Meiofaunal diversity and seasonality in the Barents Sea

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Miniscule interstitial animals (meiofauna) represent a "final frontier" in zoology and encompass a huge range of undescribed phylogenetic and functional diversity. Many fundamental aspects of meiofauna biology remain poorly understood – for instance, whether communities seasonally vary in composition or abundance.

To fill this gap in knowledge for an Arctic marine area, we sampled meiofauna in the northern Barents Sea and adjacent Arctic Basin using box cores along a fixed transect from 2018-2022 under various seasonal and sea ice conditions. After sampling, we sorted and morphologically identified meiofaunal taxa in the lab.

In our preliminary analyses, we have found that the meiofauna community is relatively stable over the year both in terms of abundance and composition. We did, however, observe some hallmarks of seasonality, such as varying abundances of juvenile stages. These new insights into the biodiversity of benthic meiofaunal animals in the Barents Sea region have implications for our general understanding of Arctic marine ecosystems, and how they may be affected by a changing environment.

Effects of oxygen loss and increasing jellyfish biomass on the trophic ecology of west Norwegian fjords

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How an organism feeds is one of the most fundamental ways in which it interacts with its environment. Feeding patterns can be affected by internal physiological stimuli, such as appetite suppression from or avoidance of hypoxia, and external factors such as changes to prey availability, competition, or anti-predator behaviors. From the direct and indirect trophic relationships of all component organisms within a community, the trophic ecology and associated productivity of an ecosystem emerges. Decreases in oxygen and increases in jellyfish biomass are two global phenomena that have recently been observed in multiple marine systems and are hypothesized to be related to anthropogenic drivers including climate change and eutrophication. However, our knowledge of how these abiotic and biotic trends affect trophic relationships within an ecosystem are lacking. Masfjord, a west Norwegian sill fjord, and the neighboring Fensfjord can offer insights into the food web effects of oxygen loss and jellyfish population expansion. Between 2011–2023, the University of Bergen Ocean Science Master course has conducted annual net-based sampling of mesopelagic and demersal communities in Masfjord, with additional sampling in Fensfjord since 2020. This time-series sampling coincided with a ~67% decline in oxygen in the basin water of Masfjord between 2011–2018, prior to a deep-water renewal event in 2021. Meanwhile, the biomass of *Periphylla periphylla*, a deep-sea jellyfish, increased ~9 fold in Masfjord between the beginning and end of the time-series, with a rapid increase occurring after 2018 and continuing after the deep-water renewal event in 2021. In contrast, Fensfjord was continuously well-oxygenated, but had higher biomass of *P. periphylla* in net-catches than in Masfjord. In this study, we make use of net-based community composition data, gut content data, and $\delta^{13}C$ and $\delta^{15}N$ stable isotope data from representative members of the mesopelagic and demersal communities in Masfjord and Fensfjord. We examine these data for trends in the diets and energetic status of key species, changes in the biomass trophic spectra of the midwater community, and reductions in bentho-pelagic coupling that coincide with changes in the oxygen and jellyfish characteristics of the two fjords. These preliminary results contribute to our understanding of how deoxygenation and increasing jellyfish biomass can affect the trophic ecology of a marine ecosystem.

The Biological Potential for Sustainable Utilisation of Bycatch Species in Norwegian Fisheries

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With a growing global population and an increasing demand for food in the future, novel marine resources are needed. Some bycatch species may have little or no commercial value when there is not an established market for the particular species and no fishery targets them directly. As a result of this, bycatch are in many instances discarded at sea and not reported. Discarding of catches is considered unsustainable and a waste of natural resources as the organisms are not utilised. The four bycatch species grey gurnard (*Eutrigla gurnardus*), long rough dab (*Hippoglossoides platessoides*), megrim (*Lepidorhombus whiffiagonis*) and Norway redfish (*Sebastes viviparus*) were examined by investigating to what extent the four species were landed and utilised in Norwegian fisheries using data from the Norwegian Directorate of Fisheries. Further, the discarded and unreported catches of the species in a coastal gillnet fishery and in offshore trawl and longline fisheries were explored using data from the Norwegian Reference Fleet. The current study found that relatively small quantities were landed of the four focus species in Norway, and that much greater quantities of the catches were discarded and not reported. On average for the four focus species, 99.6% of the total annual catch weight comprised of discarded and unreported catches in the three fisheries examined. The findings of this study indicate that there are possibilities for improved and increased utilisation of the four focus species. Considering the indices currently available for the abundance of the species, increased, sustainable utilisation of the species could be possible, as long as a precautionary approach is followed. Increased utilisation of bycatch species can provide a valuable source of food for human consumption while also reducing waste in the fisheries sector, and should therefore be considered an important resource and be better utilised in the future.

