

FACT SHEET

SUMMARY

Coastal eutrophication (excessive plant growth resulting from nutrient enrichment by human activity) has become a wide-spread phenomenon in recent decades. It can have significant negative environmental and economic impacts at local and even trans-national level.

In larger river basins and coastal sea areas of Europe, 50-80% of total nitrogen pollution is caused by run-off from agricultural land. Furthermore, households and industry still tend to be the most significant source of phosphorus pollution. Discharges from households have decreased significantly during the past 30 years whereas the loss from agriculture has remained static. Recently, several attempts have been made to restrict nutrient inputs, which have, in some cases, resulted in reduced eutrophication and recovery of marine environments.



Foam on the beach caused by the decaying remains of the brown slimy algae *Phaeocystis globosa*, Texel, Netherlands

POSSIBLE IMPACTS



Satellite image of a phytoplankton bloom in the Baltic Sea

Eutrophication usually leads to increased growth, primary production and biomass of algae, and normally favours relatively large phytoplankton species.

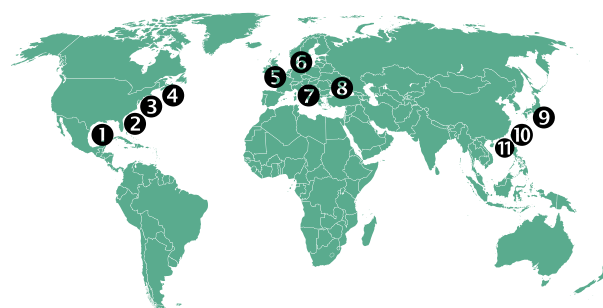
Moreover, changes in the balance of organisms caused by eutrophication can disturb local food chains. Reorganization of plankton communities might have dramatic socio-economic impacts through effects on commercial fisheries in coastal and shelf seas.

Harmful algal blooms, which occur more frequently in eutrophic waters, can significantly degrade water quality. Under particular circumstances the increase of primary production can result in the creation of hypoxic (low oxygen) conditions in aquatic ecosystems.

WHAT ARE THE FUTURE PROJECTIONS?

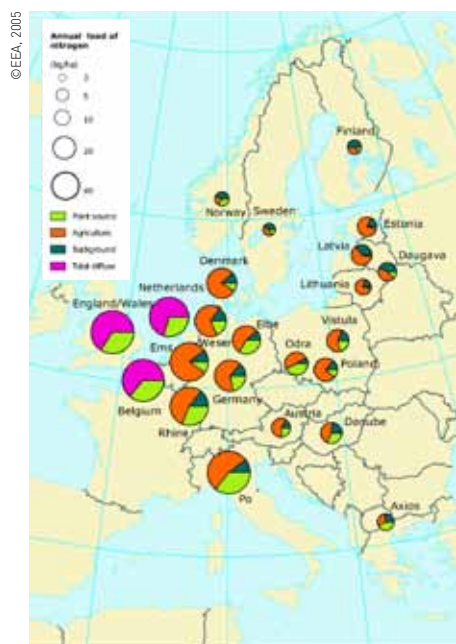
How climate change affects eutrophication patterns will vary across different coastal ecosystems as a result of complex contributing factors. For example, changes in precipitation regimes could enhance nutrient run off from the land to coastal areas. The same changes in precipitation patterns, however, could also increase freshwater discharges, thereby diluting nutrient concentrations and masking the increased loading of nutrients in freshwater and brackish reaches of estuaries.

Climate change is also expected to affect primary production through acidification and changes in light, circulation and temperature. Modeling efforts have shown, however, that the increase of primary production due to eutrophication could also counter the effects of ocean acidification in coastal environments.



- 1 N Gulf of Mexico
- 2 Albemarle-Pamlico Sound
- 3 Chesapeake Bay
- 4 Long Island Sound
- 5 E North Sea
- 6 Kattegat / Baltic Sea
- 7 N Adriatic
- 8 NW Black Sea
- 9 Seto Inland Sea
- 10 Yellow Sea
- 11 E China Sea

Locations of regions of large-scale nutrient over-enrichment leading to eutrophication, with 4 of the 12 areas located in Europe (Based on Boesch 2002)



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ONGOING RESEARCH

Improved monitoring and research mean that changes in abundance, community structure, seasonality and geographical range of phytoplankton species are now well documented. Effects on commercial fisheries and oxygen concentrations have also been studied extensively.

