Center leader: Prof. Jes Vollertsen, Aalborg University

Title: *MarinePlastic* – The Danish center for research into marine plastic pollution

Duration: January 1st, 2019 – December 31st, 2022

Short description of the Center

MarinePlastic is an interdisciplinary center for cutting-edge research into marine plastic pollution, uniting Danish researchers across institutions and disciplinary expertise. The center will develop scientifically based understanding of the types, sources, occurrence, fate and environmental consequences of marine pollution caused by all sizes of plastic materials ranging from macro- to nanoplastics, and bring this knowledge into use by proposing societal solutions and interacting with policymakers.

Background:

Marine plastic pollution is one of the fastest growing environmental problems of our time. Between 60 and 80% of today's global marine litter is comprised of plastic and 300 million tons are released annually into the marine environment [98] (references in appendix 2). This has over the last decade resulted in development of an array of policies and strategies addressing the growing pollution stemming from both macro- and microplastics [96,90,30,25]. These societal initiatives have been initiated while the scientific research within key topics concerning plastic pollution is still in its infancy. A major concerns is therefore whether societal actions (e.g. policy measures) are in sync with the scientific understanding and vice versa, and whether the progress in science sufficiently supports a sustainable societal development in regard to addressing plastic pollution. This requires that societal development form the point of departure for future research focus and that future policy measures on the other hand learn from scientific state of the art. The research strategy for the *MarinePlastic* center takes this approach by having work package (WP) 1 addressing regulatory and societal change and providing input and feedback to WP 2-5, which then address the major scientific uncertainties within the areas: detection, abundance, fate and impact of marine plastic pollution. WP 2 addresses how novel and improved quantification methods can be developed and used to assess plastic pollution. These methods are applied to identify the major sources of plastic pollution in (Danish) marine waters and to assess its fate. Based on these findings, the ecological consequences of marine plastic pollution is investigated. This investigation will be carried out not only for the petroleum-based plastics most commonly found in today's plastic pollution but also for new generation plastics including recycled plastics, bioplastics and biodegradable materials that often are considered more sustainable alternatives to current material choices. Collectively, answers to these questions will identify and inform a range of political initiatives and future societal actions that could significantly reduce the abundance and impact of marine plastic pollution and guide societal development in a more sustainable direction.

State of the Art

Plastic pollution is highly visible in the published and social media and prioritised on the political agenda both in Denmark and internationally [30,25,99]. As a result, policy proposals and guidelines, such as the EU Marine Strategy Framework Directive and the European Commission's strategies on plastics and the Circular Economy Package are not in full synergy with those that regulate production, use and disposal of plastic. There is a need to improve understanding of the advantages and disadvantages of existing policies, strategies and initiatives, as well as for continued scientific research on the specific aspects of plastic pollution that can support political activities. Concern has been raised about the lack of scientific foundation for current policy initiatives [13] in the scientific community and a similar concern has led to the Danish EPA publishing a report on single use carrier bags [8]. However, the relationship between science and regulation is extremely complex and the current debate lacks in-depth analyses to determine which societal measures that can be justified currently and which should be investigated further prior to societal action. Some of the most important scientific questions that need to be addressed in order to qualify this discussion are:

Detecting, identifying and quantifying plastic materials in complex environmental matrixes requires specialised analytical methods [e.g., 27,73]. In particular, it is a major challenge to detect plastic particles and their **occurrence** in the lower size ranges (i.e. below ca. 50 μm) [19,19,40,62], quantify plastic concentrations on a weight basis [85], and achieve rapid, automated methods for low-cost, routine analysis. While the international research community gradually moves towards a consensus on how to measure microplastics, a significant obstacle is still the lack of generally accepted standards for sampling, sample preparation and identification, which has led to many of the microplastic studies being largely incomparable [58].

It is of paramount importance to understand the relative contribution of different **sources** of marine plastics. While it is well-established that marine plastic pollution largely originates from regions with poor waste management [48] there are often significant differences between the relative importance of sources in local and regional areas such as Danish marine waters. While the number of studies documenting the occurrence of global marine plastic pollution is increasing steadily, knowledge on prevalence and distribution of plastics in Danish marine surface waters, ranging from coastal regions to more open waters, is incomplete [68,4]. Some information on macroplastic amounts, composition, distribution and sources to Danish beach litter exists from ongoing monitoring activities [92] as well as for sea floor litter monitoring and these may be used to predict the sources and abundance of secondary microplastics in the future [52].

