Dsolve

Centre for Research-based Innovation

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Biodegradable plastics for marine applications

Annual Report 2022

Photo: Norner Research

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Content

Summary

2022 was a productive year for the Dsolve consortium. We had several meetings between the industry and scientific partners, including two board meetings and two general assemblies. An annual meeting with physical participation, took place in Trondheim 27.-28. September, where we also arranged a joint meeting with SFI HARVEST. During the year, the RA leaders led several seminars and Dsolve established an International Scientific Advisory Committee. We joined a side-project funded by FHF- the Norwegian Seafood Research Fund "Alternative materials for Demersal seine ropes and dollyropes for bottom trawl codends". Further, we joined as partner in an application for EU HORIZON-MISS-2022-OCEAN grant with the title Marine litter and pollution – Smart and low environmental impact fishing gears. Dsolve was presented in many meetings and exhibitions during the year. We educated students at BSc and MSc levels, and contributed with several scientific articles. A new PhD candidate within Research Area 2 started at UiT in April, and the PhD position for Research Area 5 on inclusion of ghost fishing and its effects on ecosystems and biodiversity in life cycle impact assessment (LCIA), was announced in October.

Our three PhD candidates from Latvia, Vietnam, and Thailand, linked to Research Area (RA) 3 Tests and demonstrations at sea, RA 4 Governance incentives, and RA 2 Assessment of biodegradability, made good progress, attending compulsory university courses and presentations, preparing scientific publications, and applying for external funding to enhance research and mobility (Croatia, USA, Canada). Additionally, students at BSc levels have progressed with assignments and reports. Two MSc candidates completed thesis with a focus on challenges identified by Dsolve, i.e. on "properties affecting catch efficiency in the Northeast Arctic cod (*Gadus morhua*) gillnet fishery" and "status quo of quantities of plastic polymer(s) from fishing gear on a national level and how to evolve current models with a dynamic material flow analysis approach".

Planned activities at sea were limited mainly due to difficulties in fibre-spinning from new biodegradable resins and the production of twines, nets and ropes for fisheries and aquaculture. Basic research in laboratories is a continuous process. This laboratory work is carried out by our partners to identify properties of existing materials and new resins for the use in fishing gears. In 2022, we have conducted fishing trials with biodegradable gillnets in Norway, Denmark, and Croatia. A second generation of biodegradable plastics is now being tested in laboratories (RAs 1, 2, 3), and in Croatian fisheries.

Most of the work of our partners has been directed towards gillnet, longline, demersal seine, and bottom trawl fisheries. Their activity were mainly performed in Norwegian and Croatian fisheries with gillnets and longlines. Some of the planned activities with snow crab pots (ghost fishing) and bottom trawls in December 2022 had to be cancelled due to delays at a shipyard during the annual maintenance of the UiT research vessel "Helmer Hanssen". Experiments on ghost fishing in snow crab pots and testing of new type of biodegradable materials in components like

codend chafing mats (dollyropes) in bottom trawls were therefore postponed until 2023. Testing of alternative natural materials like wood-fibers and cowhide as substitutes for petro-based ropes and fibers (dollyropes) were terminated during 2022 following negative feedback from users of bottom trawling and demersal seine operations.

All the materials that were tested in fisheries were, apart from catch efficiency numbers, analyzed in laboratories at SINTEF Ocean and SINTEF Industry for parameters such as breaking strength, abrasion resistance, degradation profiles, and microplastic formation. Fishing gear like gillnets and sections of longlines, i.e. snoods, and protecting chafers in Demersal seines, constitute much of the marine littering from fisheries. Samples from the tested gears in Croatia, Germany, Denmark, and Norway, undergo long term degradation experiments to calculate degradation from various marine environments. The tests are made at SINTEF laboratories in Oslo, Trondheim and at UiT.

A new type of biodegradable material with similar properties to those of nylon, like elasticity and tensile strength, was produced by our industry partners in South Korea. The new material has better properties than the former PBSAT material; while the latest tests in Croatia show encouraging results for longline snoods, there are some challenges regarding its use of the material in gillnets. Further tests in trammel net fishery in Croatia are planned for 2023. In addition, the new material was tested in Demersal seine rope experiments in Norway. Results prove that the material is comparable to polyamide regarding its strength and abrasion resistance. We identified new applications for this material to replace nylon and expect positive results from 2023 test programs. Provided that the material shows comparable properties to nylon regarding efficiency and service time as well, we believe that an important barrier in polymer development will have been breached.

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The Research Area leaders have continued their arranged meetings every second month (RAs 1, 2, 3) to discuss the results from laboratories and field trials. Our international industry partners LG-Chem and S-EnPol have participated in several of these meetings. These meetings have been essential for further development of biodegradable plastics. The members of Research Areas 4 Governance incentives, 5 Circularity of plastics, and 6 Communication, dissemination and exploitation, have joined workshops and meetings including events outside the consortium, with e.g a presentation for the MarIlca project and close links to the NTNU led EU-project ATLANTIS. The Dsolve administration participated in several arrangements and gave presentations in various fora. Activities in and between Research Areas 1 to 6 and administration will be fully addressed in the section of Scientific activities and results.

Summary

Meeting with Korean partners, LG Chem, in Oslo 18. March.
Photo: Dsolve

During 2022, we had two board meetings, two general assemblies and one annual meeting. The Research Council of Norway paid the Dsolve facilities at UiT a site-visit in September. We visited several partners during this year, e.g. NOFI Tromsø, SINTEF Ocean, SINTEF Industry, Mørenot and Loran. Dsolve published a number of new articles, participated with presentations in Nor-Fishing 2022 (Trondheim), national TV, the annual Research Days, etc. Dsolve was also present at Arendalsuka (Arendal), and at The 7th International Marine Debris Conference (7IMDC) in Busan, South Korea.

Our first board leader Isabelle Sande, from Løvold, stepped down as she changed jobs, and Terje E. Martinussen, former director of the Norwegian Seafood Council and Institute leader at the Norwegian College of Fishery Science, UiT, has been elected as new board leader. An international Scientific Advisory Committee has been established with Dr. Aida Campos from IPIMAR, Portugal, Mr. Haraldur Einarsson from FAO and the Marine Institute of Iceland, and Dr. Paul Winger from Memorial University of Newfoundland Canada.

The fisheries sector is male dominated and discrimination and harassment has been observed. Dsolve is proud to proclaim that we follow the ethical standards of UiT which has zero tolerance for discrimination. Dsolve has a focus on gender balance. Three out of six research area leaders, two out of three PhD students, our administrative leader, and several members of the board, are women. As a final remark, the Dsolve team is pleased with the progress achieved during 2022, which we are eager to continue onto 2023.
Tromsø, 31. March 2023

Roger B. Larsen
Centre Director

Gillnet trials along the coast of Umag in Croatia.
Photo: K. Cerbule, 2022

Vision and Ambitions

Vision:

Reduce plastic litter and associated problems (macro-, microplastics and ghost fishing) caused by the fishery and aquaculture industries.

Ambition:

Place Norway at the forefront of research, development, and use of smart biodegradable materials to reduce the global problem of marine litter from fisheries and aquaculture.

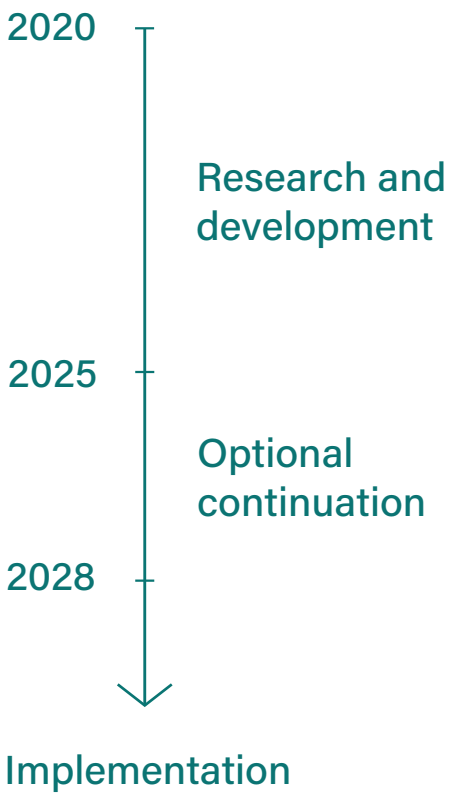


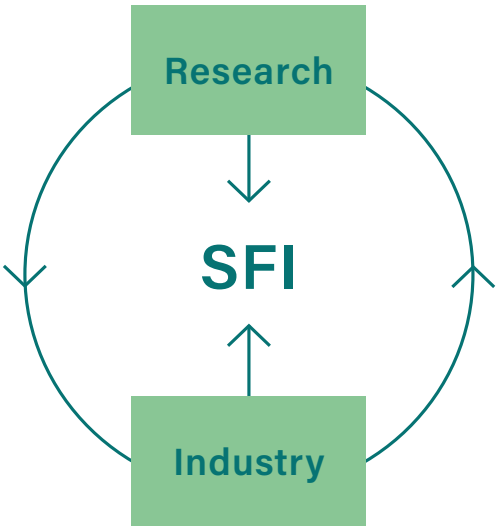
Illustration: SALT

Photo: Espen Mortensen

Objectives

The main objective of SFI Dsolve is to reduce plastic litter and its associated problems such as macro-, microplastics and ghost fishing in the marine environment caused by fishing and aquaculture industries, by replacing the traditional plastics used in gears and gear components with new biodegradable materials. This primary objective will be achieved by the following **secondary objectives:**

- Develop new smart biodegradable polymers with controllable (non-linear) degradation in the marine environment.
- Develop biodegradable filaments, twines, ropes, and netting for fisheries and aquaculture purposes.
- Create governmental incentives and restrictions to incorporate biodegradable plastics in an ecosystem-based management approach.
- Help to establish a supplier industry that can deliver biodegradable gears and services to the end-user sectors (fisheries and aquaculture).
- Develop sustainable downstream solutions and LCA for biodegradable fishing gear.
- Optimize and validate waste sorting technologies and circular waste processing options for biodegradable materials.
- Educate at least 8 PhD candidates, 4 post docs, and 30 MSc candidates.



Parts of traditional plastic nets and ropes found in beach clean-ups, and about to crumble into smaller pieces.

Photo: R.B. Larsen

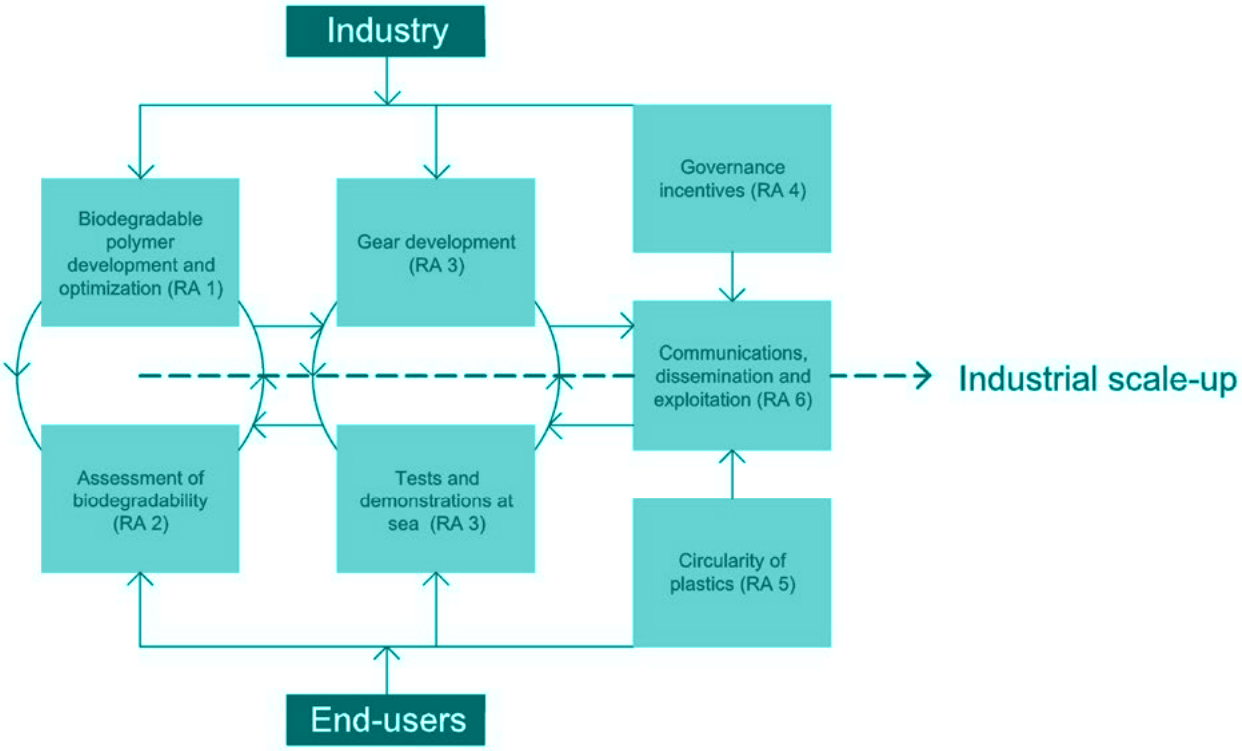
Capillary rheometer (Haul-off) to determine melt strength and melt spinnnability. *Photo: Norner Research*

Research strategy

Our main research hypotheses are:

- By replacing traditional non-degradable plastics with smart biodegradable and controllable ones, we can reduce marine litter caused by the fishing and aquaculture industries.
- By reducing ghost fishing and macro- and microplastic pollution, value creation will increase in the fishing and aquaculture industries.
- By introducing effective incentives, the fisheries management can facilitate the use of biodegradable plastics, in order to enhance the ecosystem-based management approach.
- New sustainable downstream solutions and LCA can facilitate the circularity of existing fossil-based non-degradable and biodegradable plastics.