Research is currently focused on the growth of phytoplankton, in light of multiple potential stresses such as limitation of light and macronutrients and how these changes in primary production will affect shellfish and fish stocks. The growing knowledge about the different factors driving eutrophication, including climate change, and the impacts it will have on the ecosystem can now be used to develop models in an attempt to make reliable projections.

RESEARCH GAPS AND PRIORITIES

To develop realistic and ecologically sound management strategies for sustainable use of coastal seas in a changing environment, it will be essential to:

- Improve our understanding of the impacts of nutrient loads on primary production;
- Identify and quantify trophic transfers between primary and secondary producers; and
- Develop a better understanding of ecosystem resilience to eutrophication, particularly in light of climate-induced changes.

To gain a better understanding of the effects of climate change on eutrophication there is a need for:

- Consistent measurements of pelagic primary production;
- Long-term data on benthic primary production in shallow seas;
- Knowledge on how to differentiate between the factors simultaneously affecting growth and loss rates of microalgae.

THERMOHALINE CIRCULATION CHANGES

FACT SHEET

The thermohaline circulation

is a global ocean circulation pattern, driven by density differences caused by variations in salinity and temperature. These variations arise from the heating and cooling of the surface waters and influxes of more or less saline waters.

For Western Europe, the most important current of this circulation pattern is the Gulf Stream which increases the temperature on the western seaboard of Europe by several degrees.

A second and smaller thermohaline circulation exists in the Mediterranean where evaporation and winter cooling in the east cause dense water to sink and move to the west. These denser waters flow out at the Straits of Gibraltar where they are replaced by less dense Atlantic water that enters the Mediterranean as a surface flow.

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SUMMARY

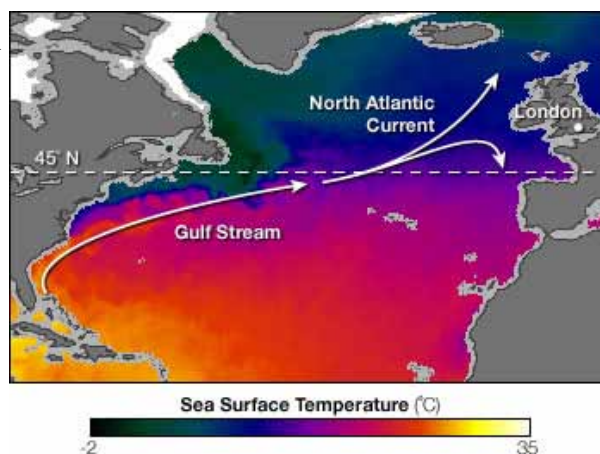
The dangers of thermohaline circulation change for European coasts include the possibility of a rapid shut-down of the Meridional Overturning Circulation (after: Parry *et al.*, 2007), potentially causing:

- Reductions in run-off and water availability in southern Europe;
- Major increase in snowmelt flooding in Western Europe;
- Increased sea-level rise on western European and Mediterranean coasts;
- Reductions in crop production with consequent impacts on food prices;
- Changes in temperature affecting ecosystems in Western Europe and the Mediterranean, e.g. affecting biodiversity, forest products and food production;
- Disruption to winter travel opportunities and increased icing of northern ports and seas;
- Changes in regional patterns of cold and heat-related deaths and ill health;
- Movement of populations to southern Europe and a shift in the centre of economic gravity;
- Requirement to refurbish infrastructure towards Scandinavian standards.

WHAT ARE THE FUTURE PROJECTIONS?

Studies have shown that an abrupt shutdown before 2100 is very unlikely and that global impacts of any slowing in circulation before then are likely to be offset by temperature increases related to greenhouse gas build up. However, on a local scale some areas, such as the Western margin of Europe, could be adversely impacted.

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Gulf Stream in the North-Atlantic is visible as a warm water current travelling northward along the coast of North America and eastward into the central Atlantic Ocean. As it continues its journey, heat from the ocean is lost to the atmosphere, warming the air above it.