The **fate** of plastics contain large knowledge gaps [35]. I.e. the processes that govern the fragmentation, translocation and impact of plastics in the environment remains partly unknown. In air, surface cracking of polyethylene carrier bags is measurable within 2 years [36] and fragmentation of plastic materials is accelerated by ultraviolet light and weathering [36,89]. By contrast, published fragmentation times for plastics in the marine environment are based on predictive modelling rather than measurements, and range from 20 to 1000 years [2]. Accurate data to describe persistency and movement of plastic litter of all dimensions between environmental compartments are essential to design and implement monitoring programs, study the environmental impacts of plastics and evaluate the effectiveness of societal actions to reduce the abundance and impact of marine plastic pollution.

It is urgent to be able to quantify the smaller plastic particles as these are of substantial importance when assessing ecological impacts and **hazards**. Experience from other science areas indicates that the smallest (i.e. nano-sized) particles are also the most hazardous due to their ability to translocate across biological barriers into the tissues of animals [61,81]. More recent studies indicate that plastic nanoparticles are able to translocate from gut into tissues [5,70]. However, many studies addressing uptake, translocation, excretion and effect of micro- and nanoplastics use pristine particles and exposure concentrations beyond what is environmentally relevant. As a result, studies conducted using more realistic exposure scenarios are essential. The number of studies addressing effects of micro- and nanoplastics on marine organisms are increasing but are still largely inconclusive [e.g. 50,101]. Similarly, there are few studies on effects at higher levels of biological organization. The transfer of additives or adsorbed chemicals from plastic materials to organisms has been the topic of numerous scientific investigations, albeit with somewhat diverging conclusions [46]. Nevertheless, there are indications that microplastics can act as vectors for other pollutants, further increasing their potential hazards [33]. In conclusion, in the absence of reliable knowledge of effects of micro- and nanoplastics on population, communities and ecosystem level, effective environmental protection regulations cannot be developed [77].

The results of the project and the findings generated in *MarinePlastic* will be communicated to political decision-makers via participation in workshops, expert committees and press releases.

Description of work

To advance the state-of-the-science and answer the above-mentioned as well as other related questions, *MarinePlastic* will take a highly innovative, interdisciplinary approach that integrates expertise in societal change and innovation, regulation and governance, ecological risk assessment, ecotoxicology, marine ecology,

environmental chemistry and material sciences. The Center will provide novel scientific insights that will support our society to move towards a future with less plastic pollution.

MarinePlastic will be a research center without borders uniting Danish plastic pollution research and actively including leading international research environments. International experts (see Appendix 4) have agreed to work with the consortium. Some will host Postdocs and PhD students, others will be visiting scholars, hosted by one of the center partners. These actions ensure that *MarinePlastic* not only brings together some of the most prominent plastic pollution researchers in Denmark but also actively draws on international expertise of the highest scientific quality. *MarinePlastic* will furthermore facilitate future collaboration by hosting meetings and workshops for researchers and relevant stakeholders as well as contributing actively to Danish and international conferences by chairing sessions on plastic pollution and sustainable solutions to problems related to marine plastic pollution.

A short description of the five scientific WPs as well as a description of the coordinating work package (WP 0) follows below. The distribution of budget versus partner and WP is given in Table 1 with the detailed budget given in Appendix 5. Thorough and detailed scientific descriptions for each WP are included in Appendix 1, where the current state of art for each focal area of *MarinePlastic* is described as well.

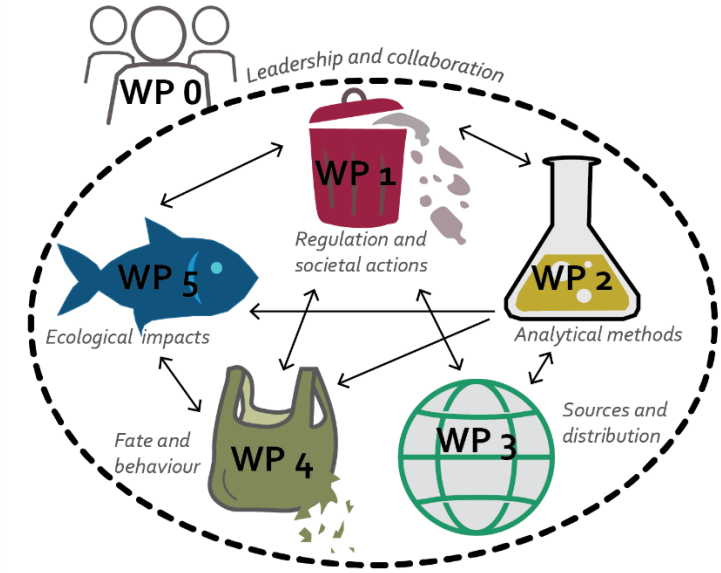

Figure 1. MarinePlastic work packages and there interactions

WP 1: Regulation and societal actions (Leader: DTU)

