

Technical University of Denmark



## Soil carbon stocks

Changes in relationship to global change factors and soil management strategies

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# ABSTRACTS



## CHANGES IN MARINE AND TERRESTRIAL PRODUCTIVITY UNDER CLIMATE CHANGE - IMPACT AND FEEDBACK

DTU Climate Change Technologies

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At the Technical University of Denmark, Risø  
12 - 13 May 2009

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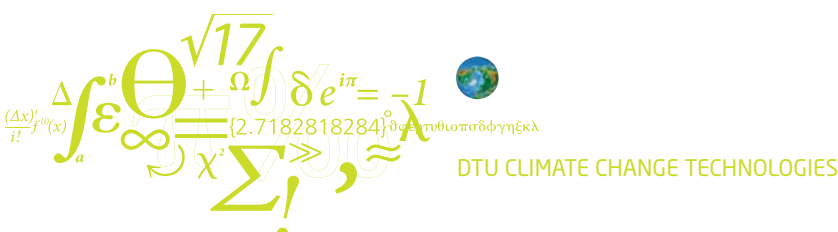


1<sup>st</sup> session: Impacts of climate change on marine productivity

**Thresholds of climate change for marine ecosystems**

Carlos M. Duarte  
*IMEDEA, CSIC-UIB, Esporles, Mallorca, Spain*

The impacts of climate change on marine ecosystems are still poorly considered in global assessments of the impacts of climate change, with the impacts on coral reefs being the best documented case. Here I broaden this view by providing evidence for major direct and indirect impacts of climate change impacting communities across all biomes of the ocean. Common to these responses is the existence of thresholds of climate forcing beyond which the responses are likely to be abrupt. Specific examples are provided for ocean metabolism, the spread of hypoxia and seagrass meadows.





### **Solutions/opportunities**

- Implement comprehensive and integrated ecosystem approaches to managing coasts and oceans, fisheries, aquaculture, disaster risk reduction and climate change adaptation;
- Reducing fishing capacity and rebuilding over-exploited ecosystems; this could be achieved partly by eliminating subsidies that promote overfishing and excessive capacity;
- Move to environmentally-friendly and fuel efficient fishing and aquaculture practices and integrate and 'climate-proof' aquaculture with other sectors;
- Provide climate change education in schools and create greater awareness among all stakeholders;
- Strengthen our knowledge of aquatic ecosystem dynamics and biogeochemical cycles, particularly at local and regional levels;
- Conduct local climate change vulnerability and risk assessments.

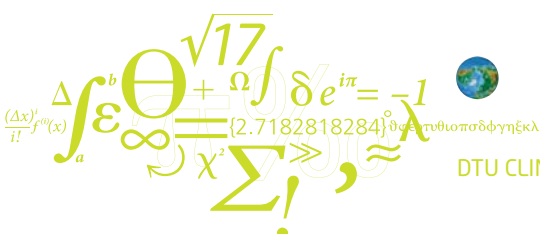
1<sup>st</sup> session: Impacts of climate change on marine productivity

**Climate and Fish Stock Dynamics**

Keith M. Brander  
DTU Aqua, Denmark, [kbr@aqua.dtu.dk](mailto:kbr@aqua.dtu.dk)

Marine ecosystems have always been affected by changes in climate at timescales from decades to millions of years. We can confidently attribute some of the recent changes in distribution and abundance of many marine taxa to global warming, but other factors (overfishing, nutrient supply, habitat disturbance and pollution) also play a part and temperature is not the only climate-related factor acting.

We depend on the oceans and coastal seas for many ecosystem services (supporting, provisioning, regulating and cultural) and there is real cause for concern that these services will be damaged and degraded by climate change. Can we identify areas and ecosystems that are particularly vulnerable? How soon could climate have an impact on marine ecosystem services? How great is the impact likely to be under different scenarios of climate change? Do we have monitoring systems in place which will warn of impending changes and provide information which can be used to respond? Are there ways in which we can adapt to climate change and mitigate? The effects of climate change can be detected at individual, populations and ecosystem level. We require better understanding of the processes which act at all these levels, from experimental and field work in order to provide credible responses to the questions posed above. Most of the studies of long term changes and climate impact to date have come from temperate parts of the Atlantic and Pacific and there is a great need for matching information from tropical areas, particularly in the Indian Ocean.



