT, PCL	This review aims to provide a comprehensive overview of the biodegradation of bioplastics in different environmental conditions and by microorganisms and their ecotoxicological impacts on soil and marine health.

Appendix 6. List of supplementary files

The following supplementary files are available with the report at VKM.no:

- Study protocol
- Data charting (Excel-files), screened studies within:
 - 1- Table 1. Original articles – Material
 - 2- Table 2. Original articles – Microbiology
 - 3- Table 3. Original articles – Ecotoxicology
 - 4- Table 4. Systematic Reviews
 - 5- Table 5. Nordic literature

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