Dsolve focus on six Research Areas that jointly address these hypotheses:



Specific objectives for the Research Areas (RAs) are:

RA 1

Dr. Ravindra R. Chowreddy
Norner Research AS

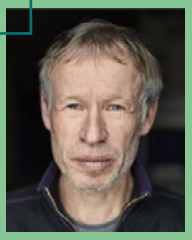
Develop a range of biodegradable plastic materials with controlled biodegradability and the properties needed for products used in the fishing and aquaculture industries

RA 2

Dr. Christian W. Karl
SINTEF Industry

Create a sustainable framework for testing biodegradability and environmental impact. Lab and field testing will be carried out in conditions representing different marine environmental factors, and marine biodegradation tested in different marine habitats and climate zones. Biodegradable and conventional tools will be compared.

RA 3



Prof. Bent Herrmann
SINTEF Ocean/UiT

Sea trials in the Norwegian, North, Baltic and Adriatic Seas including performance, catch pattern, and efficiency analyses of existing and new technology. Obtain data about the performance of biodegradable twines and ropes, the catch efficiency of nets, and how degradation varies in relation to different environmental conditions.

RA 4

Prof. Claire Armstrong
UiT Arctic Univ. of Norway

Assess the economic effects of non-biodegradable materials used in fisheries and aquaculture and evaluate costs and benefits on ecosystem services from introducing biodegradable materials in the marine industries. Further analyse institutional incentive mechanisms and assess public support systems to reduce risk and promote implementation of biodegradable innovations.

RA 5

Dr. Cecilia Askham
NORSUS AS

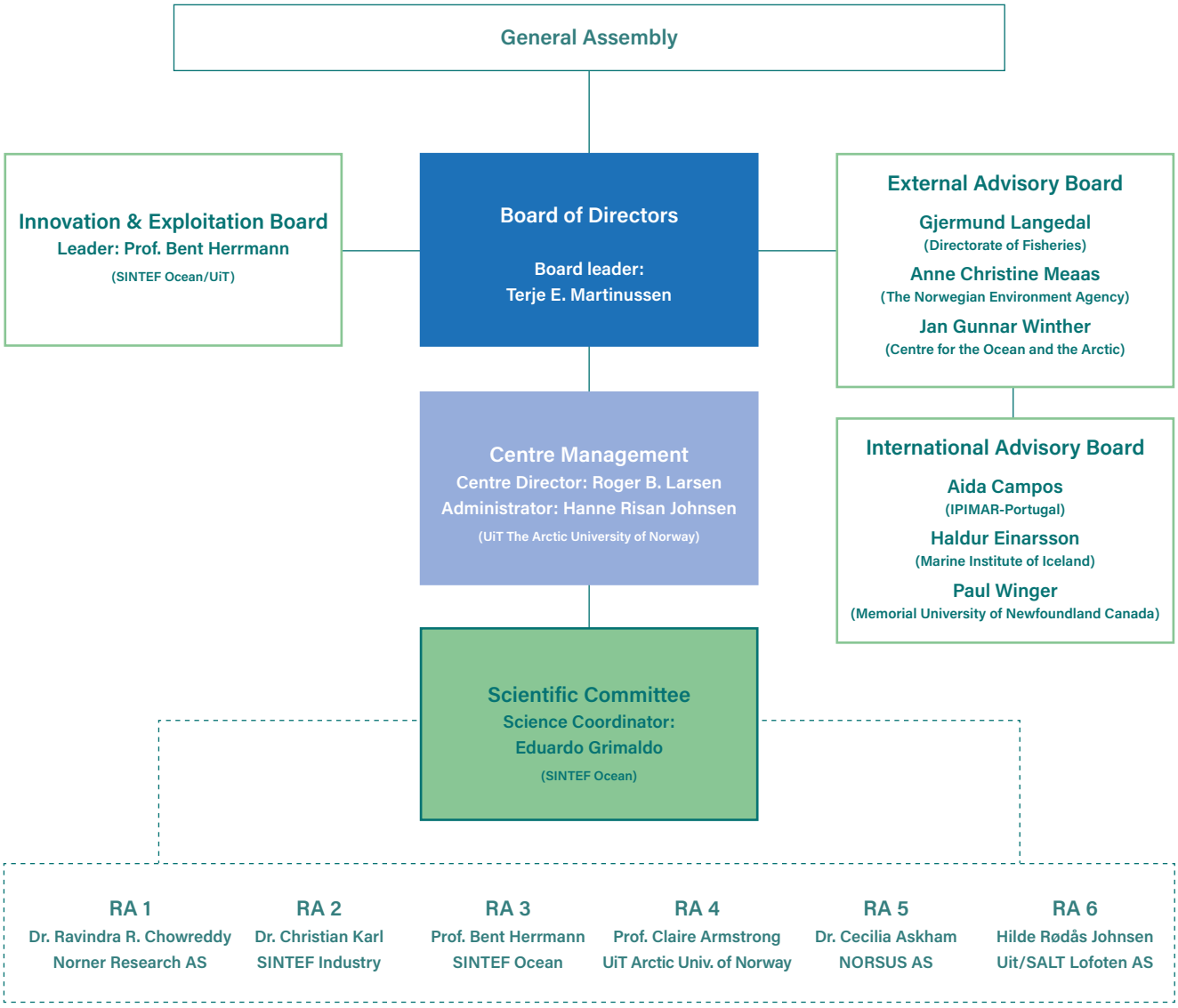
Develop sustainable circular solutions for existing non-degradable and future biodegradable fishing gear. The goal is to develop environmentally sustainable value chains which also take the level of circularity into account.

RA 6

Hilde Rødås Johnsen
UiT/SALT Lofoten AS

Develop and carry out a dynamic plan for outreach through communication, dissemination and exploitation of results in order to maximize the impact of the project results.

Organisation



The centre is organized as described in the figure above. The General Assembly consist of representatives from each partner and have the uppermost decision-making power in the centre. A Centre Board of 11 members is chosen among the partners. The board decide on organisation, budget, activities and working plans, and is responsible for the progress and scientific quality of the centre research activities. Terje E. Martinussen succeeded Isabelle Sande (Løvold AS) as leader of the board during 2022. Martinussen has long experience from the seafood industry as former director for the Norwegian Seafood Council, Institute leader at UiT, and previous experience from amongst other Nofima (former Fiskeriforskning). From 2022 the General Assembly has decided that all partners will have permanent representation in the board. Also research partners and the host institution (UiT) have a permanent representation.

Members of the Centre Board 2020 - 2022

ROLE	MEMBER OF CENTRE BOARD	AFFILIATION
Leader of the Board	Isabelle Sande / Terje E. Martinussen	Løvold AS/Private
Host Institution	Terje Aspen	UiT-BFE
Research Partners	Klaus Schöffel	Norner Research AS
	Gunvor Øye	SINTEF Ocean
	Einar Hinrichsen	SINTEF Industry
	Ellen-Marie Forsberg	NORSUS AS
Industry and organisations	Bent Gabrielsen	Øra AS
	Arne Birkeland	Opilio AS
	Lasse Rindahl	Mustad Autoline AS
	Terje Lindal	Mørenot AS
	Jan-Henrik Sandberg / Maria Pettersvik Arvnes	Norges Fiskarlag
	Ellisiv Løvold / Stig-Endre Elvevoll	Løvold AS
Observer	Inger Austrem	The Research Council of Norway

The Centre Board is advised by the Innovation and Exploitation Board and the External Advisory Board. The Innovation and Exploitation Board is led by Professor Bent Herrmann, chief scientist at SINTEF Ocean. The External Advisory Board (EAB) is selected from experts in policy and bioeconomy, governance institutions, public organisations, and NGOs. The goal of the EAB will be to guarantee quality of the research and maximise its impact. An international Scientific Advisory Committee (ISAC) has been established in 2022 consisting of Dr. Aida Campos from Institute for the Ocean and the Atmosphere (IPIMAR), Portugal, Mr. Haraldur Einarsson from the Marine Institute of Iceland, and Dr. Paul Winger from Memorial University of Newfoundland Canada.

The three members of ISAC have comprehensive networks, and they hold important positions in their research communities. They are members of ICES (the International Council for the Exploration of the Sea) and the FAO (Food and Agriculture Organisation) of the United Nations. The ISAC will be involved in advising and evaluating the progress of Dsolve, and help with international outreach of results, including scientific publications, for stakeholders and scientific communities.

Board meeting at Sommarøy
5.- 6 April. *Photo: Dsolve, 2022*

Annual meeting and General assembly

The first physical annual meeting after the pandemic, could finally take place in Trondheim on the 27.-28. September. Sintef SeaLab acted as host and also offered a tour at some of their laboratories. Part of the meeting was devoted to knowledge exchange in a joint meeting with SFI Harvest. In total 23 representatives from research and industry partners gathered in Trondheim. In addition, several participated digitally. The annual meeting offered good professional discussions and presentations, the status of the various research areas, and important clarifications on the way to developing biodegradable tools for use in fisheries and aquaculture. General assemblies were held at Sommarøy 5.-6. April, and at 28. September in Trondheim with both physical and digital participation.

Photo: Sintef Ocean

The annual meeting 2022 gathered participants from both industry and scientific partners to joint discussions.
Photo: SALT

Partners

Host Institution

UiT – The Arctic University of Norway As hosts institution, UiT contribute to the SFI with expertise in Arctic and marine biosciences, economy, and subjects relevant to the fisheries and the aquaculture industry, as well as infrastructure for lab testing and fishing gear trials. UiT is leading Research Area 4 Governance incentives, Research Area 6 Communication, Dissemination and Exploitation, and is involved in Research Area 3 Tests and demonstrations at sea.

National Research Partners

Norner Research AS contributes to the SFI with expertise in Polymer R&D services, material and analytical testing, evaluation of physical and chemical properties, environmental influence on material properties, and plastic processing techniques. Norner is leading Research Area 1 Biodegradable polymer development and optimalization.

SINTEF Ocean contribute to the SFI with expertise in ocean-based industries, including fishery and aquaculture, and with R&D infrastructure. Sintef Ocean is leading Research Area 3 Tests and demonstrations at sea, is head of the Scientific Committee of SFI Dsolve, and has also the role as Science Coordinator of the SFI.

SINTEF Industry contribute to the SFI with expertise in the entire value chain from manufacturing to finished product, for all types of plastics, including thermoplastics, plastics composites, elastomers, and gels. Sintef Industry is leading Research Area 2 Assessment of biodegradability.

NORSUS AS contribute to the SFI with expertise in LCA for analysis of environmental and resource efficiency for products and services. Norsus is leading Research Area 5 Circularity of plastics.

International Research Partners

DTU-Aqua (Denmark) Research, advice, education and innovation in sustainable exploitation and management of aquatic resources. Contribute to Research Area 3 Tests and demonstrations at sea.

Thünen Institute of Baltic Sea Fisheries (Germany) Research, advice, and monitoring on fisheries and environment in the Baltic Sea. Contribute to Research Area 3 Tests and demonstrations at sea.

University of Split (Croatia) Research, science, and innovation within oceanography and fishing, nautical science, and a range of other specific disciplines. Contribute to Research Area 3 Tests and demonstrations at sea.

International Industry Partners

LG Chem (South Korea) Supplier of biodegradable polymers and fishing gear. Contributes to the SFI with materials for testing and expertise on biodegradable plastics.