## 1<sup>st</sup> session: Impacts of climate change on marine productivity

### The acidification of the oceans

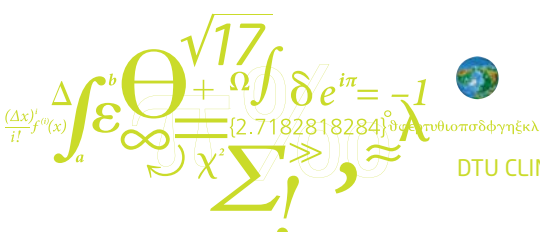
Liam Fernand, John Pinnegar and Will Le Quesne  
*Centre for Environment, Fisheries & Aquaculture Science (CEFAS)*

It is known that the oceans are becoming more acidic as increasing atmospheric carbon dioxide (CO<sub>2</sub>) is absorbed at the surface. It is thought that the pH of the global ocean has fallen by about 0.1 units over the past 200 years and that it could drop by a further 0.5 units by the year 2100 if CO<sub>2</sub> emissions are not regulated (Royal Soc, 2005;). Impacts of acidity change are likely but their exact nature remains largely unknown and may occur across the range of ecosystem processes. This aspect of climate change is potentially a precursor to the longer-term thermal effects.

This field is now the subject of much research activity; most results to date focus on calcifying organisms but these are not the only organisms of concern and may not be the most important ecologically.

Many new projects such as the EU EPOCA, German BIOACID, UK NERC –Defra Initiative, US PMEL – NOAA, are beginning to address the many scientific challenges and will lead to a much better understanding of the consequences.

This paper will show the extent of the problem, highlight the main areas of concern, but will also look into the future and point to the relevance of the recently begun programmes in addressing these issues.



2<sup>nd</sup> session: Impacts of climate change on terrestrial productivity

## Vegetation changes and plant growth – consequences of water availability and climate change

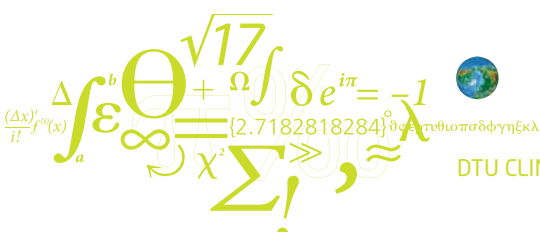
Dieter Gerten

*Potsdam Institute for Climate Impact Research*

In many regions, vegetation growth and net primary production (NPP) are limited by water availability already today, besides limitation of temperature and radiation. This presentation quantifies the degree of this water limitation around the world (expressed in terms of the ratio between water-limited and water-unlimited canopy conductance of water and carbon as computed by the LPJ Dynamic Global Vegetation Model), both for the present and for scenarios of future changes in climate and atmospheric CO<sub>2</sub> concentration. It is shown that due to increasing water limitation in response to increasing temperature and regionally decreasing precipitation, NPP will decrease in many regions. The regional pattern of response, however, will strongly depend on the chosen climate change scenario. This decrease is buffered by direct effects of elevated CO<sub>2</sub> and also by dynamic changes in vegetation composition, that is, current vegetation may be replaced by plants adapted to drier conditions such that overall NPP changes little even under drier conditions. This puts into question whether NPP is a good indicator of an ecosystem's status, and suggests that other ecosystem characteristics – such as biodiversity – need to be accounted for. The talk furthermore demonstrates that future climatic change implies critical consequences for the NPP of the world's agricultural systems, adaptation of which under conditions of increasing water limitation will require significant human intervention (e.g. consideration of different varieties or crop types, and application of fertilisers so as to ensure realisation of the beneficial CO<sub>2</sub> effects in the field).

### Solutions/opportunities

- Enhancing (or avoiding reduction of) terrestrial NPP over large regions would help preventing a turn of biosphere to net C source.
- Enhancements could be attained by increasing soil fertility (N, liming ...), regrowth from stump, fire management, and other sustainable forestry methods in specific regions and with participation of local people.
- But, natural forests are often characterised by higher biodiversity.
- Natural/managed forests may be conserved or abandoned areas afforested where appropriate, though this implies trade-offs with other land and water uses (cropland, bioenergy plantations).
- Terrestrial ecosystem needs should have a voice also in global water scarcity assessments.