About Quantifying Measurement Uncertainties for Ocean Variables

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With the adoption of the GOOS Framework on Ocean Observing the ocean science community has been defining a route on how to structure the overall observing process starting from a requirement list through the specification of fit for purpose observing systems to the final information product. By establishing a feedback mechanism from the assessment to the requirements, the entire process model of ocean observation is closed and comprehensively presented. A core element of the Framework on Ocean Observing is the concept of Essential Ocean Variables (EOVs) inspired by WMO's Essential Climate Variables (ECVs). With that concept a focus is set on those variables that are indispensable for the delivery of relevant information on the ocean environment while at the same time these variables had to pass certain criteria to specify the according maturity level (concept, pilot, mature). A description of the measurement uncertainty is a crucial element as data characterizing the ocean are inherently estimates and uncertain.

Therefore, as a requirement for proposing, planning, and implemen>ng ocean observing, modeling, and analysis systems, resul>ng data should be accompanied by clearly described and easily accessible uncertainty informa>on. The WMO has developed a roadmap to address the topic of uncertainty quan>fica>on for all ECVs and is seeking to harmonize the concept with the ocean science community.

Employing selected use cases, a generic scheme on how to quan>fy uncertain>es for EOVs will be presented. Also, the terminology used in systems engineering, the concept behind the Framework on Ocean Observing, and how it must be applied will be described.

Talk: Land use change and coastal water darkening drive synchronous dynamics in phytoplankton and fish phenology on centennial time scales
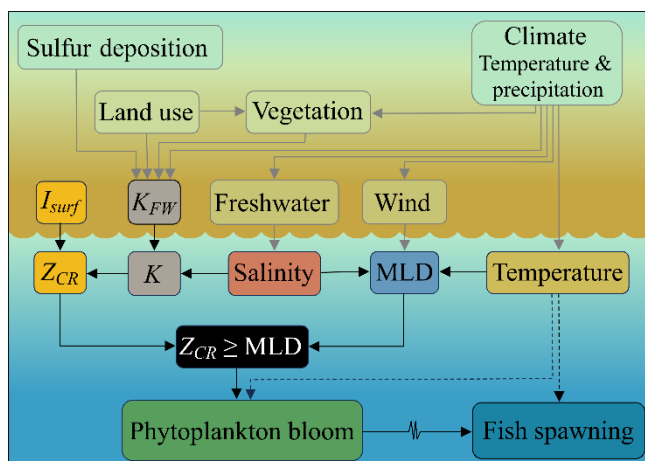
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At high latitudes, seasonality dictates that the suitable window for timing reproductive events is particularly narrow, promoting tight synchrony between trophic levels. Climate change is expected to disrupt this synchrony due to diverging responses to temperature between e.g. the early life stages of higher trophic levels and their food resources. Evidence for this is equivocal, and the role of compensatory mechanisms are poorly understood. Here, we show how a combination of ocean warming and coastal water darkening drive long-term changes in phytoplankton spring bloom timing in Lofoten Norway, and how spawning time of Northeast Arctic cod responds in synchrony. Spring bloom timing was derived from hydrographical observations dating back to 1936, while cod spawning time was estimated from weekly fisheries catch and roe landing data since 1877. Our results suggest that coastal water darkening has gradually delayed the spring bloom up to 1990 after which ocean warming has caused it to advance. The cod appear to track phytoplankton dynamics by timing gonadal development and spawning to maximize overlap between offspring hatch date and predicted resource availability. This finding emphasises the importance of land-ocean coupling for coastal ecosystem functioning, and the potential for fish to adapt through phenotypic plasticity.

Graphical abstract. A conceptual sketch of the most important atmospheric, terrestrial and hydrographic drivers and processes behind phytoplankton bloom dynamics and ultimately fish spawning time. Black boxed and whole-line arrows show drivers and processes explicitly addressed in this study, while grey boxes and arrows are drawn from other studies. Dashed black arrows indicate potential direct physiological effects on phytoplankton growth rate and fish oocyte development rate.

I_{surf}, surface irradiance (mol photons m^{-2} day^{-1})
K_{FW}, light attenuation coefficient of the freshwater endmember (m^{-1})
Z_{CR}, Sverdrup's critical depth (m)
K, light attenuation (m^{-1})
MLD, mixed layer depth (m)

Talk: Studies on the complex Warnowiaceae (Dinophyceae) I. Lohmann's *Pouchetia parva* refound and renamed *Nematodinium parvum* comb. nov. (= *Warnowia parva*)