This work package aims to investigate the drivers for societal change that can minimize plastic pollution.

1.1 "How can the generation of scientific knowledge inform regulatory efforts to reduce plastic pollution?"

Regulation of plastic pollution focuses on one of three approaches, namely: 1. Reducing land- and sea-based sources of marine litter based on environmental monitoring and assessment programs within the frames of environmental protection legislation; 2. Up-stream regulation of individual polymer/chemical/particle types; and 3. Production-oriented regulations such as those supporting waste handling in a circular economy perspective. However, the manner in which scientific knowledge is currently generated is not always designed to facilitate development within these regulatory regimes and too many regulatory questions are left scientifically unanswered. An analysis of which kinds of scientific information are needed to meet current regulatory requirements on plastic pollution at EU level (e.g. EU Strategy for Plastics in the Circular Economy, the Marine Strategy framework Directive and REACH) as well as under the regional sea conventions OSPAR and HELCOM will be conducted and will help steer the work and data generated in WPs 2-5. It also includes an analysis of whether the knowledge-base that current regulations rely on is the most relevant information and whether it can be considered the best available.

1.2 "How can regulation be designed to strengthen efforts to reduce plastic pollution and spark innovation?"
It is recognized that well-designed regulation can spark innovation within industry as well as regulatory agencies, but it has yet to be established how innovative regulations are to be designed and implemented in general and with regards to plastic specifically. Danish and European regulatory gaps will be investigated and an online database of regulatory efforts and citizen science (CS) projects (including Danish ones) to mitigate plastic pollution will be developed, evaluated and made publicly accessible. The initiatives described in the database will be compared to current political aims such as those presented in the forthcoming Danish action plan on plastics as well as European initiatives on circular economy. Taking into consideration the findings of WPs 2-5 and the literature on regulation and innovation, we will investigate how society can improve regulation of plastic pollution, including the promotion of alternatives to commonly used plastics. We will discuss the recently proposed environmental principle termed the "necessity principle" [41]. The overall viability of the identified regulatory policy options will be discussed with regulatory agencies and key stakeholders in Denmark and EU through stakeholder analysis and mapping of the criteria that various stakeholders use to assess the feasibility of the identified regulatory options.

WP 2: Analytical methods (Leader: AAU)

This work package aims to develop robust, fast and reliable methods to quantify size, shape and mass of plastic particles. It produces the analytical tools needed for the other WPs.

2.1 "How can analytical methods for quantification of plastic pollution be optimized?"
The detection limit of today's state-of-the-science analytical methods for identifying microplastics (MP) from their polymer composition, µFTIR imaging, is 10-20 µm. *MarinePlastic* has at its disposal the world's most advanced equipment for MP analysis, theoretically allowing quantification below 1 µm. We will lower the boundaries of µFTIR imaging with improved sample preparation and smarter analytical methods. For particles above 10 µm, where established methods are available, we will develop automatic procedures for polymer identifications to reduce analysis time and cost to a level where screening of plastic pollution, as required for e.g. marine monitoring programs, becomes affordable. Various types of relevant polymer materials including new biopolymers will be targeted. The use of screening tests based on simple chemical staining methods, as well as additional analytic field applications, will be explored and validated for particles >100 µm [41].

To date, MP have been measured by particle numbers only, but there is a substantial need to also include mass. Only by including mass can one relate an observed MP pollution to sources and distribution (WP 3), fate and behavior (WP 4) and regulation and societal actions (WP 1). We will develop methods to quantify particle number, size and mass in one run, by developing better sample preparation, smarter µFTIR imaging and including Py-GC-MS in the analysis train. The latter can quantify plastic mass rather exactly but cannot quantify particle number and size. By combining the two techniques we will develop exact and parallel quantification of both MP particle numbers, sizes and mass.