## 2<sup>nd</sup> session: Impacts of climate change on terrestrial productivity

### Adaption of genetic resources to a changing climate

Rikke B. Jørgensen, Georg Frenck, Leon G. Linden, Teis N. Mikkelsen

*Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Biosystems Division, Building BIO-309, P.O. Box 49, Frederiksborgvej 399, DK-4000 Roskilde, Denmark*

*Correspondence: Rikke B. Jørgensen, tel. +45 4677 4124, fax +45 4677 4160*

*E-mail: rikke.bagger.jorgensen@risoe.dk*

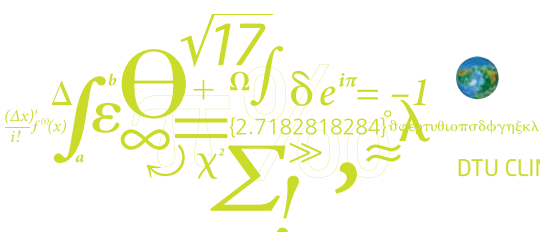
The objective of this study is to evaluate the effects to the terrestrial plant production from the future climate. The focus is on the effects of the combined action of elevated CO<sub>2</sub>, temperature and ozone to Scandinavian crop plants, as only few such multifactor studies exist. It is studied to what extent the crops respond by changing their phenotype or genotype (microevolution), when climate selections are applied over several plant generations.

The effect of elevated CO<sub>2</sub>, tropospheric ozone (O<sub>3</sub>) and temperature is investigated in oilseed rape (*Brassica napus*) and barley (*Hordeum vulgare*). Oilseed rape and barley are chosen as model species, as their genomes are well mapped and microarrays can be applied for analysis of their gene expression. Seven genotypes of each species representing different age, genetic variation and origin are cultivated in multiple or single factor treatments with CO<sub>2</sub> (385 ppm and 700 ppm), O<sub>3</sub> (20 ppb and 60 ppb) and temperature (19/12 °C and 24/17 °C). Watering of the plants is strictly controlled. Growth and production parameters are measured for both species in six different climate treatments. Currently, results on the production parameters are available for three generations of plants selected in the changed environments, but the experiment will continue and select plants for another 3-4 plant generations. In the final generation, genetic adaptations and changed gene expression will be exposed using genome scans and gene-chips.

After the first three generations of selection, some general responses were observed for both species: Elevated CO<sub>2</sub> increased yield significantly

- Higher temperatures decreased yield significantly
- The multifactor combinations of elevated CO<sub>2</sub> + temperature + O<sub>3</sub> and elevated CO<sub>2</sub> + temperature tended to decrease most production parameters
- There was a genotype-specific response to the climate treatments

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It has been predicted that the agricultural production in southern Scandinavia will increase due to the beneficial effects to plants from increased CO<sub>2</sub> and temperature. However, after having studied three generations of barley and oilseed rape grown in multifactor treatments corresponding to climate scenarios in southern Scandinavia in the year 2075, we found that the expected increase in the production may not be fulfilled, rather production is reduced. Mitigating actions could be needed to counterbalance undesirable effects from interacting climate factors. Breeding for new climate resistant genotypes, introduction of new crop types or new management strategies could be part of the mitigating solution.

### **Solutions/opportunities**

In 2040 the world's population is expected to reach about 9 billion. Production of food for all these people is essential. Scandinavia is predicted to be able to increase the agricultural production in this future climate (IPCC 2007, working group II), opposite to countries in southern Europe or most developing countries. However, if the combined action of different climate factors reduce our terrestrial productivity – as indicated by our results - this will have profound consequences not only for food production, but also species compositions in natural ecosystems, carbon sequestration etc.

How can we mitigate this?

- Breed for genotypes of present crops that perform better under climatic stress - possibly not an easy task due to the genetic basis of traits providing multi resistance to environmental stressors
- Introduce new crop species or crop types better fit for the new climate. This would probably demand major investment in new agricultural machinery, processing systems etc.
- Change our agricultural practise, e.g. harvest two times per growth season. This would probably increase undesirable environmental effects from the agricultural production, e.g. from pesticides, fertilizers etc.
- Change our diet. 18% of the global emission of green house gasses is due to animal husbandry. 20% of our food is discarded. How far will we go to change our dietary habits?

2<sup>nd</sup> session: Impacts of climate change on terrestrial productivity

**Carbon/nutrient interactions and nutrient transfer from land to sea in a changing climate**

Richard F. Wright

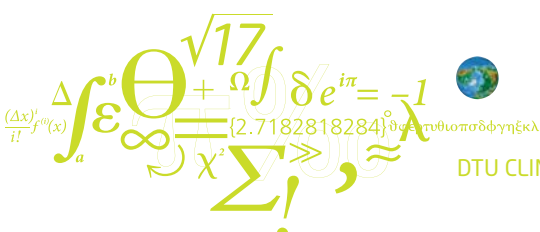
Norwegian Institute for Water Research, Oslo, Norway, [wri@niva.no](mailto:wri@niva.no)

Nitrogen is typically the growth-limiting nutrient in natural and “semi-natural” terrestrial ecosystems (forests, heathlands, alpine) in north temperate and boreal regions. Likewise, nitrogen is typically the growth-limiting nutrient in coastal marine ecosystems. Climate warming, altered precipitation and more frequent extreme events can affect productivity, carbon sequestration and retention of nitrogen in natural and “semi-natural” terrestrial ecosystems. Climate change can thus cause a cascade of biogeochemical effects from the mountains to the fjords which ultimately can affect the nutrient flux from land to sea and thus marine productivity.