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The dinoflagellate family Warnowiaceae has often been considered to include some of the most complex cells among the protists. The number of described species is around 40, but both the species and generic concepts are in need of revision. Warnowiaceans are particularly famous for the eye-like structures, termed ocelloids. Studies on warnowiaceans are hampered by lack of cultures, and our studies are therefore based on cells obtained directly from field samples. We provide a description of *Nematodinium parvum comb. nov*. (syn. *Pouchetia parva, Warnowia parva*), based on light, scanning and transmission electron microscopy, combined with phylogenetic analyses of ribosomal genes. It was described in 1908 by Lohmann from Kieler Bay, but is often common in Danish waters, allowing observations on distribution and behaviour. Crucial conditions for finding high cell abundances were periods of warm temperatures and a calm sea. Cells were yellowish, photosynthetic, and contained a net-like chloroplast, in addition to an ocelloid, trichocysts and harpoon-like nematocysts. They divided asexually but planozygotes were also seen. Following the demonstration of nematocysts, the species, which has been known as *Warnowia parva* since 1928, is transferred to *Nematodinium*. The finding of a peduncle indicates mixotrophy but all feeding experiments failed to identify a suitable prey. The phylogenetic analyses based on single-cell PCR and sequence determinations of small and large subunit rDNA confirmed that the systematics of *Nematodinium* and *Warnowia* is in a state of flux.

Talk: Investigation of gut contents of *Priapulus caudatus* using metabarcoding and X-ray microtomography

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Priapulus caudatus is a marine worm in the phylum Priapulida, commonly known as penis worms. Fossils of Priapulida from the Cambrian period are found all over the world, and extant species show that there have been little changes in their morphology since the Palaeozoic. *P. caudatus* are found in clay/muddy sediment from shallow waters to great depths and records are mostly confined to the northern hemisphere. There is not much knowledge about the role of priapulids in the marine ecosystem, but locally they can be abundant members of benthic communities. Few studies about their diet are available from e.g. the Baltic Sea and Canada. These studies indicate that extant priapulids feed on a variety of invertebrates like polychaetes, Ophiurida and Amphipoda, but also detritus and meiofauna. Likewise, the priapulid *Ottoia prolifica* from the middle Cambrian Burgess Shale biota was a very abundant species, and there is evidence that its diet consisted of both live prey such as various invertebrates, and detritus present in its habitat. For determining the diet of *P. caudatus* in Norwegian waters, DNA has been extracted from the gut of some specimens and will be further processed for metabarcoding. I will also use X-ray microtomography to make 3D-images of some specimens which will be useful to determine gut content in a more direct way in addition to genetics. By comparing results to earlier findings of their diet and what is known about the diets of priapulids from the Cambrian, this project will give interesting insights into priapulid ecology
and evolution, in addition to a better understanding of the role that priapulids play in benthic ecosystems along the Norwegian coast.

Figure 1 Priapulus caudatus *found in Tromsø. Photo: Maren Christine Hansen*

Poster: Effects of Impulsive and Continuous Noise on Spawning Cod Vocalization – Implications for Management and Conservation

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Seismic surveys are one of the main sources for the rise of sound level in the oceans. Seismic airguns, that are used to map oil and gas reserves, produce noise that is impulsive and regular with a very high sound exposure level (SEL) and low frequencies. The noise produced by the vessel engines, on the other hand, is more continuous and irregular, though with lower SEL than seismic noise. This study uses data from the NFR-funded SpawnSeis led by IMR to compare the effects of seismic noise and boat noise on the spawning behavior of Atlantic cod (*Gadus morhua*). The overlap in frequency of cod sounds, and seismic and boat noise is expected to result in masking for both noise types, with a higher effect of boat noise due to the absence of silent periods that can be used for communication. This leads to the following hypotheses: (1) Atlantic cod will alter their grunts in response to anthropogenic noise and (2) Atlantic cod will be more affected by continues irregular boat noise than impulsive regular seismic noise. In an experimental design, wild cod held in net pens were exposed to seismic noise for periods of 3 hours on 8 days in 2019 and 3 days in 2020. Boats also passed the study site, and these instances were used to compare periods with to periods without boat noise. This was done for periods of 3 hours before, during and after the seismic exposure: 6 treatments in total. The data for 2020 has been analyzed (3 replicates per treatment). We detected 3 different cod produced sounds: 4 "hummings", 302 "knocks" and 11907 "grunts". For 20 grunts per treatment and replicate we have analyzed grunt rates and several sound characteristics, which we will describe and present preliminary comparisons of between the treatments. The results will be discussed in relation to how they can be used in future advice to ensure the protection of spawning populations of Atlantic cod in noisy areas.

Talk: Hyperspectral imaging for monitoring chemical changes in fish caught by the Norwegian seagoing fleet.