THERMOHALINE CIRCULATION CHANGES

FACT SHEET

HOW CLIMATE CHANGE COULD INFLUENCE THE THERMOHALINE CIRCULATION?

- Increased melting of the ice sheets in Greenland could reduce the salinity of sub Arctic waters, making them less dense and thus less prone to sink. This could result in a reduced water/heat transport by the thermohaline circulation leading to a dramatic cooling of parts of Scandinavia and the United Kingdom.
- A decreasing frequency of cold dry spells in Southern France, responsible for generating dense sinking waters in the Mediterranean thermohaline circulation, could reduce oxygen transport to deeper parts of the water column.

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Top section of a RAPID mooring about to be deployed at 26N from RRS Discovery

ONGOING RESEARCH

The main focus currently lies in monitoring and increasing the amount of long-term data sets available. This is done, for instance, by using floating observational instruments as well as moored instruments that together provide a semi-continuous stream of data.

These datasets, in combination with an increased understanding of the different components leading to thermohaline circulation changes, are then used to increase the accuracy of the models used to make future projections.

RESEARCH GAPS AND PRIORITIES

Key open questions include*:

- What changes in freshwater input of the North Atlantic will result from global warming?
- What is the risk of exceeding a threshold for thermohaline circulation collapse for a given warming?
- What other thresholds exist?
- What consequences would result for marine biodiversity and whole ecosystems?
- How would climate over land be affected by a collapse scenario?
- How predictable is the system using today's generation of climate models and how can these predictions refine climate forecasts (particularly on the decadal scale)?

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*Partially taken from Ramsdorf (http://www.pik-potsdam.de/~stefan/thc_fact_sheet.html)

This fact sheet is based on a chapter of the CLAMER / Marine Board Special Report *Synthesis of European Research on the Effects of Climate Change on Marine Environments* (Deliverable 1.2) written by **Phil Weaver** from the National Oceanographic Centre, Southampton, United Kingdom

TEMPERATURE CHANGES

FACT SHEET

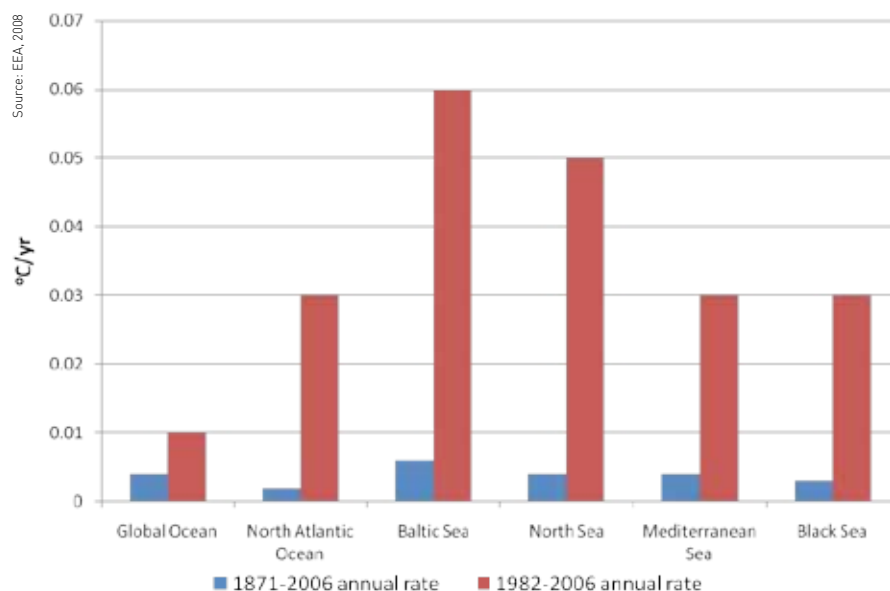
Observations of the Sea Surface Temperature (SST) (both *in situ* and remote sensing) that have been available for the last 150 years, show an overall increasing trend in oceans surface temperature. The average rate of SST rise in the last 25 years is approximately 10 times faster than the average of the past century.