Estimates of possible climate change impacts on nutrient fluxes come from ecosystem experiments, analysis of long data records, and application of ecosystem-scale models. For nitrogen in terrestrial ecosystems the evidence to date points to greater retention under warmer climate, but greater losses under wetter conditions. Both the concentration and flux of nitrogen to coastal waters can be affected, as well as the seasonal pattern.

**Solutions/opportunities**

Careful management of agricultural lands as well as forests, heathlands and alpine ecosystems can reduce nutrient losses. In Europe mitigation measures will be necessary to limit nutrient losses such that freshwater and near-coastal waters meet the requirement of “good ecological quality” as mandated by the Water Framework Directive. The forthcoming “river basin management plans” will thus reduce the risk of adverse impacts on marine ecosystems caused by future climate change. The challenge is to choose management options in agriculture and forestry that reduce both the carbon footprint as well as nutrient losses.



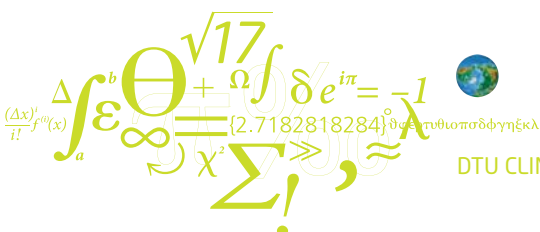
3<sup>rd</sup> session: Feedback from marine productivity changes to the climate

**Changes in shelf sea ecosystems impacting on ocean carbon cycles?**

Mike St. John

*Institute of Hydrobiology and Fishery Sciences, University of Hamburg*

Increasingly, observation and modelling programs examining the effects of climate change on marine ecosystems show clear impacts on the distribution and dynamics of these systems and their key species. From these studies it is anticipated that climate change via for example a restructuring of the base of the marine food web will impact upon the production of exploited marine resources such as fish stocks. Feedbacks to climate, an emergent property of these systems will be a result of changes in the biological carbon pump i.e. the flux of organic carbon to the deep ocean. Based on programs such as JGOFS, a reasonable understanding of the dynamics of this process exists for the deep ocean. Shelf sea ecosystems, the most productive of marine environments have recently been identified to contribute significantly to the flux of carbon to deep ocean however, a paucity of knowledge exists on this food web mediated process. Here I discuss how changes in shelf sea ecosystems driven by fisheries activities restructures these ecosystems having the potential to significantly impact upon the efficiency of the biological shelf pump and thereby feeding back to global climate.



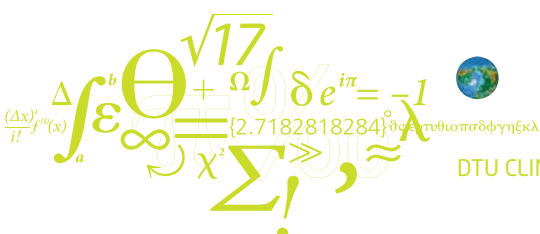
3<sup>rd</sup> session: Feedback from marine productivity changes to the climate

**Manipulating productivity – iron fertilization – pros and cons**

Dr Richard Lampitt

*National Oceanography Centre, European Way, Southampton SO14 3ZH, UK*

The oceans sequester carbon from the atmosphere partly as a result of biological productivity. Over much of the ocean surface this productivity is limited by essential macro-nutrients such as nitrate and phosphate or in some regions by the micro-nutrient iron. It is possible that sequestration of anthropogenic carbon can be enhanced by supplying these limiting nutrients and various methods have been suggested, the efficacy of each which will differ. Iron supply is a particularly attractive candidate as it is required in very small quantities. There are a number of potential unintended consequences of fertilisation and each of these must be addressed and the risks estimated before fertilisation can be considered on a large scale. Current level of knowledge from the observations and modelling carried out to date does not provide a sound foundation on which to make clear predictions or recommendations as to whether this is likely to be a prudent strategy for mitigation of climate change. For ocean fertilisation to become a viable option we need more extensive and targeted field work and better mathematical models of ocean biogeochemical processes. Models are needed both to interpret field observations and to make reliable predictions about the side effects of large scale fertilisation. They would also be an essential tool with which to verify that sequestration has effectively taken place. There is considerable urgency to address climate change mitigation and this demands that new field work plans are developed rapidly. In contrast to previous experiments, these must focus on the specific objective which is to assess the possibilities of CO<sub>2</sub> sequestration through fertilisation.