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The biochemical composition of cod (Gadus morhua) and other white fish is subject to seasonal variations leading to uneven quality of the filletsthroughout the year. These changes are related to spawning and may also be affected by available feed. The quality is at its worst during the late spring and summer right after spawning with very soft and watery flesh. If fish in such a condition is caught it will be downgraded and processed to a product of lesser value as filleting of the soft flesh is almost impossible. Data of various fish stocks chemistry in the north Atlantic is limited as sample collection and analytical methods are both time consuming and laborious. FISK 4.0 is aiming to bring the seagoing fishing fleet into the fourth industrial revolution by increased automation and implementation of innovative technologies. A part of the project will focus on the use of non-destructive methods for the quality measurement of wild caught fish. Hyperspectral imaging (HSI) within the near infrared (NIR) spectra will be used to monitor the chemical composition of fish. The application of HSI in the seagoing fleet could give new insights to the biochemistry of important commercial fish species in Norway and will also accumulate vast amounts of data. FISK4.0 want to use this data to look at the biochemical changes of commercial fish species over the seasons, and to get a better understanding of how these variations affect food quality. To get there we will also have to develop powerful algorithms that can interpret the spectroscopic signals into useful information, such as moisture content, water holding capacity, and texture.

The collected data can be a useful tool for all actorsinterested in the research of north Atlantic fish stocks.

Talk: Training future Marine Scientists at UiB using student active research in west Norwegian fjords

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Experience from fieldwork and general knowledge on marine biological field methods are essential knowledge for marine scientists. At the University of Bergen such training for Master students has had high priority at the Department of Biological Sciences (BIO), where the first semester in the M. Sci study starts with fieldwork and student-active research onboard a research ship to west Norwegian fjords. Here students learn the basics of sampling and processing samples as well as organizing data and analyzing and interpreting findings. Annual visits to the same fjord(s) have provided standardized time-series of environmental and biological data since 2011 from semi-enclosed study sites. This has provided important information on climate-induced changes in oxygen levels of in particular one fjord, Masfjorden. The outcome of student-active research has furthermore attracted external funding to study the effect of oxygen loss on mesopelagic and bottom-associated ecosystems linked to training of graduate students. In addition, hands-on learning onboard research ships have also provided insight into more practical aspects of being on fieldwork at sea. Students learn that plans change all the time due to unexpected events with equipment failures as well as with unexpected catches. We will give an overview of the background and contents of the teaching onboard the research ship, and give some glimpses of events and results from student-active research projects.

Talk: Environmental Drivers of Demersal Fish and Crustacean Community Structure in West Norwegian Fjords

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Norwegian fjords, with their complex bathymetry and deep basins, are easily accessible study areas for deep sea communities. Impacts of climate change and increasing pressure from anthropogenic activities on fjord ecosystems, especially the aquaculture industry, reinforce the need to assess the state of the often poorly studied ecosystems. Less frequent basin water renewal linked to ocean warming can result in deoxygenation and hypoxic conditions, with unknown implications on the fjord communities. This study aimed to identify environmental drivers of benthopelagic and hyperbenthic community structures in West-Norwegian fjords, with a particular focus on fish and crustacean species composition, diversity and catch rates. Catch rates and distributions of *P. periphylla* were also investigated. The datasets consisted of 88 bottom trawl stations paired with CTDs, sampled from 2011 to 2022.

The results show that diversity (H) decreases with bottom depth and is highest for stations located in fjords with intermediately deep sills (150 to 250 m). Fish and crustacean catch rates decreased with distance to the coastline, whereas catch rates of *P. periphylla* were linked to lower temperatures. Catch rates of *P. periphylla* were also lower in basins with intermediately deep sills, where diversity was highest. Four community clusters were identified, in which bottom depth and geographic distributions had the strongest differentiation effects: 1) fjord stations at intermediate depths ($\overline{H} = 1.91$) linked to higher temperatures and salinity, 2) mostly coastal stations at shallower depths ($\overline{H} = 1.85$) linked to higher oxygenation, 3) deeper fjord stations ($\overline{H} = 1.26$) with inverse relationships to oxygen, and 4) both coastal and fjord stations with high prevalence of *P. periphylla* ($\overline{H} = 0.87$) linked to lower temperatures. Fjord communities were dominated by vulnerable key species with complex life history traits and lacked gadoid species in contrast to the coastal communities. These results illustrate how deep-sea fjord community composition, diversity and density responses are complex, with a multitude of interacting environmental variables shaping the observed communities. Long-term monitoring over a larger scale might be necessary to assess community responses to changing environments, which will be key for sustainable management of vulnerable fjord ecosystems.