S-EnPol (South Korea) Supplier of biodegradable polymers and fishing gear. Contributes to the SFI with materials for testing and expertise on biodegradable plastics.for testing and expertise on biodegradable plastics.

National Industry partners - suppliers

Nofi Tromsø AS	Supplier of fishing gear. Contribute to the SFI with expertise on fishing gear, and in particular nets.
Mørenot Fishery AS	Supplier of applications to the fisheries and aquaculture industry. Contribute to the SFI with expertise on fishing gear and aquaculture equipment.
Løvold AS	Supplier of applications to the fisheries and aquaculture industry. Contribute to the SFI with expertise on fishing gear and aquaculture equipment, and in particular ropes.
Mustad	Supplier of fishing gear. Contribute to the SFI with expertise on fishing gear, and in particular longlines.

National Industry partners - users

Øra AS (coastal gillnetting)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the 11 m coastal gillnet-vessel "Karoline".
Tustern AS (demersal seining)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the 30 m seine-vessel "Fortuna".
Hermes AS (demersal trawling)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the 62 m trawler "Hermes".
Legøy Rederi AS (gillnetting)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at a 15 m coastal gillnet-vessel.
Martin Solhaug (longlining)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the 15 m coastal longliner "MS Vibeke Cathrin".
Opilio AS (snowcrab potting)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the snowcrab vessel "Northeastern".
Loran AS (mechanical longlining)	Contribute to the SFI through full-scale tests of biodegradable fishing gear at the mechanized longliner "Loran".
Kvarøy Fiskeoppdrett AS	Contribute to the SFI as end user within salmon farming. Owns and operates two ordinary salmon farming licenses and one R&D license.

Organisations

Norges Fiskarlag	Contribute to the SFI as representative for Norwegian fishers. Participate in Research Area 6 Communication, dissemination, and Exploitation.
Norges Råfisklag	Contribute to the SFI as representative for Norwegian fishers. Participate in Research Area 6 Communication, dissemination, and Exploitation.

External Advisory Board

Senter for Hav og Arktis	Contribute to the SFI with expertise on blue sustainability in the arctic and partnerships for sustainable blue business.
Miljødirektoratet	Contribute to the SFI as representative for Norwegian authorities with authority on environmental management and legislation.
Fiskeridirektoratet	Contribute to the SFI as representative for Norwegian authorities with authority on fishery and aquaculture management and legislation, and expertise on retrieval of lost fishing gear.

International Scientific Advisory Board

Institute for the Ocean and the Atmosphere, Portugal	Contribute to the SFI with expertise in ocean science and technology research.
Marine and Freshwater Research Institute, Iceland	Contribute to the SFI with expertise in marine and freshwater research.
Memorial University of Newfoundland	Contribute to the SFI with expertise in fishery research.

Scientific activities and results

The goal of our centre for research-based innovations is to develop technologies and new products, improve the governance framework, and foster innovations that enable the plastic value chains to become more circular and resource efficient. This will reduce the carbon and greenhouse gas footprints to be more in line with the UN climate, energy, and sustainable development goals. The main working hypothesis is that the problems associated with marine plastic litter caused by the fishery and aquaculture sectors can be significantly reduced if traditional plastics in these sectors are replaced with new biodegradable materials. Today marine litter from non-degradable plastics end up as macro- and micro-plastic while lost and abandoned fishing gears can cause "ghost fishing", resulting in unaccounted mortality. The centre is designed to address these challenges.

The section below describes the status for the various research areas, plans and achievements in 2022. Status and results for each research area is described with a summary of objectives and motivation, key research tasks, and achievements.

RA 1 Biodegradable polymer development and optimization

Objectives and motivation

The main objective of Research Area 1 is to develop a range of biodegradable plastic materials with the properties needed for products used in fishing and aquaculture industries (e.g., twines and netting, ropes, gillnets, coatings, pots and traps, foils and boxes, pipes, and connectors). The developed materials should meet a range of processing and performance requirements, including biodegradability.

The motivation behind this research area is that the conventional plastic materials used in construction of fishing gear and aquaculture equipment are not biodegradable and remain in the aquatic environment when they are lost during operation. This leads to plastic pollution, microplastic formation and ghost fishing issues. Utilisation of biodegradable plastic materials in fishing gear and aquaculture equipment would reduce the plastic pollution and ghost fishing due to the shorter lifespan of biodegradable plastic materials. None of the commercial biodegradable plastics meets the performance and biodegradability requirements needed for the fishing gear and aquaculture equipment. Therefore, the Research Area 1 in the Dsolve project intends to develop a range of biodegradable alternative materials.

The overall key research tasks of Research Area 1, and key research tasks prioritised for 2022 is presented below.

Key research tasks

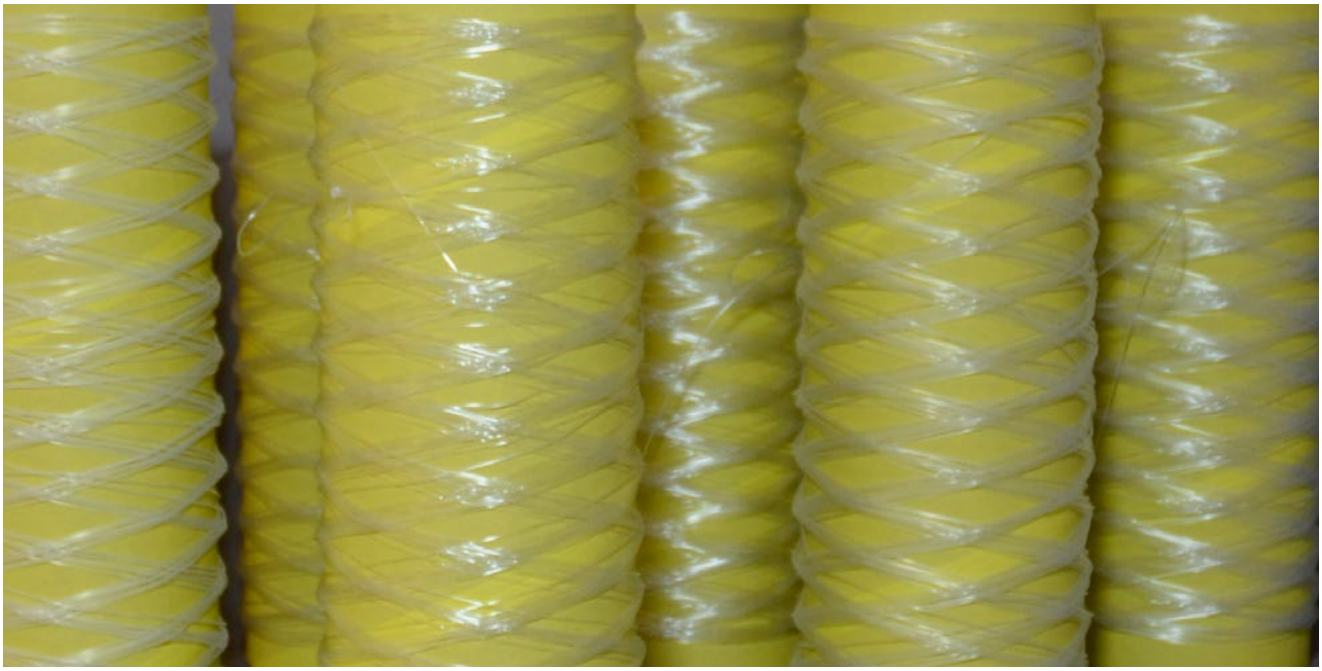
- Selection, identification, sourcing, and suitable modification of biodegradable plastic materials for marine fishing and aquaculture applications.
- Development of the biodegradable materials with optimal processability, performance for various applications, such as for fibres (twines, netting, ropes, etc.), for injection molding (pots, traps, boxes, etc.), and for coatings (steel rope coatings).
- Investigation of potential microplastics formation from the biodegradable plastics and prediction of the degradation products.
- Establishing collaborations with materials suppliers to ensuring availability of biodegradable plastics in the project.
- Develop new material and design concepts to meet the requirements of marine biodegradability, processability and performances for marine fishing and aquaculture applications.

Key Research tasks prioritised for 2022

- Desk-top study to map various bioplastic modification strategies to meet the performance, processability, and biodegradability for fishing gear and aquaculture applications.
- Technical development, identification of gaps to close and recommendations for materials development with commercial bioplastics in order to meet process and performance needs for fishing applications.
- Identification, selection, and sourcing of biodegradable plastics for fibre applications.
- Processing and performance evaluation of biodegradable fibres produced from selected commercially available and development biodegradable plastics.
- Desk-top study to identify methods for formation, separation, quantification, and characterisation of microplastics.
- Development of methods for investigation of microplastics formation, separation, quantification, and characterisation.
- Scouting, sourcing, and preliminary characterization of selected biodegradable materials

Achievements for 2022

- A desk-top study was carried-out to map various strategies to modify bioplastics to meet performance, processability, and biodegradability needs for fishing gear and aquaculture applications and is reported in NR230125 (Deliverable D1.4). The main findings of the study were that the bioplastics possess inherent poor processability and mechanical properties. To utilize these bioplastics successfully for construction of fishing gear and aquaculture equipment, suitable modification of the resins is necessary. Technical development is currently underway based on the findings of this desk-top study.
- About eight different bioplastic materials were sourced and processed into monofilaments and were stretched at different rates. The fibres produced were being characterised for mechanical properties. The results of fibre processability of different bioplastic materials and the results of the mechanical testing will be summarised in technical report (Deliverable D2.2; Q1 2023).
- A desk-top study was carried-out to identify the methods for formation, separation, quantification, and characterisation of microplastics. The findings of the study are summarised in the deliverable report D5.1.
- Development of methods for investigation of microplastics formation, separation, quantification, and characterisation.
- The materials sourced during 2021 were extensively characterised for basic properties and the findings of the characterization were summarised in deliverable report D6.1 (NR22760).
- New bioplastic material suppliers were identified, and new materials were sourced during 2022. Currently, the preliminary characterization of these materials is ongoing. The findings of the characterization will be summarised in deliverable report D6.2.



Monofilaments produced from different bioplastics materials in the Dsolve project.

Photo: Norner Research 2022

Publications

- State-of-the-art materials for fishing gear and aquaculture applications, Norner, Ravindra Chowreddy.
- Potential biodegradable plastic alternatives for fishing and aquaculture applications, Norner, Ravindra Chowreddy.
- Critical performance requirements for fishing gear applications, SINTEF, Christian Karl, Kjell Olafsen, Stephan Kubowicz.
- State-of-the-art fibreprocessing methods for fishing gear, Norner, Vinh Cao.
- Memo describing different concepts for methods to study the formation of microplastics as well as their separation, quantification, and characterization, SINTEF, Christian Karl, Kjell Olafsen, Stephan Kubowicz.
- Summary of characterization results on 1st GEN bioplastics, Norner, Ravindra Chowreddy.
- Potential modification strategies for biodegradable plastics in Dsolve project, Norner, Ravindra Chowreddy.

RA 2 Assessment of biodegradability

Objectives and motivation

In the second work package, assessment of biodegradability, the degradation behaviour of fishing gear or other equipment for marine applications made of biodegradable polymers will be investigated in more detail. These fishing gears should have the same or better mechanical properties and fishing efficiency than the non-biodegradable plastics. These common polymers currently used in the fishing and aquaculture industries include primarily polyamide (PA). Gillnets made from synthetic materials are durable and have high tensile strength, which becomes problematic when lost at sea as they contribute to ghost fishing. Issues such as ghost fishing, marine plastic pollution, shipping risks, and the introduction of synthetic materials into the marine food chain have become much more acute with the increase in fishing activity. In recent years, biodegradable gillnets (e.g. made of PBSAT) that can be degraded by naturally occurring microorganisms in seawater have been increasingly discussed and researched as a replacement for conventional PA gillnets. The catch efficiency of these nets made of biodegradable polymers is in some cases comparable to nets made of PA, polyethylene (PE), and polypropylene (PP). However, significant research is still needed to improve the mechanical properties, catch efficiency and biodegradability of these gillnets and other devices of interest for future applications. In addition, the degradation of biodegradable polymers with controllable and nonlinear degradation profiles that exhibit stable mechanical properties during their lifetime and degrade rapidly thereafter will be investigated. Additional suitable materials are currently being investigated.

The Dsolve project consortium will work closely with academic and industrial partners to make biodegradable plastics commercially available and economically accessible to end users.