Accurate detection and modelling of SST patterns and trends is critical for understanding the potential response of the climate system to increased greenhouse forcing. The speed at which water masses are warming up, however, differs considerably for different regions. Winter and summer SST data also show different trends, resulting in a complex spatio-temporal pattern of temperature changes in European waters. Aside from changes at the sea surface, there is evidence of subsurface and deep water temperature changes in European regional seas.

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Rising sea water temperatures could impact local fisheries



Observed annual warming rate of Sea Surface Temperature for global and European Seas

FUTURE CLIMATE PROJECTIONS

At a global scale, an increase of 2°C in SST is expected by the end of this century. This is derived from coupled and non-coupled atmosphere – ocean circulation climate models and based on existing emission scenarios. Warming in the North Atlantic will be slower than the global average.

At a local and regional scale, the estimates differ significantly between different areas. For example, a rise of 2-4°C in SST is expected for the Baltic and 1.7°C for the North Sea by the end of the 21st century. These estimates are based on downscaled regional climate models in combination with 3D baroclinic ocean models.

THE POSSIBLE DANGERS OF SEA TEMPERATURE RISE

Warming of the air and sea surface affect critical physical conditions and the biological processes of living organisms. This is expected to stimulate the migration of species towards the poles. Species migration can influence both the food chain and community structure, which may lead to changes in the composition of fish species with potential impacts on local fisheries. These kinds of regime shifts have already been reported in the North Atlantic, North Sea and the central Baltic Sea.

FACT SHEET

A number of EU and national projects and initiatives have contributed to a better understanding of temperature change, both in global oceans and European regional seas. The main focus of research has been on:

- Increasing the predictive capacity of models by coupling the various parameters which influence temperature changes;
- Providing quality controlled long-term observation products;
- Intercomparison of regional climate models.



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This fact sheet is based on a chapter of the CLAMER / Marine Board Synthesis Report *Effects of Climate Change on Marine Environments* (Deliverable 1.2) written by **Jun She** of the Danish Meteorological Institute (DMI), Denmark

RESEARCH GAPS AND PRIORITIES

The current coupled atmosphere - ocean models still show substantial regional biases in the SST distribution. These biases are sometimes larger than the simulated SST warming in the late 20th century (IPCC, 2007).

To make sensible projections of sea temperature for future climate scenarios, more knowledge is required on:

- SST-related processes in atmosphere and ocean models (cloud feedback, aerosol forcing and ocean - atmosphere interaction, waves-induced mixing and light attenuation, etc);
- The possible change of deep convection and related atmosphere - ocean - ice interactions in melting Nordic and Arctic oceans.

To improve this knowledge, there is a need to:

- Identify and reduce the SST and sea-ice related uncertainty in climate modeling;
- Increase the resolution and number of coupled regional atmosphere - ocean circulation models;
- Improve the parameterization of dominant processes for accurate SST simulation in coupled climate models, both in global and regional scales; and
- Develop reliable 3D baroclinic ocean climate models for climate study.

DRIVERS OF SEA LEVEL CHANGE

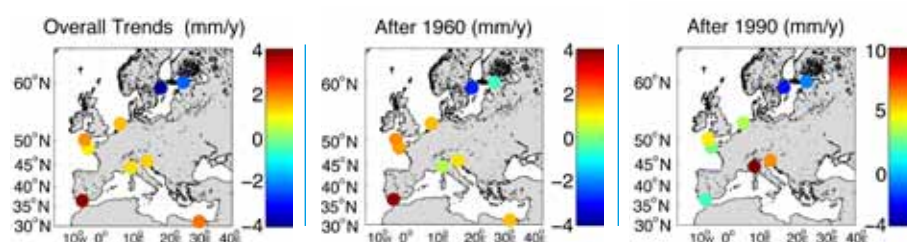
Global mean sea level change is primarily driven by the addition of heat and mass to the oceans. The first is due to rising atmospheric temperatures which lead to a thermal expansion of the water. The second is caused by the melting of ice-sheets and glaciers. Changes in salinity are of lesser importance on a global scale.

Local sea levels are influenced by further factors, including changes in atmospheric pressure and wind distribution, oceanic circulation, local temperature and salinity, sediment supply and sediment compaction at estuaries, land movements caused by removal of mass from the earth's crust and tectonic movements.