Talk: Exploring the relationship between hypoxia and mesopelagic fish growth using otolith increments: a case study from Norwegian fjords

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In the last decade, warming of the North Atlantic Ocean has contributed to reduced ventilation and subsequent oxygen depletion in the mesopelagic zone of Masfjorden, a fjord in western Norway. Semi-enclosed systems such as fjords are prone to rapid and intense oscillations in their physical parameters, and provide unique conditions to study the effects of climate change on fish populations. Using this natural infrastructure, we aimed to assess whether low-oxygen conditions affect the growth and recruitment of one of the key mesopelagic fish species in the North Atlantic, the glacier lanternfish *Benthosema glaciale*. Biological samples and environmental information were collected at fixed depth intervals over several years (before, during and after the hypoxic event) in Masfjorden and in nearby fjords. In this study, we compare growth patterns in each area and for multiple cohorts, and model otolith annual increments as a function of the key environmental drivers oxygen, temperature and food availability at the time of increment formation. Our analyses show that the species is quite resilient to abrupt and prolonged changes in environmental conditions, and might have evolved mechanisms to cope with low-oxygen zones. Ocean warming and deoxygenation are pressing concerns in coastal areas worldwide, and the mesopelagic zone is one of the most understudied marine regions in the world. Since mesopelagic fish play a key role in marine ecosystems across the globe and are considered a potential food source for the future, it is crucial to assess their vulnerability to climate-induced changes.

Invited talk: Fishguider – an IBM for herring migrations to assist decision making in fisheries

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Globally, between 30 and 50% of fisheries costs are from fuel usage, depending on the fishery. In addition, declining supplies of fossil fuels and geopolitical conflicts lead to volatility in energy prices. The Norwegian fishing industry is seeking solutions to ensure sustainable yields whilst limiting costs. The Fishguider project was a collaboration between researchers at SINTEF, NTNU and a consortium of pelagic fishing companies called NAIS (North Atlantic Institute for Sustainable fisheries) to research solutions (see: https://www.nais-institute.no/ and https://www.sintef.no/en/projects/2019/decision-support-for-fishing-vessels-based-on-marine-ecosystem-models-and-fishery-data/). NAIS consists of vessels mainly targeting migratory pelagic species such as herring and mackerel. Thus, based on discussions with industry partners, the Norwegian Spring-Spawning Herring stock was chosen as a target species for research in the Fishguider project. An individual-based (lagrangian) model of the herring migration was developed and coupled to the SINMOD ocean model developed at SINTEF, with a horizontal resolution of 4km^2 and time step of 4h, centred on the Norwegian Sea. Horizontal current velocities, temperature, and bathymetry data from SINMOD drove the model dynamics. The model forecasted the migration for the spawning season along the Norwegian coast. Uncertainties in parameterizations, forecast errors and gaps in knowledge limit the predictive capacity of such models. Available data sources can be used to initialize, verify, and improve model output. A data assimilation method, the Ensemble Kalman Filter, was used to incorporate observation data and correct model states. Corrected model estimates may provide short-term forecasts of fishing hotspots, assisting fishing vessels in decision-making, reducing search times and fuel consumption. Research continues into potential decision-support solutions, for example as part of the SFI Harvest project, Research Area 3 (see: https://sfiharvest.no/)

Poster: The effect of seismic shooting on the spawning behaviour of Atlantic cod

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Anthropogenic noise, such as e.g., seismic shooting used to locate oil and gas in the seabed, is recognized as a significant pollutant in the oceans. The sounds produced by the seismic airguns is of a low frequency, overlapping with the hearing range of many teleost fish, such as cod (*Gadus morhua*). Cod also produce sounds in this frequency range, particularly during spawning season. Cod also do a series of different types of physical behaviours during courtship, some in correlation with these sounds. Seismic therefore, have the potential to disrupt the communication and related behaviour. The spawning stage is generally a sensitive period for fish and disturbance can then have potential effects on spawning success and the strength of the next year-class. For my master thesis I'm investigating what the short- and long-term effects of seismic shooting on spawning cod are by studying the behaviour of cod that are exposed to periods of seismic shooting.

I'm analysing videos of spawning, captive cod with respect to changes in courtship behaviours in response to seismic shooting. For short-term analysis I watched videos 10 minutes before the first shot in an exposure period to 10 minutes after, to see what the immediate response was. To study the long-term effect, I'm watching videos from the days before exposure, days during exposure (but not during shooting) and days after. I'm interested to see if there is a change over time and when and if they habituate.

Preliminary results show an initial reaction in that the fish often get startled or become more active just after hearing the first shot, as well as a short-term reduction in observed courtship. Though one type of behaviour, "jerk", increased. The exact meaning of this behaviour is not well understood, and if it is a part of the courtship ritual is not clear.

The long-term effect has not yet been analysed. However, my hypothesis is that the cod will habituate in the days after shooting. If there is a reduction and a change in courtship behaviour it's important to document its duration, as that will have the biggest impact on reproduction success. Such knowledge is highly important for giving advice for future seismic surveys in areas of actively spawning fish.