Key research tasks

One of the main focuses of this work package is to investigate modified and unmodified biodegradable polymers for fishing gear that have the same or better mechanical properties and catch efficiency than the non-degradable plastics currently used by the fishing and aquaculture industry. The physical and chemical integrity and degradation of biodegradable and conventional nets and twine will be evaluated in laboratory and field tests over an extended test period (5 years or complete degradation). Accelerated weathering tests in the laboratory, especially the influence of UV radiation and temperature, will be compared with field tests and experiments conducted under controlled laboratory conditions. The work plan describes in more detail the activities planned to achieve these objectives. The following main tasks are relevant:

- Task 2.1: Investigation of the marine biodegradation of gillnets and twines with PBSAT as test and PA6 as control material in situ in different marine habitats and in different climate zones (Skagerrak Sea, North Sea, Baltic Sea, Adriatic Sea, and Norwegian Sea) to cover a wide temperature range from 4 to 27°C and

analyse the samples.

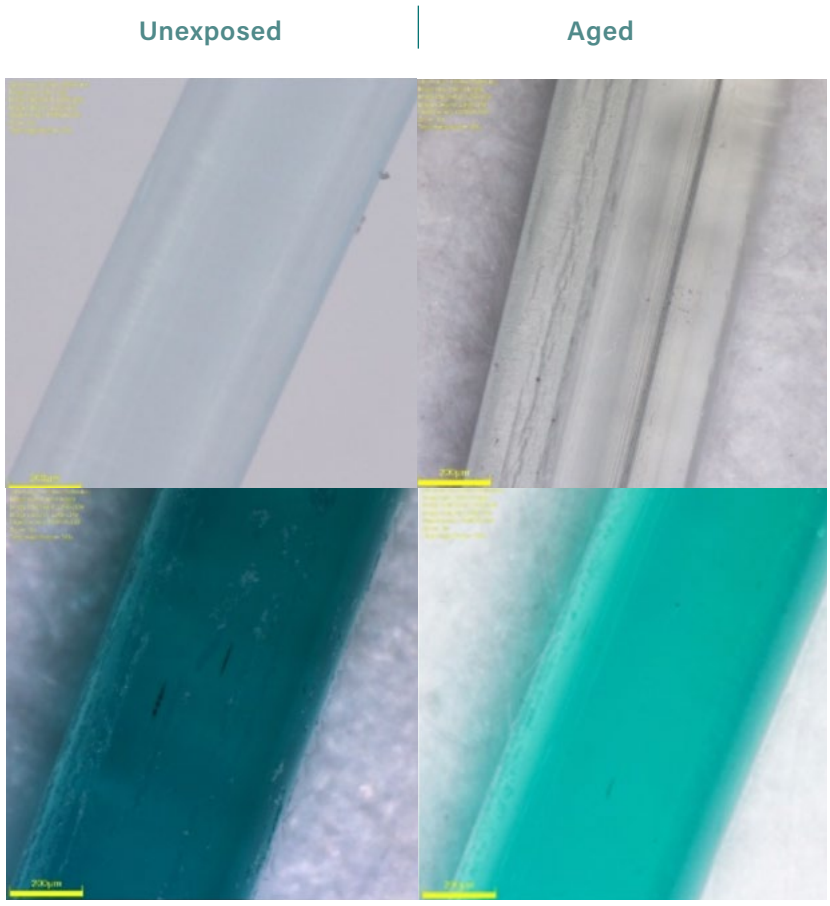
- Task 2.2: Investigation of the biodegradation in laboratory systems (controlled conditions) consisting of natural seawater. Analysis includes monitoring microbial biodegradation, performing microbiome analyses, and analysing the materials (chemical and physical properties) during and after degradation.
- Task 2.3: Evaluation of the effects of UV radiation with simultaneous changes in temperature, humidity, and pollutants (and the combination of these factors) on the physical properties of PBSAT nets and yarns and PA6 as control.

Achievements 2022

- The monofilament polymer samples described in Task 2.1 were collected in January 2022 after six months (Croatian testing sites), and in June/July 2022 after 12 months from all testing sites (Norway, Denmark, Germany, and Croatia). Analysis have been performed on the six-month samples (Croatian testing site) and initially from the 12- month samples from all testing sites. A report describing the collected samples at the testing sites has been finalized accordingly (Task 2.1 report). The photo below shows a temperature logger and monofilament samples from the Norwegian test area fixed in a pot.

Temperature logger and monofilament samples fixed in a pot.
Photo: SINTEF Ocean

- Polymer biodegradation experiments in lab-based systems using natural seawater (microbial biodegradation and microbiome analyses) described in Task 2.2, have been successfully set up in September 2022.
- Accelerated weathering experiments of the monofilaments (PA6 as reference and PBSAT as biodegradable polymer) were carried out in Task 2.3 and methods (chemical, physical, surface characterization) for characterization were selected, which are important for the whole Research Area in the future, especially field experiments in Task 2.1 and the controlled laboratory experiments in Task 2.2. The photo below exhibits the polymer monofilaments of PA6 and PBSAT before and after ageing. A test report summarizing the results from the field and lab-based degradation studies in Task 2.1 (after 12 months) and Task 2.3 has been finalized.
- PhD candidate recruited for the Research Area 2 (assessment of biodegradability) – and started in April 2022.



Polymer monofilaments (PA6 and PBSAT) before and after ageing (ca. 1000 hours).
Photo: SINTEF Industry

Dissemination and public outreach

- A guest lecture ("Plastics in the ocean-ghost fishing and impacts of marine litter") in the Polymer Chemistry Course TKP4130 at the NTNU (organizer: Kristofer G. Paso) was held in January 2022.
- Presentation "Biodegradable Plastics and Circularity" (NCMT bioplast workshop in March 2022, organizer: NCMT: Norwegian Circular Materials Technology)/ SINTEF AS).
- Participation in the Tribology conference in Ålesund in June 2022
- A summer school lecture ("Use of sidestreams to produce biodegradable plastics in a circular economy perspective") in the Materials from biomass - summer school was held in September 2022 at the NTNU (organizer: Green Chemistry of Advanced Materials, GREENCAM: NTNU/University of Bucharest).
- Two scientific articles have been published in January and February 2022:
  - Modelling of Environmental Ageing of Polymers and Polymer Composites—Modular and Multiscale Methods: https:// www.mdpi.com/2073-4360/14/1/216
  - Modelling of Environmental Ageing of Polymers and Polymer Composites—Durability Prediction Methods: https://www.mdpi.com/2073-4360/14/5/907
- A further manuscript (scientific article) has already been submitted in October 2022 and will be published soon.
- Participation in a research cruise in collaboration with members of the SFI Harvest and researchers from other institutions in Europe.

Related projects

In-No-Plastic: Innovative approaches towards prevention, removal and reuse of marine plastic litter.

SHIFT-PLASTICS: Shifting to sustainable circular values chains for handling plastics in the fisheries and aquaculture sector.

PLASTICENE: Development of tools for increased resource utilisation, circularity and regulatory support of plastic use in Norway

Publications

- Modelling of Environmental Ageing of Polymers and Polymer Composites—Modular and Multiscale Methods: https://www.mdpi.com/2073-4360/14/1/216
- Modelling of Environmental Ageing of Polymers and Polymer Composites—Durability Prediction Methods: https://www.mdpi.com/2073-4360/14/5/907

RA 3 Tests and demonstrations at sea

Objectives and motivation

This research area will develop, test, validate, and optimize biodegradable gears for specific applications in fisheries and aquaculture. The industry will need robust and convincing results before production, sales, and practical use (fishing) on a large scale can take place. We expect that identification of accurate needs, development of products, and testing (documentation) will take several years for each research area. Furthermore, a change from traditional petro-based to new smart biodegradable materials must include performance (including catch pattern), service time, handling and mending costs and efficiency analyses (in the case of fishing gears) of existing and new technology. Sea trials will be conducted in Norway, Denmark, Germany and Croatia.

Testing in the Norwegian, North, Baltic, and Adriatic Seas will ensure that we obtain data about the performance of biodegradable twines and ropes, the catch efficiency of nets, and how degradation varies in relation to different environmental conditions. This will enable extrapolation to other fisheries and help to promote use of biodegradable fishing gears internationally. In Norway, sea trials will be conducted under commercial conditions on board fishing vessels. Catch comparison analysis will be based on comparing length size distributions of species caught and will be carried out using appropriate software and following established statistical methods and models for scientific journals. Catch quality will be assessed if needed. Assessing the extent of unaccounted for fishing mortality of gillnets and pots will be conducted by simulating lost gears in pre-defined and controlled areas. Full-scale testing will be conducted by building codends with "dolly-ropes" (one type of chafing mat for trawl codends) made of conventional PE filaments and biodegradable filaments. The codends will be fished simultaneously in a twin trawl setup and used by a trawler during the fishing season. Researchers will weigh the amount (and measure the length) of dolly-ropes in the codend before and after the fishing trials, and they will measure the length of the dolly-rope fibres monthly. In Denmark, Germany, and Croatia, a similar methodology will be used to evaluate catch efficiencies and gear degradation.

Photos: SINTEF Ocean AS

Key research tasks

- Task 3.1: For gillnets (inshore and deep-sea gillnetting), find a combination of strength/elasticity and catchability that is comparable to or better than existing PA twines during multiple trials conducted on board commercial gillnetters.
- Task 3.2: Develop pots and traps based on biodegradable materials targeting brown crab, snow crab, red king crab, and lobster, including recreational pot fisheries.
- Task 3.3: Develop biodegradable ropes and components for coastal and deep sea longlines, because millions of nylons and polyester snoods are replaced every season and a substantial proportion of these get lost at sea.
- Task 3.4: Identify several possibilities for replacing PE, PA, PP and PES fibres with biodegradable fibres for use in twines, ropes, and netting (all fishing gears), as all fishing gears and aquaculture equipment are composed of a range of twines with various tensile strengths, abrasion resistance, twine surface area, etc.
- Task 3.5: Full-scale tests of dolly-ropes and other types of chafing mats for use in demersal (bottom) trawling.
- Task 3.6: Develop an alternative to combination ropes (30–60 mm thick steel wire ropes coated with PE fibres) for demersal seining; while they help to herd fish, thus increasing catch efficiency, they lose almost half their mass as microplastics during their service time due to abrasion against the seabed.

Achievements for 2022

- Based on longline experiments carried out in Norway during 2021, a scientific paper entitled Can biodegradable materials reduce plastic pollution without decreasing catch efficiency in longline fishery? was published in Marine Pollution Bulletin (doi.org/10.1016/j.marpolbul.2022.113577). This publication is associated to the PhD being conducted in research area 3. The study showed that catch efficiency does not represent a barrier for replacing nylon for the longline snoods with new material made of biodegradable plastics. This can potentially reduce macro- and microplastic pollution caused by longline fishery.

Photo: Jørgen Vollstad, 2022

- Based on gillnet experiments carried out in Denmark in 2021, a scientific paper entitled Quantification of catch composition in fisheries: A methodology and its application to compare biodegradable and nylon gillnets was published in Journal of Nature Conservation (doi.org/10.1016/j.jnc.2022.126298). This publication is associated to the PhD being conducted in research area 3. The study showed no significant differences in catch composition between gillnets made of the two materials. Therefore, the catch composition obtained using the more environmentally friendly biodegradable materials does not represent a barrier in this specific gillnet fishery.

Examples of species observed during gillnet retrieval process.

Photo: K. Cerbule et al

- Based on gillnet experiments carried out in Norway during 2021, a scientific paper entitled Comparison of the efficiency and modes of capture for biodegradable gillnet versus nylon gillnets in the fishery for Northeast Atlantic cod (*Gadus morhua*) was published in Marine Pollution Bulletin (doi.org/10.1016/j.marpolbul.2022.113618). This publication is associated to the PhD being conducted in research area 3. The study showed that on average, new biodegradable gillnets caught 25% fewer cod compared to new nylon gillnets. The main capture modes were by the gills and by the body in used and new biodegradable gillnets, respectively. Differences in catch efficiency are related to specific modes of capture that may be related to differences in material properties.

Gillnets tested in sea trials in Croatia.