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The Maeslantkering storm surge barrier in the Netherlands automatically closes when needed for protection. It is part of the Delta Works and it is one of the largest moving structures on Earth.



Long-term trends of sea-level rise in major European cities: yearly values of sea level in various European coastal locations and Alexandria (Developed by Andrew Shaw and Mikis Tsimplis based on data from the Permanent Service for Mean Sea Level website, <http://www.psmsl.org/>)

Sea level changes pose significant risks to European coastlines, thus changes in local mean sea level and sea level extremes are presently the primary concern for policy makers.

The rate of global sea level rise has been 1.8 ± 0.3 millimeter per year over the last century, but has increased drastically up to 3.3 ± 0.4 millimeter per year for the period from 1993 onwards.

However, sea level trends in Europe are not uniformly distributed and regional differences are evident from observations. These observations highlight the importance of obtaining regional and local estimates of sea level rise, as a global mean value cannot be used for coastal protection purposes.

POSSIBLE IMPACTS

Sea level rise poses significant threats to human, plant and animal populations of low lying areas as a result of:

- Increased flooding and associated impacts;
- Loss of coastal ecosystems and associated services:
 - Increase of coastal erosion,
 - Salt contamination of ground water,
 - Loss of arable land,
 - Loss of salt marshes and mangroves.

Protection against rising sea levels is possible (e.g. in the Netherlands) but not always financially and/or ecologically feasible. In most cases human development will need to adjust and populations to be relocated.

FACT SHEET

WHAT ARE THE FUTURE PROJECTIONS?

Future projections of global sea level change are currently based on empirical estimates or on recent climate models which take into account two key components:

- The thermal expansion of water (the steric component).
The steric component is considered to be quite reliable for the upper part of the water column and is already integrated in most climate models. Current projections estimate the global sea water level increase due to thermal expansion, to be less than 60 cm by the end of the 21st century (for the climate change scenarios determined by the Intergovernmental Panel on Climate Change, IPCC).
- The melting of ice-sheets (the mass addition component).
There is a high level of uncertainty in these projections due to the fact that the non-linear process of ice-sheet breaking is not yet fully understood and that ground truth measurements to test models of these processes are lacking. The mass addition component has not yet been integrated in current climate models and must be calculated separately. Current projections estimate an increase in global sea water levels of 0-2 m due to mass additions, by the end of the 21st century.

None of the methods widely used has the resolution or skill to provide estimates for regional or local sea level. High resolution regional models with downscaled atmospheric forcing have been developed over the past five years. However, sea level parameterization has only recently come under scrutiny.



RESEARCH GAPS AND PRIORITIES

- Develop a robust and efficient monitoring system for mass changes in Greenland and Antarctica;
- Understand the relative importance of ice-sheet breaking processes;
- Integrate modeling of ice-sheet changes into global climate models;
- Resolve whether sea level accelerated at the beginning of the 20th century;
- Understand the contribution of waters deeper than 1000 m to sea level changes due to the thermal expansion component;
- Improve the understanding of coastal sea level forcing mechanisms and coupling them with the regional variability in climate model;
- Develop reliable techniques to estimate regional / local sea level rise;
- Improve and expand the sea level monitoring network.

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This Fact Sheet is based on a chapter of the CLAMER / Marine Board Special Report *Synthesis of European Research on the Effects of Climate Change on Marine Environments* (Deliverable. 1.2) written by **Michael Tsimplis** of the National Oceanographic Centre, United Kingdom.

OCEAN DEOXYGENATION AND COASTAL HYPOXIA

FACT SHEET

SUMMARY

The secondary effect of climate change on seawater oxygen levels has only recently gained attention, but the consequences could be substantial.

The decline of oxygen concentrations in seawater is alarming. The average ocean oxygen concentration is expected to decline over the next century by up to 7%, leading to a large increase in the extent of hypoxic water bodies in the ocean interior. Hypoxia is the condition in which dissolved oxygen is below the level necessary to sustain most animal life. Declining oxygen concentrations have already been observed in several locations, most notably in the North Pacific and the tropics. There is also strong evidence for a global increase in the frequency, extent, intensity and duration of coastal hypoxia linked to global warming and eutrophication.