Talk: Decoding marine mammal toxicology through *in vitro* and *in silico* approaches: Whales and polar bear in a petri dish

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Marine mammals are central components of ocean biodiversity and sentinels of marine ecosystem health. Their high energy intake is often accompanied with high intake of lipophilic contaminants with bioaccumulating and biomagnifying properties, and this is especially the case for top predators such as the killer whale (*Orcinus orca*) and polar bear (*Ursus maritimus*). Today, these animals face escalating threats from marine pollution, climate change, and other human activities. Their captivating diversity make them attractive study objects, but both ethical and logistical constraints restrict their use in many forms of experimental research. Thus, novel approaches are essential for advancing this field of research.

Both legacy persistent organic pollutants (POPs) and chemicals of emerging concern (CECs) are endocrine and/or metabolic disruptors, and can disturb animal physiology, growth, and reproduction as well as immune function, and hence impair overall health of individuals and populations. To date, only a small number of studies have given mechanistic insights in contaminant responses in marine mammals. In recent years, we have established alternative approaches to overcome these hurdles using *in vitro* and *in silico* methods. The goal of this work is to characterize functional properties of key molecular targets for environmental contaminants in killer whale (*Orcinus orca*), fin whale (*Balaenoptera physalus*), and polar bear (*Ursus maritimus*), and to establish fibroblast cell cultures from skin-blubber biopsies that can be further used in reprogramming into stem cell lines and in characterizing toxicological responses in these animals. Results from ongoing studies will be presented and plans for the newly funded Marma-detox project will be discussed.

Talk: Spatial restrictions inadvertently doubled the carbon footprint of Norway's mackerel fishing fleet

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The ocean is increasingly used for industry, energy, recreation, and conservation, resulting in increasing spatial restrictions for fisheries. At the same time, producing seafood with a low climate footprint is becoming increasingly important. Yet the effects of spatial restrictions on the emissions of fishing fleets are poorly known. In the Northeast Atlantic, the withdrawal of the United Kingdom from the EU (Brexit) suddenly imposed a spatial restriction for fisheries targeting Northeast Atlantic mackerel (*Scomber scombrus*). Here, we profit from this natural experiment and use open fisheries data to investigate how Brexit affected the performance and emissions of the Norwegian mackerel fishery. We find that as the fishery was displaced from the good fishing grounds in the UK, the catch per trip almost halved, while the number of fishing trips per vessel doubled. As a result, fuel use intensity (FUI) more than doubled from ~0.08 to ~0.18 L fuel per kg mackerel. We estimate that this shift required an additional 23 million liters of fuel per year, causing additional fuel costs of ~€18 million annually and emitting an additional ~72 000 tonnes CO_2 per year. The policy change undid ~15 years of improved fuel efficiency in Norwegian pelagic fisheries. These findings provide rare empirical evidence on how spatial restrictions can undermine progress towards decreasing greenhouse gas emissions in fisheries, highlighting the need to monitor and account for emissions in fisheries management and consider these trade-offs in marine spatial management.

Poster: Influence of offshore transport on small pelagic fish larval dispersion and recruitment in the Western Iberian Margin: A Lagrangian perspective

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The recruitment levels of European pilchard (*Sardina pilchardus*) have decreased in the last decades in the western margin of the Iberian Peninsula, compounding stock pressures and capture collapse. In this work we studied the relationship between offshore transport and European pilchard recruitment in the Iberian Peninsula Upwelling and the role played by Lagrangian Coherent Structures in the offshore larval transport.

Changes in the yearly upwelling regime of the western Iberian margin are thought to be a major factor in the observed decline of recruitment levels, due to their impact on offshore transport patterns. As a proxy for offshore transport, the finite-size Lyapunov exponent is a possible tool to study this phenomenon and identify its root causes.

The finite-size Lyapunov exponent λ is a measure of dispersion at finite scales, and is defined as:

$$\lambda(x, t; \delta_0, \delta_f) = \tau^{-1} log(\delta_f/\delta_0),$$

where x is the position, t is time and δ_0 and δ_f are distance parameters. The variable τ is the time it takes for two particles, initially located at x at time t and separated by δ_0 to reach a separation δ_f. Thus, λ measures the rate of growth of the separation between particles, which depends on the initial position x and time t, in addition to δ_0. The use of λ to study dispersion and transport problems in oceanography is well established (Bettencourt et al., 2012, 2017; among others). The ridges of $\lambda(x,t)$ approximate the Lagrangian Coherent Structures of the underlying velocity field, that are avenues and barriers to transport or eddy boundaries.

Using recruitment and hydrodynamic model data we established a connection between the recruitment level and the finite-size Lyapunov exponent in the western Iberian margin area and revealed a strong inverse correlation between these quantities in the period 2000-2005 and beyond.