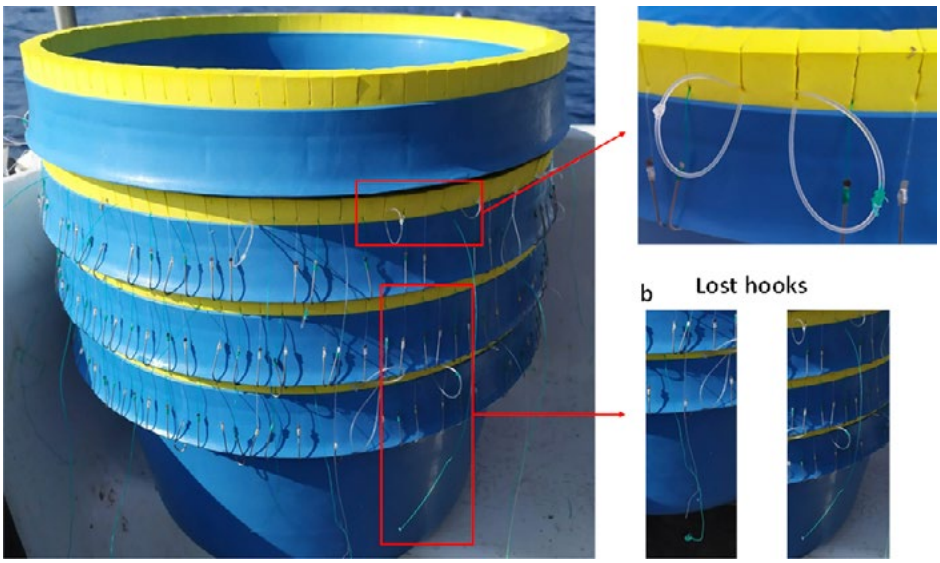
Photo: Sintef Ocean, 2022

- Gillnet experiments were conducted in Croatia. The trials demonstrated a problem with the tensile strength of the biodegradable compared to nylon gillnets. Improved biodegradable gillnets are needed before such materials can replace traditional materials in this gillnet fishery.
- Longline experiments were conducted in Croatia during October 2022 comparing risk for snood and hook loss as well as capture patterns and efficiency between nylon longline snoods and similar biodegradable (PBSAT) snoods. A scientific paper based on those trials was initiated. This work is associated to the PhD being conducted in research area 3. The results showed no significant differences between the two materials. Therefore, these trials show that initial catch efficiency does not represent a barrier for future use of biodegradable plastic materials in this fishery with a potential to reduce the fisheries related plastic pollution.

Gillnets tested in sea trials in Croatia

Photo: K. Cerbule, 2022

- Snow crab pot trials with purpose of estimating ghost fishing efficiency for lost, abandoned, or discarded pots were conducted in the Barents Sea during March 2022. A scientific paper based on those trials was initiated. This work is associated to the PhD being conducted in research area 3. The study showed that on average, the ghost fishing pots captured 8.29% (CI: 4.33-13.73%) target-sized snow crab when compared to the actively fishing pots, demonstrating that conical snow crab pots can continue fishing even when the bait is decayed. Given the large number of pots each vessel operates, and the large number of pots lost each year, the demonstrated ghost fishing efficiency is a considerable challenge in this fishery.



Longline experiments conducted in Croatia, October 2022.

Photo:Jure Brcic, 2022

Snow crab pots.

Photo: Dsolve, 2022

- Gillnet experiments were conducted in Norway during January and February 2022 comparing capture modes and efficiency of gillnets with two different twine thicknesses in the netting. A scientific paper based on those trials was initiated. This work is associated to the MSc completed during 2022 in research area 3. The results showed no significant differences between the two materials. Therefore, these trials demonstrated that a 30% increase in breaking strength and twine stiffness did not affect the catch performance. Therefore, thicker gillnet twine can potentially reduce marine litter by plastic debris from damaged and lost gears without compromising catch performance.

Estimating ghost fishing efficiency for lost, abandoned, or discarded pots in the Barents Sea, March 2022.

Photo: Dsolve, 2022

- Experiments with different rope materials were carried out in September – December 2022. These experiments investigated use of alternative materials for demersal seine ropes and other rope components in demersal seines that are exposed to wear and tear caused by abrasion against the seabed. We used the demersal seiner "Fortuna". Traditionally used nylon material performed best in a controlled abrasion resistance test conducted in the laboratory conditions. However, biodegradable PBSA ropes also showed promising resistance to abrasion. Based on controlled abrasion tests, the following materials were used in the experiment: 12 mm biodegradable PBSA rope from LGChem (South Korea), 10 mm PE/PP danline rope, 10 mm nylon (PA) rope and 10.2 mm decommissioned PE autoline rope (each rope was 20 m long). The ropes were exposed to at least 100 deployments during the sea trials. Each rope was accurately weighed at the beginning and at the end of the experiments. The data is to be analysed.



Photo: Dsolve

- Experiments comparing different materials in trawl codend dolly-ropes were carried out in December 2022 on board the bottom trawler "Hermes". This experiment was aimed at assessing the performance of alternative materials for dolly-ropes in the bottom trawl codends. We tested standard polyethylene fibres against more abrasion resistant polyester fibres in a specially designed codend that combined both materials enabling a direct comparison of the materials under similar conditions. The materials were accurately length measured before the experiment begun. Samples of fibres were taken from the codend after four weeks of fishing. These experiments are continued in 2023.

Photo: Sintef Ocean




RA 4 Governance incentives

Objectives and motivation

The central objectives of Research Area 4 (RA 4) are to:

- 4.1 Assess economic effects of non-biodegradable materials used in fisheries and aquaculture.
- 4.2 Determine costs and benefits related to ecosystem services from introducing biodegradable materials in the fisheries and aquaculture industries.
- 4.3 Investigate institutional incentives to increase the use of biodegradable applications used in marine industries and help supporting the public support systems to reduce risk and promote implementation of biodegradable innovations.

The motivation for these objectives is to broaden our understanding of the consequences of non-biodegradables materials in fisheries and aquaculture to also include economic aspects. Furthermore, this work will provide input into how these consequences could be lessened by governance actions.

Key research tasks 2022

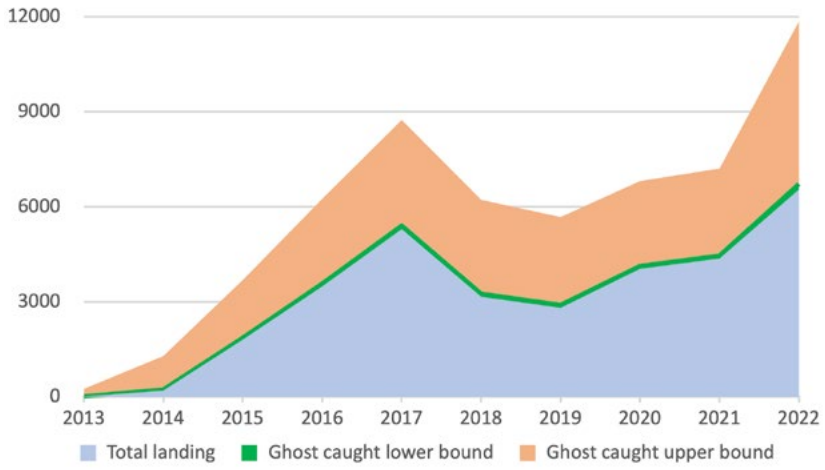
RA 4's research tasks are closely linked to the objectives. Early tasks have therefore focused on ghost fishing, as a central consequence of non-biodegradables in fisheries, specifically involving gathering relevant knowledge and data, especially to determine the costs of non-biodegradable fishing gear:

- Publish paper on literature survey of ghost fishing.
- Analyse data regarding lost fishing gear and gear retrieval in Norwegian waters. This data was shown to have a number of challenges which are being worked upon.
- Develop, write, and submit paper on ghost fishing costs in the snow crab fishery in the Barents Sea.
- Develop, write and submit paper on the ghost fishing effect of the "olympic fishery" on snow crab fishery in the Barents Sea.
- Develop and write governance section for Dsolve common paper (C. Karl (ed)) Knowledge gaps and governance aspects in relation to introduction of biodegradable materials in fishing gear.
- Carry out survey of fishers re. ghost fishing and biodegradable fishing gear.
- Applied for funding for valuation surveys regarding biodegradable fishing gear to several sources. Successful application to Handelens Miljøfond providing funding for three surveys for Huu-Luat Do's PhD papers within the Dsolve project. The three surveys involve 1) willingness to pay by consumers for biodegradably fished fish, 2) willingness to pay for policies that involve biodegradable fishing and aquaculture gear, and 3) willingness to accept compensation by fishers for using biodegradable fishing gear.
- Developing bioeconomic models of fisheries to link with non-use values connected to ghost fishing. Develop survey plans that provide non-use values that can be applied in above mentioned models.

Achievements 2022

Most studies of ghost fishing argue that retrieval programs to extract abandoned, lost or otherwise discarded fishing gear (ALDFG) from the ocean are economically beneficial when compared to the lost market value of ghost fishing. In this paper we depart from the comparisons made in previous studies between the costs and benefits of retrieval programs, in how we assess the benefits of retrieval, and include costs of fishing. Where the earlier literature assumes all ghost fished fish is lost harvest, we assume it is lost fish stock. Applying a case study of the Norwegian snow crab fishery, we develop a simple cost assessment of retrieval of lost snow crab fishing gear which is compared to estimated upper and lower bounds of economic benefits of reduced ghost fishing resulting from retrieval.

We first find the total ghost fishing catch and compare to the actual catch (see Figure 1 below), for the upper and lower bound of ghost fishing, dependent on a number of different assumptions. For the compete time period of 2012-2022, ghost fishing can be estimated to be over 65% of actual commercial catches, in the upper bound case, and 2% in the lower bound case.



Lower bound (3 crabs/cage - green) and upper bound (89 crabs/cage - orange) of ghost caught and fished snow crabs (tons - in blue) in Norwegian waters 2012-2022

When estimating the value of lost crab due to ghost fishing, we depart from the previous studies and assume that the ghost caught fish may not in its entirety be attributed to lost marketable catch. Instead, we treat the ghost caught crabs as reduced stock size and allow the fishing mortality share of this reduction constitute the lost catch. I.e., we apply a fishing mortality to the ghost caught fish, to determine lost catch, which is then multiplied by the market value in each year of the study period. Including discounting of future values, the lower bound present value of revenue loss is NOK 18 mill, while the upper bound is more than NOK 534 mill.

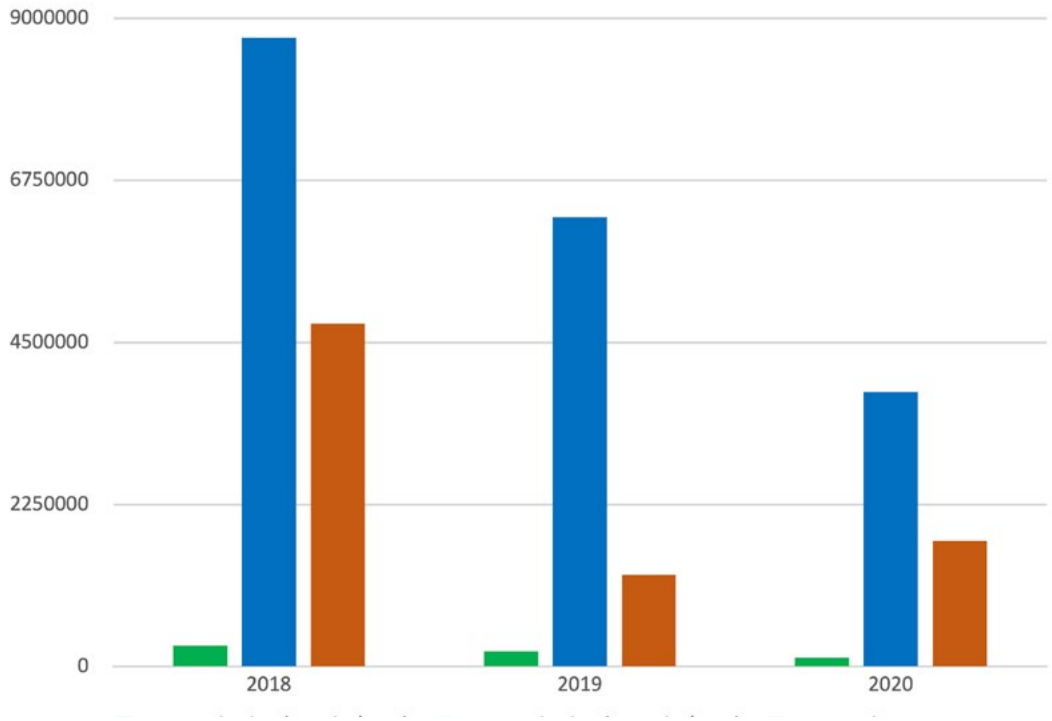


Figure 2. Upper (89 crabs/cage – blue) and lower bound (3 crabs/cage - green) scenarios of benefits from retrieval compared to retrieval cost (orange).

Figure 2 presents three scenarios of value-cost comparison of the retrieval program for the time period of 2018-2020, given assumptions of cost of retrieval, and other relevant parameters. The results show greater cost of retrieval compared to gains at the lower bound, but the opposite at the upper bound. However, retrieval costs should furthermore be compared to the net benefit of reduced ghost fishing, after also costs of fishing are subtracted, something that is lacking in earlier studies. In this case the retrieval program seems less efficient, also in relation to the upper bound. Nonetheless, other negative externalities than those resulting from fisheries losses should be included to holistically assess the effects of ALDFG compared to the value of retrieval programs and other costly ALDFG reducing measures. That ghost fishing catches may be large, economically wasteful, and socially unacceptable is undisputed.