2.2 "How can analytical methods for nanoplastics be developed?"
Plastics break down from macro to micro to nano sizes, a process studied in detail in WP 3. Today there are no methods that allow quantification of nanoplastics, which is a major issue as the smallest plastic particles may have the greatest impact on marine species (WP 5). In task 2.1 we addressed the size range down to 1 µm. In 2.2 we address the mass of nanoplastics in the sub-micron range. The core analytical technique is Py-GC-MS combined with particle separation to isolate nanoplastics from microplastics. Py-GC-MS is a highly sensitive technique, but for an environmental sample, simple one-shot pyrolysis will not work as too many substances contribute to the pyrograms. To overcome this challenge, a targeted sample preparation and Heart-Cut Evolved Gas Analysis GC-MS (HC/EGA GC-MS) analysis techniques will be developed.

WP 3 Sources and distribution (Leader: AU)

This work package aims to qualify and quantify the magnitude and spatial distribution of plastic pollution in Danish waters and to identify its most significant sources.

3.1 "What is the magnitude of plastic pollution in Danish coastal and open waters and how much does the pollution vary between different areas?"

Comparative studies of amounts and polymer compositions of macro-, meso- and microplastics in different environmental compartments, i.e. water column, sediment/sea floor and on shorelines will be conducted in selected, representative areas of Denmark comprising both coastal and open water environments. The latter partly through an expedition with the research ship Dana. Studies will employ both internationally recommended protocols as well as novel techniques developed in WP 2. Depth profiles to map microplastic distribution and deposition e.g. in mixing zones between water bodies with different salinities will also be studied during ship expeditions. Attempts will be made to assess occurrence of nanoplastic in environmental samples with pyrolysis HC/EGA GC-MS techniques.

3.2 "Which are the most significant sources of plastic pollution in Danish coastal waters?"

To address this research question, we will investigate the various sources of plastic marine pollution with respect to macro- and microplastics and develop a ranking list based on significance. Gradient studies of the most and least highly source-impacted areas of coastal and open water environments in Denmark identified in WP 3.1 will be compared for amounts and polymer compositions. Source characterization of macroplastic will be performed and possible relationships between compositions of macro- and microplastic explored. Methods developed in WP 2 to quantify contributions due to urban and rural sources will be applied to map urban and highway stormwater as well as rural rivers for plastic runoff. Attempts will also be made to quantify the contribution from atmospheric deposition by measuring microplastics in air.

WP 4 Fate and behavior (Lead: NatMus)

This work package aims to investigate the persistence of today's and future plastic litter and to identify the environmental conditions most likely to inhibit and promote its degradation to secondary microplastics. It will also identify the processes most significant for dispersal and deposition of plastic litter and fragments.

4.1 "How do plastics degrade in the marine environment?"

An important source of secondary micro- and, perhaps, nanoplastics is the physical breakdown or fragmentation of macroplastics. However, there is little scientific knowledge about the primary causes for fragmentation, whether internal due to chemical and physical compositions of the plastic particles or external due to exposure (oxygen, ultraviolet radiation, mechanical weathering, hydrolysis, etc.), or about the fragmentation rates and patterns in the marine environment. We will expose a wide range of new petroleum-based, recycled, bio- and biodegradable plastics of the types and forms most frequently identified in marine litter, including packaging, single-use cups, fishing lines and nets and carrier bags, to controlled, accelerated weathering microclimates and to natural surface waters and sediment at a coastal research site in Denmark. The rate of fragmentation from macro- to microplastics of different plastics types will be monitored at six months' intervals. A novel Plastic Degradation Index will be formulated from the most significant indicators of physical breakdown, chemical breakdown and biological activity (biofouling) and determined for samples exposed to accelerated and natural weathering. This approach will generate data from the laboratory and field not available today and will feed into regulation, governance and education.

4.2 "Which processes are the most significant for dispersal and deposition of plastic fragments in the marine environment?"

Plastic fragments have been identified in all environmental compartments including shorelines, surface layers, water columns and sediments, often also at long distances from their likely sources of origin. The processes by which fragments are dispersed and the controlling factors are largely undefined but are important to establish in order to determine their persistence and hazard potentials. To address this research question, we will explore primary interactions between selected physico-chemical properties of plastics (e.g. density, dimensions and shape, surface profile and polarity), the Plastic Degradation Index formulated in WP 4.1 and selected marine environmental parameters (e.g. wind, ocean currents, salinity and biological factors/biofilms). This will be achieved in practice using the degraded model plastics and accelerated weathering chambers developed in WP 4.1. Results will be related statistically to samples of fragments

collected from various environmental compartments in WP 3 with respect to quantities, plastic type and physical properties.