POSSIBLE IMPACTS

The sensitivity of a specific marine organism to changes in seawater oxygen concentrations is highly non-linear and depends strongly on the temporal dynamics (episodic, periodic, seasonal...) and spatial extent of the changes.

Oxygen concentration	Impact on organisms
\nearrow 60 $\mu\text{mol/kg}$	No observed effects
\leftarrow 60 $\mu\text{mol/kg}$ (Hypoxia)*	Organisms show reduced fitness and aberrant behaviour. Depending on dynamics in oxygen changes and motility of the organisms, further decrease in oxygen concentrations would lead to migration and increased mortality of the different species
5 – 10 $\mu\text{mol/kg}$ (Suboxia)	Disappearance of practically all multi-cellular life
\sim 0 $\mu\text{mol/kg}$ (Anoxia)	Only anaerobic microorganisms present

* This is the conventional reference level for hypoxia; thresholds can vary strongly between different groups of organisms. Crustaceans and fish, both important for the fishing industry, seem to be the most sensitive.

Declining oxygen concentrations can also have a large impact on global biogeochemical cycles. In so-called 'oxygen minimum zones' (large hypoxic water bodies in the ocean interior), denitrification rates increase, releasing more nitrogen into the atmosphere which can limit ocean productivity.

In coastal areas, hypoxia can also initiate a feedback loop by increasing nutrient release from sediments, stimulating primary production and further increasing the oxygen consumption by micro-organisms that live on the algal biomass.

WHAT ARE THE FUTURE PROJECTIONS?

Climate simulations predict:

- An overall decline in ocean oxygen concentrations;
- An expansion of mid-depth 'oxygen minimum zones';
- An increased prevalence of coastal hypoxia and the formation of 'dead zones' characterized by the absence of benthic fauna and fish.

OCEAN DEOXYGENATION AND COASTAL HYPOXIA

FACT SHEET

HOW DOES CLIMATE CHANGE AFFECT OCEAN OXYGEN LEVELS?

- Higher seawater temperatures will increase the respiratory and metabolic rates of organisms, thereby increasing the biological oxygen demand;
- Oxygen is less soluble in warmer water and an increase in global temperature will decrease the inventory of oxygen within the ocean;
- Higher temperatures in combination with changes in wind and precipitation patterns will increase ocean stratification, thereby reducing the downward oxygen transport;
- In coastal areas, the increase in nutrient run-off will stimulate primary production, increasing the supply of organic matter sinking down and stimulating respiration in bottom waters.



Hypoxia scheme design: S. Luedeling, www.medieningenieure.de

ONGOING RESEARCH

Several European projects are currently investigating the effects of declining oxygen concentrations. The main focus of these projects is on the deployment, upgrading and linking of observatories for continuous oxygen monitoring to resolve temporal dynamics and long-term trends in oxygen concentrations (for example, EU FP7 HYPOX www.hypox.net).

Research is also investigating the mechanisms leading to hypoxia, placing the emphasis on the interplay between hypoxia and the availability and regeneration of nutrients.

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RESEARCH GAPS AND PRIORITIES

- Characterise spatial and temporal dynamics of oxygen in both open ocean and coastal environments;
- Identify drivers of oxygen depletion;
- Identify effects of oxygen depletion processes on biodiversity in diverse environments;
- Separate natural variability from anthropogenic impacts;
- Establish a global observation system that continuously monitors oxygen concentrations at high resolutions, linked to other physical, biogeochemical and biodiversity parameters as well as climate observations;
- Improve models to better predict the frequency, intensity and duration of future hypoxia.



Deployment of the Loch Etive Cabled Observatory (LECO)

This fact sheet is based on a chapter of the CLAMER / Marine Board Special Report *Synthesis of European Research on the Effects of Climate Change on Marine Environments* (Deliverable 1.2) written by **Filip Meysman** (Netherlands Institute for Ecology of the Royal Netherlands Academy of Arts and Sciences) and **Felix Janssen** (Max Planck Institute for Marine Microbiology, Germany).