Publications

Do, H.-L., & Armstrong, C. W. (2023). Ghost fishing gear and their effect on ecosystem services – Identification and knowledge gaps. Marine Policy, 150, 105528. https://www.sciencedirect.com/science/article/pii/S0308597X23000556

Submitted papers:

- "Olympic ghost fishing" – A case study of the management of the Norwegian snow crab fishery in the Barents sea. Standal, Armstrong, Do and Grimsrud. *Marine Policy*
- Ghost fishing and retrieval of lost fishing gear - A case study of the Norwegian snow crab fishery in the Barents Sea. Do, Armstrong and Standal. *Marine Resource Economics*

RA 5 Circularity of plastics

Objectives and motivation

Ghost fishing and plastic littering caused by losses of gear from fishing and aquaculture are environmental problems causing impacts on marine ecosystems. These impacts are only partially understood and due to the longevity and strength of this gear, these problems accumulate over time, meaning that the impacts from these losses are felt for the long lives of the durable materials they are made from.

Development of sustainable circular downstream solutions for existing fossil-based, non-degradable and future bio-based and biodegradable plastic fishing gear and aquaculture equipment will benefit the fishing and aquaculture industries and marine ecosystems.

Understanding key aspects of the value chains involved, analysed using life cycle assessment (LCA), will enable the value chain partners involved in Dsolve to understand the positive and negative impacts associated with different materials that can be used to develop innovative solutions to the ghost fishing challenge.

Benchmarking and modelling of gear losses based on data from Norwegian partners will enable quantification of the scale of the impacts and potential benefits of innovative solutions.

Key research tasks

The work on defining material flow of fishing and aquaculture gear on a national and regional level has been ongoing in 2022. A Master's thesis was completed on the theme of dynamic modelling for gear losses from Norwegian fishing activities (*Investigating dynamic quantum of plastics from Fishing Gear in Norway*, Ragnhild Bjerkvik Alnes).
The goal and scope for the LCA assessments of different fishing gear systems and materials has been defined. This will be the framework for LCA assessments going forward in 2023. Strategies for filling data gaps have been identified. In 2023 further data will be gathered for both fishing gear and aquaculture materials and their life cycles to perform LCAs for reference systems. These reference systems will form the basis for comparison with system models where data for the new biodegradable materials identified in Work Areas 1-3 will be used.

RA 5 is also contributing to international development of LCA methodology in order to include plastic losses and marine litter through MarILCA (Integrating potential environmental impacts of marine litter into LCA, marilca.org) and GLAM (Global Guidance for Life Cycle Impact Assessment Indicators and Methods).

Achievements 2022

Reference systems for the LCAs of fishing gear and aquaculture have been identified in 2022. Data gathering for these reference systems started in 2022 and will be completed in 2023. This activity has included collaboration with industrial partners in Dsolve. Close collaboration with industry partners to get specific equipment data will continue, particularly in the first quarter of 2023.
There is an international research effort to include plastic losses in life cycle impact assessment (the calculation steps needed to calculate the environmental impacts in an LCA). The framework for inclusion of these effects is described in Figure 3 below.

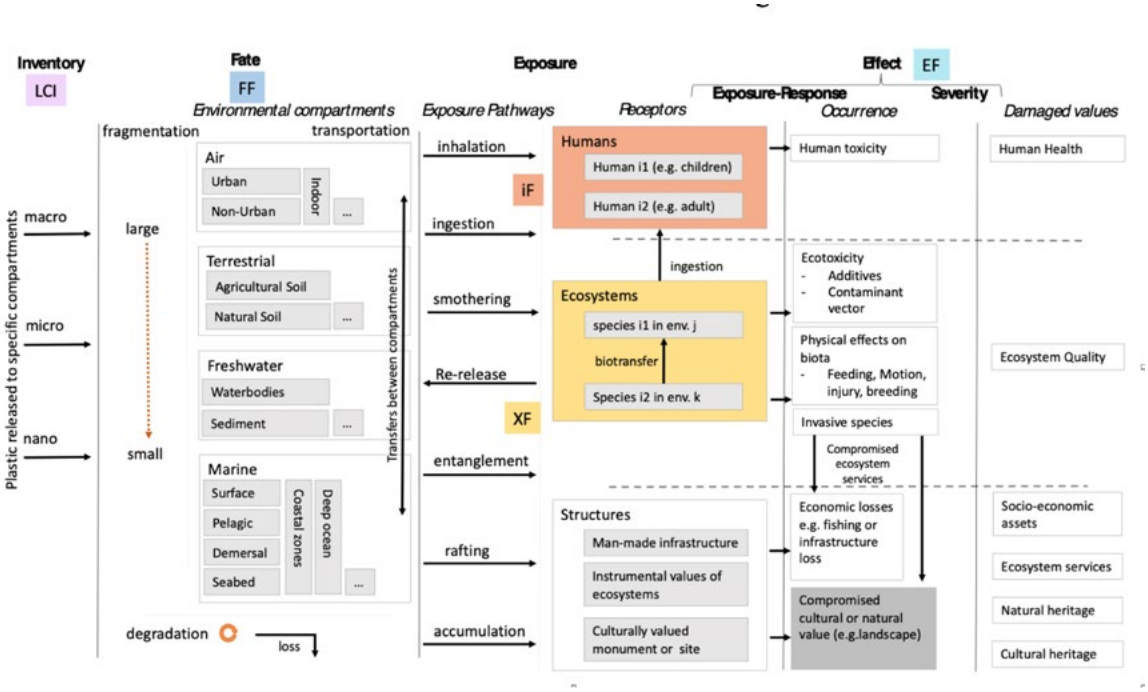


Figure 3. Quantified mass of plastics and knowledge gaps for commercial fishing and aquaculture, numbers in tons per year.
Based on: Deshpande et al. (2020a), Hognes and Skaar (2017), Tore Syversen (2020), Vangelsten (2019) and Gomiero et al. (2020).

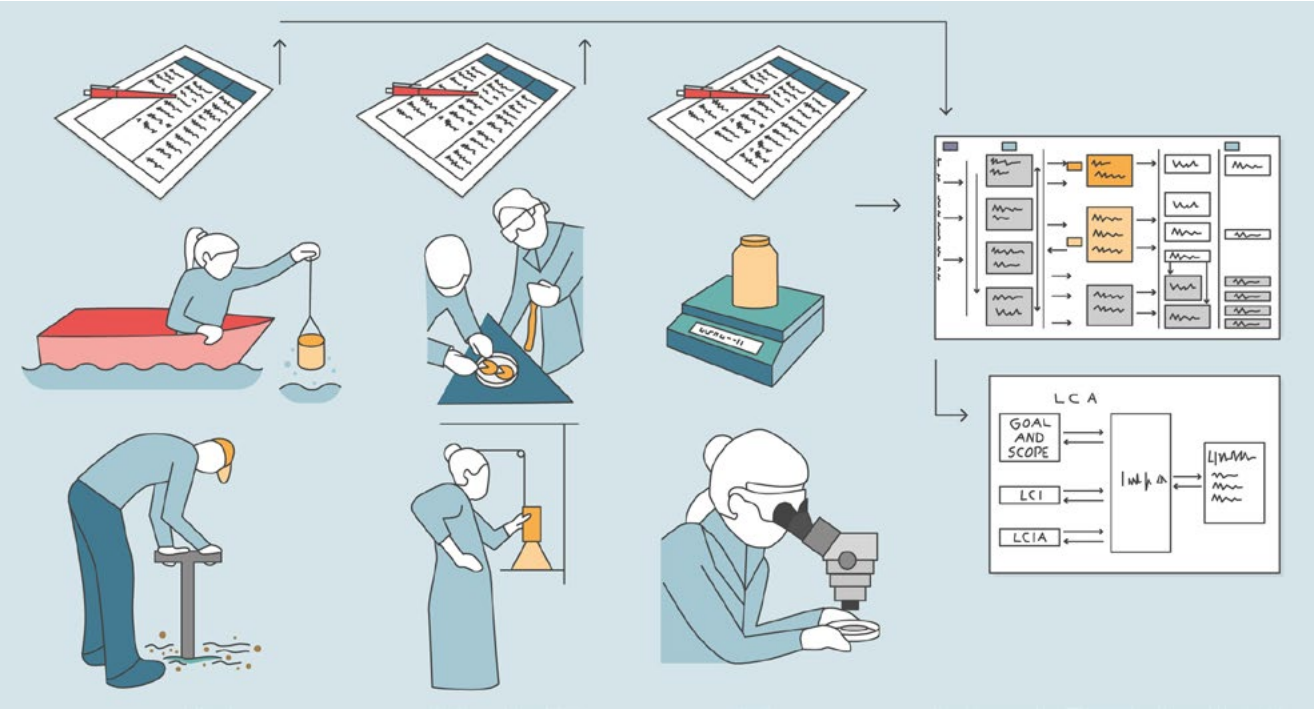
For this framework, macroplastic is defined as over 5mm, so this would typically be gear, or parts of gear, that are lost at sea. Microplastic is under 5mm which would be the size we would expect from wear and tear losses. This mapping and how the data from environmental sampling of the marine environment can be used in life cycle impact assessment calculations is in focus in a paper that was published online in Science of the Total Environment by NORSUS and collaborating international researchers in 2022, see Publications for the details.

Dsolve (marine) and another research project called Dgrade (soil) were in focus when Cecilia Askham presented LCA modelling of biodegradable plastic products in soil and sea environments – what data and fate information do we have versus what we need? At the LCA Discussion Forum 82 at ETH Zurich (November 4th 2022). There was a lot of interest in Dsolve and how biodegradable plastics may contribute, but also questions about the amount of microplastics generated and the overall sustainability if more plastic is continually added to the marine system. These are important points that will be explored further in Research Area 5.

Weighting is a part of LCA methodology that can be employed when comparing product systems with different types of environmental impacts. This aids in decision-making when the impact results point in different directions. Cecilia Askham co-chairs the weighting subtask in the GLAM-project. GLAM is a project for the United Nations Environment Programme's Life Cycle Initiative. This resulted in a conference presentation Criteria Used to Review Weighting Methods As Part of the UN Environment Life Cycle Initiative's Global Guidance on Environmental Life Cycle Impact Assessment Indicators (GLAM) Project at the SETAC Europe 32nd Annual Meeting, Copenhagen, Denmark (15th-19th May 2022).

NORSUS has also contributed to an upcoming book publication, to be published in 2023. The book's working title is: Springer Handbook of Circular Plastics Economy. Our contributions are to the chapter Consideration of plastic emissions in life cycle assessments. The international writing team for this book chapter is: Daniel Maga (Fraunhofer UMSICHT, Germany), Ian Vazquez-Rowe (Pontificia Universidad Católica del Perú, Peru), Francesca Verones (NTNU, Norway), Anne-Marie Boulay (Polytechnique Montreal, Canada), Elena Corella-Puertas (Polytechnique Montreal, Canada) and Cecilia Askham (NORSUS, Norway).

Publications



Cecilia Askham, Valentina H. Pauna, Anne-Marie Boulay, Peter Fantke, Olivier Jolliet, Jérôme Lavoie, Andy M. Booth, Claire Coutris, Francesca Verones, Miriam Weber, Martina G. Vijver, Amy Lusher, Carla Hajjar Generating environmental sampling and testing data for micro- and nanoplastics for use in life cycle impact assessment, Science of The Total Environment, Volume 859, Part 2, 2023, 160038, ISSN 0048-9697.

https://doi.org/10.1016/j.scitotenv.2022.160038.

https://www.sciencedirect.com/science/article/pii/S0048969722071388

Key researchers and key personnel

Dr. Cecilia Askham, Senior Researcher **Dr. Valentina Pauna, Senior Researcher**

Mafalda Silva, Researcher.

Photo: Norsus

PhD candidates and Master students

Master Student - Ragnhild Bjerkvik Alnes, Department of Energy and Process Engineering, Faculty of Engineering, NTNU.

A PhD position on the theme of inclusion of ghost fishing and its effects on ecosystems and biodiversity in life cycle impact assessment was advertised in 2022. The work will start in 2023. Professor Francesca Verones from NTNU's industrial ecology programme will be a key supervisor for this PhD effort.