WP 5 Ecological impacts (Lead: RUC)

This work package aims to explore the uptake and potential impact of plastic particles on key marine species and communities with the ultimate aim of providing knowledge for assessing the risk of nano- and microplastics in the marine environment.

5.1 "What are the underlying mechanisms of microplastic uptake and translocation into marine organisms and food webs?"

The potential for trophic transfer through food webs as well as effects of plastic particles, rely on the uptake and possibly on translocation of particles from the gut into tissues. Addressing this question will generate new knowledge on the interactions between microplastics and key elements of marine food webs, answering important questions related to biological fate of microplastics in the environment. With the aim of identifying micro- and nanoplastic properties that are significant for their risk of ingestion, and investigating the mechanisms of uptake, translocation and depuration, we will examine these processes for weathered plastic particles and particles created from virgin materials as well as for chemicals commonly associated with plastic particles. This will provide insights into how breakdown and weathering affect the fate of microplastics and associated chemicals in marine food webs as well as their potential for trophic transfer to humans through seafood. Studies will be carried out using relevant polymer materials, including biopolymers, and natural particles will serve as negative controls in both this and question 5.2.

5.2 "Are marine microplastics likely to cause organism, population and community level effects at environmentally realistic concentrations?"

Although protecting ecosystems are the focus of environmental risk assessment and management, few published studies focus on microplastic impacts at higher levels of biological organization, such as populations, communities and ecosystems. Addressing higher level effects as part of this research question will provide important and necessary new knowledge on the potential environmental impacts of micro- and nanoplastics. With the aim of identifying properties of plastics that may lead to effects from organism to community levels, we will study how environmentally realistic plastic particles and their associated chemicals affect key marine invertebrate species with different feeding strategies under long-term exposure. We will do this for plastic particle sizes ranging from large (approx. 100 µm) to nanoplastics. Individual level effects will be scaled up to estimate population level effects and to develop small indoor mesocosm systems to explore effects at the community level.

WP 0 Leadership and joint activities (Lead: AAU)

This WP organizes and plans activities across the other WPs, administers the center, coordinates workshops and outreach, and provides feedback to the VELUX Foundation. WP 0 will synergize the collaboration within *MarinePlastic* through cross-WP activities and by coordinating the involvement of external partners. The tools are regular center meetings, annual scientific workshops at Roskilde University and PhD courses. It is an ambition that these workshops can continue beyond the four years of *MarinePlastic* and become a natural meeting point for Danish and Nordic plastic pollution researchers as well as relevant stakeholders. WP 0 will coordinate outreach activities and the external communication of center activities and results, and coordinate the research expedition with Dana. A part-time academic center coordinator will assist the center leader and the five WP leaders in the continuous management and coordination of the different tasks and activities in *MarinePlastic*.

An advisory group with representatives from industry, NGOs and authorities have been established. This group of key stakeholders will meet with the consortium once every year to provide feedback on past achievements and future plans

Novelty and interdisciplinarity of *MarinePlastic*

MarinePlastic will significantly advance the current state of the science within marine plastic pollution by combining samples and data generated from modelling studies, laboratory experiments and an expedition with the research ship Dana, thus drawing on a variety of research methods and approaches. *MarinePlastic* identifies the knowledge gaps needed to understand plastic pollution in order to meet current regulatory requirements, with the latter steering will steer the research and data generated by the technical WPs. *MarinePlastic* is also novel in its ambition of applying a holistic and interdisciplinary approach to research in marine plastic pollution. The consortium behind *MarinePlastic* consists of experts at the forefronts of different but complementary fields that are essential for an interdisciplinary study of plastics pollution. The specializations represented in the consortium cover regulatory engineering, climate and oceanography, chemical and biological processes in the environment, population biology, environmental biology and chemistry, ecotoxicological effects and risk assessment of hazardous substances, nanomaterials and microplastics, wastewater and soil treatments, plastics formulation, product and degradation.