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Visiting student program for TUMSAT, Japan at Runde

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Tokyo University of Marine Science and Technology (TUMSAT) and Runde Env. Centre (REC) signed a MoU for joint collaboration in 2017. Since then, and as part of the collaboration, a group of students in marine research and teachers from TUMSAT visits Runde for about 10 days every year. The 3rd grade students belong to the Faculty of Marine Resources and Environment. REC develops a new programme for the students every year, that includes such as lectures by REC officers, scientific excursions, company visits and field trips. In 2023, the students visited the MOWI salmon processing factory, the Ulstein Yard and a modern fishing vessel at Fosnavaag. They were introduced to the misc. research activities at REC and also at NTNU in Aalesund with visit to a fish farm. Leisure activities included hiking on the mountain, coasteering and boat trip off Runde, with observations and fishing. The group also took part in the annual Forskningsdag (Research Day) at REC. This programme provides a unique opportunity for the Japanese students to familiarize with Norway, and paving the way for long term relationships. This presentation high-lights some of the endeavours of the students, with extracts from their personal presentations. The student programme is sponsored by Japanese companies, Penta-Ocean Construction and Toyo Construction and TUMSAT. The photo shows the group visiting in 2023.

Invited talk: Remote acoustic monitoring of Antarctic krill using an unmanned surface vehicle

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Acquiring sufficient information for managing Antarctic krill, a key species in the Southern Ocean, is a challenge of growing importance. The krill are under pressure both from climate change and the emerging interest from commercial fisheries, where the krill have the potential to become an important food source for humans. Increased data collection using conventional trawl-acoustic surveys has caveats such as vessel availability, funding, vessel- and trawl avoidance, and weather sensitivity. In this work, an unmanned surface vehicle capable of persistent operation in remote areas was doing acoustic measurements on Antarctic krill using a scientific echosounder. Advantages using the unmanned surface vehicle were identified, such as the low cost, the low noise, and the small acoustic blind zone. The experimental effort of this work detected approximately 31 % of the krill acoustic backscatter in the near-surface layer (0-20 m). The depth profile of krill detection was compared to a modern research vessel measuring in the same area. The advantages and caveats of the unmanned surface vehicle were discussed with respect to the conventional survey approach.

Invitert presentasjon: Utviklingen av en verdikjede basert på raudåte

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Raudåte (*Calanus finmarchicus*) er en av de store marine ressursene nasjonen Norge disponerer over. Den samlede årlige reproduksjonen i Norskehavet er større enn summen av all globalt fiskeri og akvakultur. Til tross for dette har utviklingen av høsting på raudåte gått sakte fremover, og det har i praksis bare vært en aktør, Calanus AS, som har drevet hele verdikjeden fremover. Selskapet har levert data til forvaltningsplanen, hatt kontinuerlig dialog med norske myndigheter, utviklet teknologi, bygget fabrikk, laget ulike produkter, utviklet markeder og sertifiseringer over hele verden og spilt en sentral rolle i flåteleddet. Dette foredraget vil omhandle denne industriutviklingen over en 20 årsperiode, belyse noen av de fundamentale utfordringene som er løst, samt kaste et blikk på fremtidenes teknologiske behov og markedet for raudåte.

Talk: Constraints and opportunities of sustainable Integrated Multitrophic Aquaculture in Norway.

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As new production areas on land are scarce, developing innovative production systems at sea would contribute to answering these challenges. In the last 10 years, global aquaculture has grown at a staggering annual rate of 4,4 percent. Despite being renowned for its quality, sustainability and high consumer protection standards, EU aquaculture is currently stagnating at approximately 2,7% of the worldwide aquaculture production, with Atlantic salmon (*Salmo salar* L.) aquaculture in Norway being the largest contributor at more than 45% of the European total[1]. Despite excellent expansion prospects over the coming decades, the industry suffers from controversies over its social, economic and environmental sustainability[2]. Investigations in Scotland and Norway show that social acceptance is largely connected to environmental concerns, in which environmental, social as well as economic sustainability are considered[3,4].

In Norway, the government has set strategic goals for a fivefold increase in seafood production from aquaculture by 2050. To achieve these goals, one needs to work with innovation and development of existing production systems, as well as diversification of aquaculture products. Current and future challenges of intensive aquaculture need to be addressed by appropriate research programs and based on principles of environmental, economic and societal sustainability.

Integrated Multi-Trophic Aquaculture (IMTA) is a concept where different species are grown together in such a way that the invertebrates and/or algae can recycle the nutrients that are lost from the culture of other species. IMTA has been practiced for centuries in freshwater systems, particularly in China. Although the potential benefits of such system are well understood, IMTA is practiced to a very limited degree in Norway.

In connection with offshore salmon farming, macroalgae would be optimal candidates for extraction of inorganic nutrients from the water to produce new biomass through photosynthesis[5,6]. Therefore, the rapid development of macroalgal farming in Europe and Norway could contribute to addressing the challenges encountered by aquaculture today[7]. Macroalgal aquaculture will, however, also have to address the effects of climate change and overcome its impacts by rising innovations at various levels i.e. technology, biology, policy[8,9]. This lecture will present example of IMTA systems being tested in Norway, as well as address the multiple issues and integrated actions resulting from the foreseen rapid expansion of the macroalgal industry as part of the growth of the IMTA sector.