RA 6 Communication, dissemination and exploitation

Objectives and motivation

Research Area 6 (RA 6) is led by UiT and carried out in cooperation with Salt Lofoten AS (SALT) as subcontractor. The motivation of this Research Area is to maximise the impact of the results from the SFI Dsolve project. The results of the project will provide valuable scientific knowledge on biodegradable products, which are necessary for the sustainable, circular economy. The work undertaken by SFI Dsolve is essential for advancing the research, innovation, documentation, and design of these novel products. The resulting innovations will be important to enhance Norway`s leading position with global fishery and aquaculture and reflect its ambition to be at the forefront of research and innovation on marine plastic pollution.

Through the activities in RA 6, SFI Dsolve has adopted a comprehensive communication approach. This research area presents an agenda aiming at maximising the visibility of the Centre, its goals, and challenges. The communication agenda also aims at making the Centre´s results visible for stakeholders, including industry, the scientific community, authorities, policy makers, and the general public. The concrete objectives of the agenda can be described as: 1) Develop and apply actions to maximise the impact of the SFI research. 2) Ensure a wide dissemination and uptake of the results of the SFI. 3) Ensure a close relationship between the academic community and industrial partners and facilitate the exploitation of results and the transfer of technology.

RA 6 developed a dynamic dissemination and exploitation plan (DEP) in a preliminary phase at the commencement of the SFI Dsolve. This plan, called DEP 2021-2028, will be regularly updated throughout the Centre's life span. The plan includes a) the participation in conferences, trade fairs, and national and international exhibitions; b) specifications about the promotion channels to be used; c) timing for outreach activities and raising awareness of results, and d) partners responsible for the various activities. The main communication activities for each year are described in the respective annual plans. Deliverables for RA 6 include, amongst others seminar and workshop proceedings, a publicly accessible website, presentations at major events, publications in specialised journals and magazines, press releases, video productions, social media, and public datasets used in the SFI. Finally, the communication strategy emphasizes dialogue with industry and other stakeholders through seminars, workshops and networking using already existing meeting arenas and networks.

Key Research tasks

- Dissemination activities
- Communication activities
- Exploitation of results

Achievements 2022

Dissemination activities

- Communication and dissemination Plan 2021- 2028
- Social media strategy
- Annual plan 2022
- Dsolve social media videos
- Social media Campaign Week on Biodegradable Plastics
- Podcast Biodegradable plastics and Industry perspective on new materials
- Press/media

The dynamic dissemination and exploitation plan (DEP) 2021-2028 has been further developed and carried out in 2022 through the determination of an annual activity plan for the RA. The research area produced the following outcomes: 1) A social media campaign week focusing on degradation and environmental impact of biodegradable plastics at sea. During the campaign week scientist from the SFI Dsolve answered questions and addressed concerns submitted by environmental actors and actors involved in beach clean-ups, regarding the impact of biodegradable fishing gear on the environment. 2) A series of social media videos describing the project and reflecting the point of view of fishermen published on Facebook. 3) A podcast discussing industry perspectives on new materials, produced in cooperation with industry partner Mørenot. The podcast is available at popular streaming services. Lastly, 4) News from the project have been disseminated through traditional and social media throughout the year.

Task 6.2 Communication activities

- Webpage
- Facebook, LinkedIn, Twitter
- Profile material, photos and graphics
- Newsletters
- Poster, flyer, fact sheet
- Business-cards for SFI promotion
- QR-coding
- Dsolve intro for SoMe videos

The SFI website has been updated in 2022. This website, with the following URL: https://uit.no/research/biodegradableplastics is available in both English and Norwegian. In 2022 publications and news from the centre were continuously published at the website, including both scientific and popular science articles. The Centre`s Facebook, LinkedIn and Twitter pages were continuously updated in line with the social media strategy, to communicate information about the Centre, its research, progress, and results, and to raise awareness on biodegradable plastics and relevant events. Profile materials, posters, flyers, fact sheets etc. were

produced as needed to promote the Centre at conferences, fairs, and events; a QR-code were used to direct audience to the project webpage and podcasts. A Dsolve intro sequence were produced for future use in all the project´s videos, with the goal of increasing the project´s recognizability. Finally, a SFI Dsolve newsletter was introduced to strengthen the communication among partners.

Exploitation of results

- Annual report 2022
- Lofotfishing
- Nor-Fishing
- Arendalsuka 2022
- The 7th International Marine Debris Conference, South-Korea
- Other conferences and events

SFI Dsolve was presented at selected conferences, fairs, meetings, and events, where RA 6 facilitated the representation of the Centre in collaboration with scientific and industry partners. Events included Lofotfishing 2022, Nor-Fishing, Lofoten Lighthouse by the Norwegian Centre against Marine Litter (MARFO), and the UiT Anniversary Conference. SFI Dsolve were also present with a poster presentation at the 7th International Marine Debris Conference in South-Korea in September 2022, and represented at the SETAC conference in Copenhagen in May 2022 (RA 5), the ETHs 82nd LCA Discussion Forum in Zürich (RA 5), and at the international InnovAzul Meeting in Cadiz, Spain in December 2022. A debate on degradable materials for future use in fisheries and aquaculture were arranged during Arendalsuka 2022. Scientists, public authorities, environmentalists, and industry stakeholders took part in the event. Among the organisations represented in the panel discussion were research partners Norner and Sintef and industry partner Norges Fiskarlag (The Norwegian Fishermen`s Association). The event was streamed online.

Some of our Dissemination Activities in 2022

The 7th International Marine Debris Conference:

Poster stand presenting SFI Dsolve at the 7th International Marine Debris Conference in Busan, South-Korea 18. – 23. September 2022. The conference brought together governments, industry, academia, civil society, and relevant stakeholders, to discuss the latest science, strengthen collaborations, find solutions, and catalyse action to address the global problem of marine litter and plastic pollution. Dsolve was included in the Technical Session 3.10: Biodegradable Plastics in the Open Environment – Opportunities and Challenges.

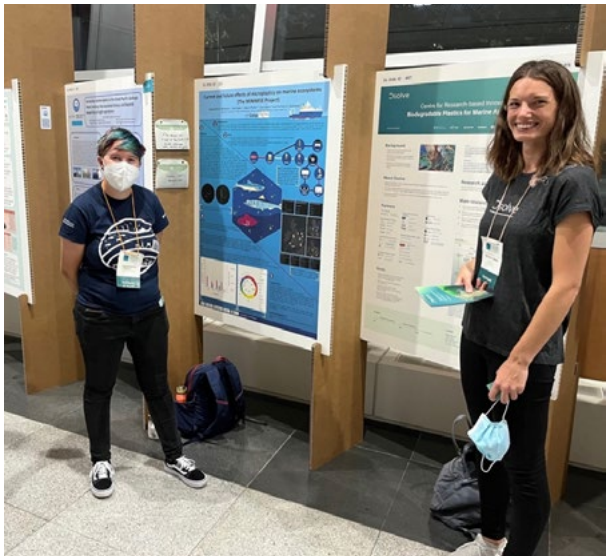


Photo: SALT

Arendalsuka 2022:

As part of the annual Arendalsuka, SFI Dsolve invited incumbent stakeholders to a panel debate addressing the status of research, innovation, and potential challenges, of biodegradable materials for fisheries and aquaculture. The debate was held on the 17th of August 2022 as a public event and was simultaneously streamed online. The event included participants from The Ministry of Trade, Industry and Fisheries, scientists, environmentalists, and industry representatives.

Industry perspective on biodegradable plastics:

A podcast was produced and published in 2022, in cooperation with industry partner Mørenot. The podcast discusses the perspectives of industrial manufacturers of fishing gear on new materials. Info material with QR codes linking to the podcast and the SFI Dsolve website, were distributed at different events. The podcast is available at Spotify, Soundcloud and Buzzsprout, as well as on the SFI Dsolve website.
https://soundcloud.com/sfidsolve

Social media campaign:

A Dsolve Campaign Week was carried out on Facebook in June 2022. The aim of this event was to address public concerns regarding the impact of the degradation process of biodegradable plastics on the marine environment. During the campaign week scientist from the SFI Dsolve answered questions and addressed concerns submitted by environmental actors and actors involved in beach clean-ups regarding the impact of biodegradable fishing gear on the environment. Several of the questions were related to the degradation and fragmentation of biodegradable plastics in the sea.

Photo: InnovAzul

The International meeting on Knowledge and Blue Economy:

SFI Dsolve were presented by SALT at the international InnovAzul Meeting held in Cadiz, Spain, November 29th to December 2nd 2022. The Meeting gathered professionals from the Blue Economy sectors to promote innovation, knowledge transfer and the exchange of innovative technological solutions that increase the competitiveness of industry and society.

Photo: SALT

Photo: Norges Fiskarlag

Photo: Norges Fiskarlag

Nor-Fishing and Lofotfishing 2022:

Dsolve were represented both at the Lofotfishing (1st-3rd April, 2022), and at the Nor-Fishing fairs (23rd- 26th August, 2022). We met with fishers, suppliers, researchers, and stakeholders to promote the project and gather feedback for the Centre`s research. SFI Dsolve was presented with exhibits in cooperation with industry partners Norges Fiskarlag (The Norwegian Fishermen`s Association) and Norges Råfisklag (The Norwegian Fishermen`s Sales Organisation), as well as UiT. A presentation was held by the Centre`s Director Roger Larsen at Nor-Fishing on the topic New harvest technology, as part of the official program. SFI Dsolve was also presented in an interview session led by Norges Fiskarlag.

Dsolve

Norwegian Centre for Research-based Innovation

Centre for Research-based Innovation
Biodegradable Plastics for Marine Applications

uit.no/research/dsolve

UiT The Arctic University of Norway · norner · SINTEF · NORSUS

Background

- Fisheries and aquaculture represent major sources of marine litter at sea
- Ghost fishing, macroplastics and microplastics are among the associated problems caused by these industries
- Development of biodegradable materials in seafood industries could help reduce these problem

Vision:
Our research aims to reduce plastic litter and associated problems (ghost fishing, macro and microplastic) caused by the fishery and aquaculture industries

Ambition:
Our ambition is to place Norway at the forefront of research, development and use of smart biodegradable materials to reduce the global problem of marine litter caused by the use of plastic in fisheries and aquaculture

About Dsolve

- Dsolve is a Norwegian Centre for research-based innovation established to address the possibilities and challenges described above
- The centre includes partners from Norwegian and international research institutions, from seafood industries and equipment suppliers, as well as public agencies and organizations from the Norwegian seafood sector
- South-Korean producers are involved in the centre to test biodegradable materials for fishery- and aquaculture equipment

Research aim

The aim of the Centre is to contribute to the replacement of traditional plastics in the fisheries and aquaculture sectors with new biodegradable materials.

Partners

Host Institution
UiT – The Arctic University of Norway

National Research Partners
Norner Research AS
SINTEF Ocean
SINTEF Industry
NORSUS AS

International Research Partners
DTU-Aqua (Denmark)
Thünen Institute of Baltic Sea Fisheries (Germany)
University of Split (Croatia)

International Industry Partners
LG Chem (South Korea)
S-EnPol (South Korea)

National Industry partners - suppliers
Nofi Tromsø AS
Marenot Fishery AS
Lovold AS
Mustad Autoline AS

National Industry partners - users
Øra AS (coastal gillnetting)
Tustern AS (demersal seining)
Hermes AS (demersal trawling)
Legøy Rederi AS (gillnetting)
Martin Solhaug (longlining)
Opilio AS (snowcrab potting)
Loran AS (mechanical longlining)
Kvaroy Fiskeoppdrett AS

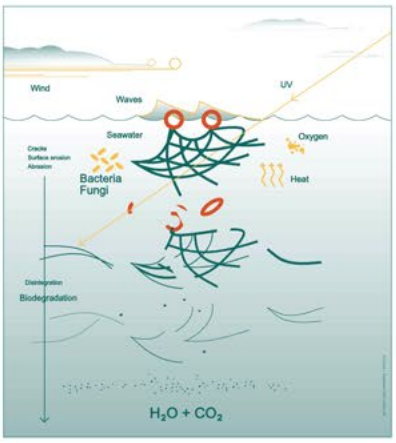
Organisations
Norges Fiskarlag
Norges Råfisklag

National Advisory Board
Senter for Hav og Arktis
Miljødirektoratet
Fiskeridirektoratet

International Advisory Board
IPMA – Institute for the Ocean and the Atmosphere, Portugal
Marine and Freshwater Research Institute, Iceland
Fisheries and Marine Institute of Memorial University of Newfoundland

Main research hypothesis

1) By replacing traditional non-degradable plastics with smart biodegradable and controllable ones, marine litter caused by the fishing and aquaculture industries can be reduced
2) By reducing ghost fishing and macro- and microplastic pollution, value creation will increase in the fishing and aquaculture industries
3) The use of biodegradable plastics, as part of an ecosystem-based management approach to these industries, can be promoted by effective incentives
4) The circularity of existing fossil-based non-degradable and biodegradable plastics can be facilitated by new sustainable downstream solutions and Life Cycle Assessment (LCA)



Biodegradation

Exposure to UV radiation, oxygen, heat, wind, waves, seawater, and bacteria all influence the degradation of synthetic materials in the environment. The impact of these factors leads to cracks, surface erosion and abrasion of the material, which further leads to its disintegration into macro-, micro-, and nano-sized plastic pieces. Biodegradation is based on chemical-biological processes induced by the interaction of the surface of the polymer with enzymes secreted by microorganisms, such as bacteria and fungi. This process is cleaving off molecular fragments, which then can be digested by the microorganisms. The rate of biodegradation depends strongly on the environmental conditions, such as temperature and number of suitable microorganisms.