In the field of characterization, analysis and quantification, *MarinePlastic* will develop novel methods to analyze the smallest size-ranges of microplastics and nanoplastics. This is essential when addressing ecological impacts as the smallest particles are likely to cause the greatest impacts. For the larger sizes (> 10 µm), *MarinePlastic* will develop faster and more robust screening and analytical methods to be used in future marine monitoring and assessments of pollution sources and trends.

MarinePlastic will apply these methods to quantify plastic pollution in coastal and open waters in Denmark and for the first time study how macro-, micro- and nanoplastics are distributed in the marine environment. This will result in enhanced understanding of the exposure opportunities of marine organisms to plastics and produce data needed to understand the fate of plastics in oceans. *MarinePlastic* will determine the most important routes of plastic pollution to the environment, addressing hitherto unstudied pathways. This will help govern societal efforts to protect the environment and generate awareness of the challenges of managing plastic pollution.

Secondary microplastics, the most abundant form identified in plastic pollution, are produced by fragmentation of larger plastic items. The factors controlling the rate of fragmentation are poorly understood. *MarinePlastic* will investigate this fragmentation from macro-litter to nanoplastics, studying not only new plastic materials, but also by accessing a unique collection of naturally aged marine plastics collected over 20 years by partner NatMus in Danish surface waters and sediments. Based on these reference samples, *MarinePlastic* will develop a Plastics Degradation Index thereby investigating for the first time the link between plastic degradation, distribution and dispersion in marine compartments, to plastic formulation and the physical, chemical and biological conditions present in the marine environment. *MarinePlastic* will also conduct pioneering research by comparing the impacts of naturally formed secondary microplastics with artificial secondary microplastics created from virgin materials, and to investigate the impact of such particles on ecosystems at environmentally realistic concentrations.

For the first time *MarinePlastic* will address how Danish regulation can be designed to strengthen efforts to reduce plastic pollution and how this is integrated in an European context. *MarinePlastic* will generate an overview of serious gaps when it comes to plastic pollution followed by recommendations on what role science should play in future development of policy measures. This overview will be made easily accessible to interested stakeholders from academia, industry, government, NGOs and private citizens. *MarinePlastic* will further address the importance of scientific understanding among stakeholders and their role in policy making, and assess possible societal actions to minimize plastic pollution of the marine environment. Danish and European regulatory gaps will be investigated and an online database of regulatory efforts and citizen science projects (including Danish ones) to mitigate plastic pollution will be developed, evaluated and made publicly accessible.

MarinePlastic, its competences and research record

MarinePlastic comprises the majority of the leading experts in Danish plastics materials, plastic litter and microplastics research. The latter is a novel research field that has only gained attention from scientists, the public and politicians within the last decade. Expertise of microplastic research within *MarinePlastic* is reflected by the fact that the primary author of 13 out of the 18 Web Of Science articles addressing the subject since 2013, where the main author is Danish, is a member of *MarinePlastic*. In addition, consortium members have published several more monitoring and advisory oriented reports to e.g. the Danish EPA and Nordic Council of Ministers and are highly active and involved in the major Danish research projects on plastic pollution [42,100]. This clearly shows that the past research of the members of *MarinePlastic* is substantial and leading in a Danish context. Internationally, the various members are active in this highly competitive research field, for example by participating in international projects like the JPI Oceans project 'Baseman' that strives to evaluate and improve approaches for microplastic quantification from sampling to identification.

Members of *MarinePlastic* contribute to projects ranging from public participation and engagement to fragmentation of plastics to the fundamentals of microplastics and targeted solutions to the microplastic issue. Members also actively support regulatory needs by conducting contract work commissioned by the Danish Ministries and by interacting with various governmental bodies, for example by discussions with the Environment and Food Committee of the Danish Parliament on the planned national plastic strategy, marine litter experts groups within EU and the regional sea conventions HELCOM and OSPAR, as well as providing expert advice to the European Commission with regards to scientific support to future policy development for nano- and microplastics.

The following are short resumes of their qualifications and roles in the center (CVs are in Appendix 3):

Professor Jes Vollertsen will be the center leader. His ability to lead *MarinePlastic* is based on a strong record of project management and leadership. He leads a research group of currently 12 people, of which half work solely on microplastics. He did, for example last year attracted external microplastics research projects worth in excess of 5 million DKK to his group. He has experience from the first large national study on the efficiency of Danish wastewater treatment plants to retain microplastics and studied treatment technologies to mitigate the issue. He is head of the section of Water and Environment at Aalborg University. He and his group of researchers focus on analytical methods to quantify microplastics in environmental systems and he commands a top-end analytical lab equipped with the most advanced equipment for this purpose. His research role in MarinePlastic is developing and refining analytical methods (WP 2) and applying them in the field (WP 3).