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Effects of climate change on top-down herbivory processes in macroalgae.

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The use of macroalgae has expanded worldwide from specialized applications, such as agar preparations, to more generalist uses like biomass production or fertilizers. However, the escalating threats of climate change pose a significant risk to coastal macroalgae ecosystems, for example affecting fucoid macroalgae populations and their associated edible epiphytes. High temperatures associated with climate change also impact grazers that consume these fucoid species, leading to increased metabolic rates and heightened herbivory. To address this issue, our study investigated whether the grazer *Littorina obtusata* exhibited high herbivory rates on the fucoid *Ascophyllum nodosum* under three different temperature regimes (10, 16, and 20 °C). Our findings revealed a significant increase in thallus and gamete area grazed after a three-week experimental period. Additionally, we analyzed the defense substances produced by *A. nodosum* and observed significant changes in response to herbivory. Overall, our results underscore a growing concern that could result in substantial losses regarding edible epiphytes associated with *A. nodosum*. This research highlights the urgent need to address the impact of climate change on coastal macroalgae ecosystems and their associated ecological dynamics, ultimately opening the door for further experiments on top-down preferences under climate change projections.

Mapping Long-Term Changes in Eelgrass Meadows Using Aerial Photography

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Coastal ecosystems such as seagrass meadows, are threatened by a changing climate and growing human impacts, and have declined globally. Mapping efforts have overall increased, but remain low in Norway, where the dominant seagrass is eelgrass (Zostera marina). Thus, knowledge on the historic and present extent of eelgrass meadows, and the processes governing them, is lacking. To sustainably manage these ecosystems, there is a strong need to fill these knowledge gaps. A large database containing readily available, geo-referenced aerial photography from the past century, is a potential source of information on eelgrass extent in Norway, but has remained an untapped source. In this study we examined to what extent aerial photography can be used for mapping Norwegian eelgrass meadows, assessed temporal changes in meadow extent in southern Norway, and indicated likely causes from available data on pressures. The results showed that aerial photography can be successfully used for mapping shallow meadow extent, and can serve as a cost-effective tool for increasing mapping and monitoring effort. We revealed that temporal trends in meadow extent have varied greatly between stations, but during the last two decades there seem to be a shift, from high variability to predominantly expansion. These results suggest there is an ongoing natural recovery in southern Norway. The variability between stations indicate that temporal change is a result of local changes in water quality, and seems highly dependent on local conditions. Thus, managing these ecosystems entail assessing how different stressors may act on both regional and local scales.

Sil på Norskekysten

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Sil, også kjent som tobis, er relativt små, avlange fisk, typisk mellom 10 til 20 cm lange. Det finst fem artar innan silfamilien (Ammodytidae) i Noreg. Havsil, Ammodytes marinus, er den viktigast av artane, både økologisk og økonomisk. I Nordsjøen og langs Norskekysten er havsil en nøkkelart, eit viktig bindeledd i det marine næringsnettet mellom dyreplankton og diverse fisk og andre predatorar. Sil er mellom anna ein av dei viktigaste fødeartane for dei fleste sjøfuglane i Noreg. Trass i dette er bestandane og biologien til sil i kystomtådene lite undersøkt og kunnskapen om effekten av sil i økosystemet er mangelfull.

Det er store variasjonar i silbestanden frå år til år. Dette har ein stor effekt på sjøfuglane, og hekkesuksessen av fleire trua sjøfuglarter er avhengig av forekomsten av sil. Som viktig byttedyr påverkar sil også bestandane av fleire rovfiskartar, til dømes torsk. Sil har ein spesiell økologi, og åtferda er sterkt knytt til årstida. Om sommaren samlar dei seg i stim for å jakte etter plankton i ope vatn. Sil har den spesielle eigenskapen at han kan grave seg hurtig ned i sanden, der han skjuler seg om natta og gjennom vinteren. På grunn av dette er sil sterkt knyta til områda med sandbotn, noko som fører til ei veldig ujamn fordeling av bestanden langs kysten.

På Runde Forsking jobbar vi med kartlegging av biologi, habitattilknyting og bestandsutvikling av sil i samarbeid med Havforskingsinstituttet og NINA. Vi brukar mellom anna botnskrape til innsamling av sil når han ligg nedgraven i sediment, opparbeiding av sil frå mageinnhaldsprøver frå ymse fisk frå fiskeri, mengdemålingar av biomasse med akustikk, og dialog med fiskarar.

Lunde med havsil i nebbet. Foto Christoph Noever, Runde Miljøsenter