Goals

- Develop technologies and new environmentally friendly products for the seafood industries based on biodegradable plastics
- Facilitate the environmental management of marine plastic litter
- Promote innovations that can make plastic-based value chains more circular and resource-efficient
- Reduce the carbon and greenhouse gas footprints of products for the seafood industries, in line with climate, energy, and sustainable development goals (UN SDG 12, 14)

Timeline

Research and development (2020 – 2025) · Optional continuation (2025 – 2028) · *Implementation*

Contact

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Learn more

Web
uit.no/research/dsolve

Social

Personnel

Key Researchers

NAME	INSTITUTION	MAIN RESEARCH AREA
Roger Larsen	UiT	Centre leader
Prof. Claire Armstrong	UiT	Leader RA 4. Bioeconomic modeling
Dr. Christian W. Karl	SINTEF Industry	Leader RA2. Polymer materials and degradation mechanisms/polymer characterization
Stephan Kubowicz	SINTEF Industry	Microplastics and nanotechnology/polymer characterization
Kjell Olafsen	SINTEF Industry	Polymer characterization/ chemical analysis
Rune H. Gaarder	SINTEF Industry	Polymer characterization
Bjørnar Arstad	SINTEF Industry	Polymer characterization
Szymon Bernat	SINTEF Industry	Polymer characterization/ tribology
Gaute Stenerud	SINTEF Industry	Polymer characterization/ tribology
Sergio Armada N.	SINTEF Industry	Polymer characterization/ tribology
Eduardo Grimaldo	SINTEF Ocean	Science coordinator. Fishing gear
Sigrid Hakvåg	SINTEF Ocean	Microbial biodegradation and microbiome analyses
Lisbet Sørensen	SINTEF Ocean	Analytical chemistry
Heidi Moe Føre	SINTEF Ocean	Structural Engineering
Esther Savina	DTU Aqua	Fishing gear/gillnet
Rikke P. Frandsen	DTU Aqua	Fishing gear/fisheries
Jure Brčić	University of Split	Fishing gear/fisheries
Juan Santos	Thünen Institute	Fishing gear technology
Dr. Ravindra Reddy Chowreddy	Norner Research AS	Microplastics and nanotechnology/polymer characterization
Dr. Siw Bodil Fredriksen	Norner Research AS	Sustainable feedstocks and bioplastics
Dr. Vinh Cao	Norner Research AS	Polymer rheology
Chun Hwa Lee	LG Chem	Biodegradable polymer development
Yong Man Lee	LG Chem	Biodegradable polymer development

Key Researchers

NAME	INSTITUTION	MAIN RESEARCH AREA
Kyung Min Min	LG Chem	Biodegradable polymer development
Ji Hyun Choi	LG Chem	Biodegradable polymer development
Hilde Rødås Johnsen	UiT	Leader RA 6
Dr. Cecilia Askham	NORSUS	Leader RA5. LCA
Valentina Pauna	NORSUS	LCA RA 5
Mafalda Silva	NORSUS	LCA RA 5
Dag Standal	Sintef Ocean	Governance

Key Personell

NAME	INSTITUTION	MAIN RESEARCH AREA
Charlotte Ramberg	SINTEF Industry	Administrative support
Einar L. Hinrichsen	SINTEF Industry	Research manager/polymer expert
Birgitte Vågenes	SINTEF Industry	Lab engineer
Britt Sommer	SINTEF Industry	Lab engineer
Huiting Jin	SINTEF Industry	Lab engineer
Marius Johansen	SINTEF Industry	Lab engineer
Ann-Karin Kvernbråten	SINTEF Industry	Lab engineer
Arezoo Banaei	Norner Research AS	Administrative support
Ole Jan Myhre	Norner Research AS	Marketing manager/ Polymer expert
Thor Kamfjord	Norner Research AS	Sustainability advisor/ Polymer expert
Jake Chang	LG Chem	Bio-Business development
Ryan Yoon	LG Chem	Bio-Business development
Kim Seihoon	S-EnPol Company	Biodegradable Polymer R&D
Niclas Risvoll, adviser,	SALT (subcontractor)	Web and graphics RA 6
Vilde Sørnes Solbakken	SALT (subcontractor)	Communication and outreach, RA 6
Helene Skjeie Thorstensen	SALT (subcontractor)	Communication and outreach, RA 6
Tomas Brage	SALT (subcontractor)	Graphics Area 6
Terje Lindal	Mørenot	Gear supplier
Gunnar Kupen	NOFI	Gear supplier
Olav Småbakk	NOFI	Gear supplier
Jan Henrik Sandberg/ Maria Pettersvik Arvnes	Norges Fiskarlag (The Norwegian Fishermen's Association)	RA6 (end users)

NAME	INSTITUTION	MAIN RESEARCH AREA
Benedicte Nielsen	Norges Råfisklag (The Norwegian Fishermen`s Sales Organisation)	RA6
Dr. Aida Campos	IPMA	International Scientific Advisory Board
Haraldur Einarsson	Marine & Freshwater Research Institute	International Scientific Advisory Board
Dr. Paul Winger	Marine Institute	International Scientific Advisory Board
Gjermund Langedal	Fiskeridirektoratet	External Advisory Board
Jan Gunnar Winther	Senter for Hav og Arktis	External Advisory Board
	Miljødirektoratet	External Advisory Board
Terje E. Martinussen		Leader of the Board

PhD candidates with financial support from the Centre budget

NAME	NATIONALITY	PERIOD	SEX M/F	TOPIC
Kristine Cerbule		2021-2025	F	RA 3. Field experiments with passive fishing gears like gillnets, longlines, and crabpots. The trials will be carried out in Norway (Arctic), Denmark and Croatia. The experiments will focus on efficiency and catch patterns when changing from petro-based to biodegradable gears.
Huu-Luat Do	Vietnamese	2021-2025	M	RA 4. Modeling social costs and optimal management of ghost fishing.
Waranya Wataniyakun			M	RA 2. Perform degradation-analyses on samples from fishing gears tested in Norway, Denmark, Germany and Croatia using facilities at UiT and SINTEF.

Master degrees

Name	Period	Sex M/F	Topic
Ragnhild Bjerkvik Alnes	2021-2022	F	Examine the status quo of quantities of plastic polymer(s) from fishing gear on a national level and investigate how to evolve current models with a dynamic material flow analysis approach.
Ilmar Brinkhof	2021-2022	M	Comparing the efficiency and catch modes of fish in two types of nylon gillnets. The data and analyses will produce new and necessary knowledge about properties of gillnet capture. The results are important for the design of biodegradable gears.

Annual accounts for 2021

Funding (1000 NOK)	Amount
Research Council	10 359
Host institution (UiT)	5 500
Research Partners*	1 761
Industry Partners**	22 064
Other funding	688
Organizational partners***	94
Total	**40 468**

Costs (1000 NOK)	Amount
Host institution (UiT)	8 554
Research Partners*	9 755
Industry Partners**	13 564
Industry and Organizational partners ***	94 375
Equipment	8 500
Total	**40 468**

* SINTEF Ocean, SINTEF Industry, Norner Research AS, Norsus, University of Split, Thünen Institute of Baltic Sea Fisheries, and DTU-Aqua

** Hermes, Kvarøy Fiskeoppdrett AS, LG Chem, Løvold AS, Mustad Autoline AS, Mørenot Fishery AS, NOFI, Tustern AS, Øra AS, and S-EnPol

*** Norges Fiskarlag, Norges Råfisklag

Publications 2022

Askham, Cecilia; Pauna, Valentina; Boulay, Anne-Marie; Fantke, Peter; Jolliet, Olivier; Lavoie, Jerome; et. al: Generating environmental sampling and testing data for micro- and nanoplastics for use in life cycle impact assessment, 2022

Bjerkvik, Ragnhild Alnes: Investigating dynamic quantum of plastics from Fishing Gear in Norway, MSc Thesis, Department of Energy and Process Engineering, Faculty of Engineering, NTNU, 2022

Brinkhof, Ilmar: How does twine thickness and mesh size affect catch efficiency and ways of capture in the Northeast Arctic cod (Gadus morhua) gillnet fishery? MSc thesis, the Norwegian College of Fishery Science, UiT the Arctic University of Norway.

Brinkhof, Ilmar and Herrmann, Bent and Larsen, Roger and Brinkhof, Jesse and Grimaldo, Eduardo and Vollstad, Jørgen, Effect of Gillnet Twine Thickness on Capture Pattern and Efficiency in the Northeast Arctic Cod (Gadus morhua) Fishery. Available at SSRN: https://ssrn.com/abstract=4299919 or http://dx.doi.org/10.2139/ssrn.4299919

Cao, Vinh: State-of-the-art fibreprocessing methods for fishing gear, 2022

Cerbule, Kristine; Grimaldo Eduardo; Hermann, Bent; Larsen, Roger, B.; Brcic, Jure; Vollstad, Jørgen: Can biodegradable materials reduce plastic pollution without decreasing catch efficiency in longline fishery

Cerbule, Kristine; Grimaldo Eduardo; Hermann, Bent; Larsen, Roger, B.; Savina, Ester; Vollstad, Jørgen: Comparison of the efficiency and modes of capture of biodegradable versus nylon gillnets in the Northeast Atlantic cod (*Gadus morhua*) fishery

Cerbule, Kristine; Savina, Ester; Herrmann, Bent; Larsen, Roger B; Feekings, Jordan, P. Feekings; Krag, Ludvig Ahm; Pellegrinelli, Alina: Quantification of catch composition in fisheries: A methodology and its application to compare biodegradable and nylon gillnets

Cinelli, Marco; Askham, Cecilia; Koffler, Christoph; Amadei, Andrea; Arendt, Rosalie; Bachmann, Till; et.al: Criteria Used to Review Weighting Methods As Part of the UN Environment Life Cycle Initiative's Global Guidance on Environmental Life Cycle Impact Assessment Indicators (GLAM) Project, Published Conference paper, SETAC Europe 32nd Annual Meeting, Copenhagen, Denmark, 15th-19th May 2022

Chowreddy, Ravindra: State-of-the-art materials for fishing gear and aquaculture applications, 2021

Chowreddy, Ravindra: Potential biodegradable plastic alternatives for fishing and aquaculture applications, 2022

Chowreddy, Ravindra: Summary of characterization results on 1st GEN bioplastics , 2022

Chowreddy, Ravindra: Potential modification strategies for biodegradable plastics in Dsolve project, 2023

Do. H.L. & Armstrong, C.W: Ghost fishing gear and their effects on ecosystem services – Identification and knowledge gaps, Marine Policy 150, 105528, 2003

Johnsen, Hilde R.; Risvoll, Niclas; Lie, Amalie Hefre; Thorsteinsen, Helene Skjeie; Lindal, Terje: Podcast: Industry perspective on biodegradable plastics, https://soundcloud.com/sfidsolve

Karl, Christian; Olafsen, Kjell; Kubowicz, Stephan: Critical performance requirements for fishing gear applications, 2022

Karl, Christian; Olafsen, Kjell; Kubowicz, Stephan: Memo describing different concepts for methods to study the formation of microplastics as well as their separation, quantification, and characterization, 2022

Krauklis A., Karl C. W., Rocha I., Burlakovs J., Ozola-Davidane R., Gagani A., Starkova O. (2022). Modelling of Environmental Ageing of Polymers and Polymer Composites—Modular and Multiscale Methods. Polymers 2022, 14(1), 216. https://www.mdpi.com/2073-4360/14/1/216

Starkova O., Gagani A., Karl C. W., Rocha I., Burlakovs J., Krauklis A. (2022). Modelling of Environmental Ageing of Polymers and Polymer Composites—Durability Prediction Methods. Polymers 2022, 14(5), 907. https://www.mdpi.com/2073-4360/14/5/907

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