Associate Professor Asbjørn Haaning Nielsen studies environmental process engineering with focus on obtaining fundamental knowledge trough experimental studies. Main research areas are impacts on the environment of urban and highway stormwater runoff, microbial and chemical processes in urban water systems, and analytical methods to measure micropollutants and microplastics. He has published numerous papers and co-authored two text books and has a h-index of 15 (WOS). His main role in *MarinePlastic* is to develop novel methods to quantify nanoplastic, and apply these in the marine environment.

Associate Professor Kristian Syberg works with environmental risk and environmental regulation. He has an interdisciplinary focus drawing upon natural and social scientific disciplines. He is currently PI from RUC on the first holistic plastic pollution project in Denmark (Plastfrit Roskilde Fjord funded by VELUX Foundation). He has published several scientific papers on plastic pollution covering environmental monitoring, ecological impact and regulation of plastic pollution. He has made a report on plastic pollution in Danish coastal waters for the Danish EPA. He collaborates with external partners such as the plastic industry and environmental NGOs, proving a strong platform for outreach activities and involvement with stakeholders. He is involved in the current negotiations on a Danish action plan for plastic hosted by the Danish EPA. His main role in *MarinePlastic* is to investigate drivers for societal change that can minimize plastic pollution and contribute to joint activities in terms of outreach and external communication.

Associate Professor Annemette Palmqvist has a background in ecotoxicology, zoophysiology and population ecology. Since 2005 she has developed and tested scientifically-based methods for extrapolation of effects of pollutants observed at the organismal level to population level with the purpose of improving the knowledge base for conducting risk assessments. In recent years, her research has focused primarily on the fate and effects of particulate pollution including both metal nanoparticles and microplastics, and among other projects she is currently involved in three projects on microplastics, which in addition to academic partners include industry-, consultancy-, regulatory- and NGO stakeholders. Her main role in *MarinePlastic* is to assess the risk of nano- and microplastics in the marine environment

Associate Professor Farhan Khan studies ecotoxicology and ecophysiology and works on the effects of toxicants and understanding their underlying mechanisms. His research on microplastics covers different aspects including field studies into environmental prevalence and laboratory studies on negative impacts and how such particulates affect the interactions between exogenous chemicals and organisms (i.e. 'vector effect'). He has made the first reporting of microplastics within continental African freshwaters and one of the first descriptions of how microplastics can influence the uptake of metal pollutants. Currently he has an industry co-funded PhD investigating the impacts of microrubber. His main role in *MarinePlastic* is to assess the risk of nano- and microplastics in the marine environment

Senior Researcher Jakob Strand studies environmental biology and chemistry. His research has focused on sources, distribution and composition of macro- and microplastics in Danish waters and Greenland. He also develops improved methods for identifying and quantifying microplastics. He is involved in national MSFD monitoring of beach litter and microplastics as assigned by the Danish EPA and in establishing analytical methods for microplastic in e.g. drinking water for the Danish EPA. He began his work on marine plastic debris in 2013 and today supervises 2 Postdocs on microplastic research. He is currently involved in 8 projects on plastic debris and microplastic, e.g. two projects funded by VELUX/VILLUM. His main role in *MarinePlastic* is to study sources and distribution of microplastic and develop novel methods for quantification.

Senior Researcher Nanna B. Hartmann studies ecotoxicology and environmental fate and effects of microplastics. She has a longstanding involvement in OECD test guideline development and a thorough experience in investigating the fate of particles (including microplastics). She has extensive experience in working on the interface between science and regulation through previous and current employments. She is involved in national studies of microplastics for the Danish EPA, she provides expert advice to the European Commission's Chief Scientific Advisors on policy development for micro- and nanoplastics, and is an invited speaker by the European Commission's Joint Research Centre later this year. Her main role in *MarinePlastic* is to assess the risk of nano- and microplastics in the marine environment.

Associate Professor Steffen Foss Hansen studies regulatory engineering, where he holds a Doctor Technices degree. He researches how science and engineering can best be used in regulatory settings in situations pervaded by scientific uncertainty and complexity and risk analysis, regulation and governance of nanotechnologies and the applicability of decision-making tools under uncertainty. He has e.g. six publications in Nature Nanotechnology and 60 ISI publications. His h-index is 15 (WOS). He is associate editor of the journals NanoImpact and Chemical Processes and Materials and is actively involved in the expert advisory group on nanotechnology of the World Health Organization and he is a Member of the ECHA Nanomaterial Working Group representing the European Environment Bureau on Scientific and Technical issues. His role in MarinePlastic is to study regulation and social actions on plastic pollution.

Professor, Dr. scient, Ph.D Torkel Gissel Nielsen is specialized in experimental plankton ecology, regulation of structure and composition of pelagic food web. Impact of climate change, oil exploration and microplastics on food web composition and energy transfer. Field and experimental work in arctic, temperate and tropical ecosystems. Participation (often as cruise leader) in more than 50 multidisciplinary research cruises since 1987. The last 20 years he has on average received more than 1 mill DKK per year in external founding through projects he has coordinated or contributed significantly to. Supervision of master (60) and Ph.D. (15)

students. He has published 180 ISI registered papers (H-index 40). His role in MarinePlastic is to study the risk of nano- and microplastics in the marine environment.

Senior Research Scientist Yvonne Shashoua has more than 20 years' experience of plastics formulation, manufacture and degradation mechanisms and focuses her research on investigating factors and rates for breakdown of polymers in real time and developing innovative strategies to control their lifetimes. She is a key partner studying the degradation of nanomaterials in the EU Horizon 2020 research project NANORESTART and comparing the performance and lifetimes of virgin, recycled and bio-polyethylene building materials in a project funded by Grundejernes Investeringsfond. She has more than 100 peer-reviewed articles and is a visiting lecturer at several universities and e.g. The Royal Danish Academy of Fine Arts. Her role in MarinePlastic is to investigate fate and behavior of microplastics in the marine environment.

Budget versus work packages and partners

Table 1 presents the distribution of total budget versus partners and work packages. All partners are involved in several WPs. AAUs budget includes cost for center administration and joint activities such as costs related to the kickoff workshop and the expedition with Dana. RUCs budget covers the 3 annual workshops. The budget of all 5 partners include 0.2 million DKK joint activity costs to cover international hosting and exchanging PhDs, Postdocs and visiting scholars. The detailed budget is given in Appendix 5.

Table 1 Distribution of total budget versus partners and work packages. Lead partners in bold, numbers in million DKK

	AAU	RUC	AU	NatMus	DTU	Total
Regulation and societal actions	0	2.3	0.1	0	1.9	4.3
Analytical methods	3.8	0	1	0	0	4.8
Sources and distribution	0.5	0	2.2	0.6	0	3.3
Fate and behavior	0.4	0	0.7	3.6	0	4.7
Ecological impacts	0	3.5	0	0	3.6	7.1
Leadership and joint activities	1.3	0.6	0	0	0	1.9
Financed by Velux foundation	4.8	4	3.4	3.4	4.4	20.0
Co-financing from partner	1.3	2.4	0.7	0.9	1.1	6.4
Total	6	6.4	4.1	4.3	5.5	26.3

Timeline, deliverables and milestones

MarinePlastic's timescale of 4 years will create an intense project executed at a high level of activity that reflects today's urgency of filling knowledge gaps. Parallel activities will further optimize synergy between project partners and work packages. Hence, all WPs start within the first half year of the project and will continue until the end of Year 4. The details of deliverables, milestones and a breakdown of the timeline are shown in Appendix 1 together with detailed descriptions of the WPs.

MarinePlastic delivers a substantial number of scientific research papers. It achieves additional scientific dissemination through presentations at national and international conferences and symposia. Broader dissemination will be achieved through popular science papers, active interactions with social and political decision makers and with the broadcast, published and social media. The latter, for example, through promotion of the science expedition with Dana planned 18 months into the project, during the summer of 2020. The Dana cruise is an important milestone that brings together all researchers and includes the international partners, generates important research data on microplastics in the Danish marine environment, and enhances the visibility of the research to the decision makers and the Danish public in general. All WPs are targeted to maximize the full scientific, educational and communication outputs of the expedition. All WPs interact with, and depend on, each other, for example the detailed targets of WP 2-4 depend on the answers to WP 1.1 "How can the generation of scientific knowledge inform regulatory efforts to reduce plastic pollution".