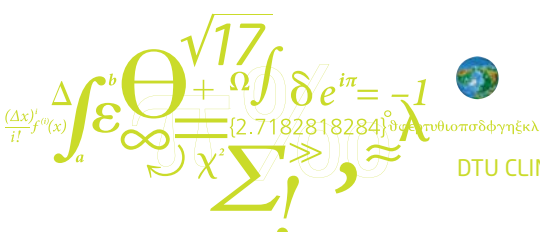
## Climate change and manipulating productivity in freshwater ecosystems – a global perspective

Erik Jeppesen

National Environmental Research Institute, Department of Freshwater Ecology, Vejlsovej, 25, DK-8600 Silkeborg, Denmark, [ej@dmu.dk](mailto:ej@dmu.dk)

Many lakes across the world are highly eutrophic due to a too high loading of nutrients from cities or diffuse sources such as agriculture. In some areas eutrophication is enhanced by stocking of fish, most notably carp. Carp disturb the sediment and thereby release nutrients and they also eat the water fleas that are supposed to control the algae in the water. The result of high nutrient loading is algae blooming, including dominance of toxic bluegreen algae, and turbid water. Worldwide, lake managers now undertake huge efforts to reduce the external nutrient loading to improve the ecological status of degraded lakes. Removal of carp and other coarse fish is also used to facilitate a shift to a clear state. With global warming, lakes show enhanced symptoms of eutrophication. Fish become more numerous (higher biomass and production per unit of phosphorus) and smaller, and the predation pressure from fish on the water fleas increases. This, in turn, leads to higher risk of algae blooming and dominance of bluegreens, the latter being reinforced by higher temperatures and a temperature-mediated increase of phosphorus release from the sediment. The critical nutrient threshold for good ecological status will therefore be lower in a warmer world, and more effort is needed to shift turbid lakes to a clearwater state. Recently, it has been suggested that nutrient enrichment of water-bodies, especially of nutrient poor lakes, may help modulate the anthropogenically induced increase of CO<sub>2</sub> concentrations in the atmosphere. Simultaneously, arguments are raised that a favourable side effect will be an increase in the production of fish. In lakes, an increase in fish production certainly occurs with fertilisation and also higher temperatures, but at high nutrient loading and higher temperatures a shift occurs to dominance of less attractive (for humans!) species. The biodiversity of lakes shows a unimodal relationship to nutrients and is highest at intermediate nutrient concentrations. Fertilisation may therefore enhance biodiversity in oligotrophic lakes, but will impoverish it on a global scale. Moreover, we demonstrate that fertilisation can be risky; once a lake has been eutrophied the way back can be very long. We argue that inland fish production should be concentrated in fish ponds/cages, with opportunities of recycling nutrients and of avoiding pollution of natural water bodies. Moreover, the production per unit of area is 1-2 orders of magnitude higher in fish ponds than in natural lakes.

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3<sup>rd</sup> session: Feedback from marine productivity changes to the climate

**Solutions/opportunities**

Global warming enhances fish production, but also leads to higher eutrophication and higher release of green house gasses. Fish production in natural waters is many-fold lower than in fish ponds and cages, and such methods should therefore be used for enhancing fish-food production in the non-marine environments, and not through fertilisation natural lakes and reservoirs. **Artificial fertilisation is not the way forward to reduce the carbon release from lakes and not the way forward to enhance fish production either!!!** The enhanced risk of eutrophication with warming calls for **additional external nutrient loading reduction** from point sources and diffuse sources (agriculture) - (i) the former e.g. by better treatment of sewage, better storage capacity for water during extreme rainfall and better sewer systems, also with a higher transport capacity, and (ii) the latter e.g. by re-meandering streams, establish buffer strips, wetlands, streams and lakes that have disappeared during the period of intensification of agriculture. Removal of carp and other coarse fish and reducing internal loading by chemical treatment of sediment in degraded lakes may at places be helpful as well, provided that the external loading has been reduced. All actions can be taken immediately and will also help improving the ecological state of lakes in general, and prepare us for the coming changes in climate. Climate change and manipulating productivity in freshwater ecosystems – a global perspective.



### 3<sup>rd</sup> session: Feedback from marine productivity changes to the climate

## Climate change and fisheries management

Poul Degnbol  
*European Commission*

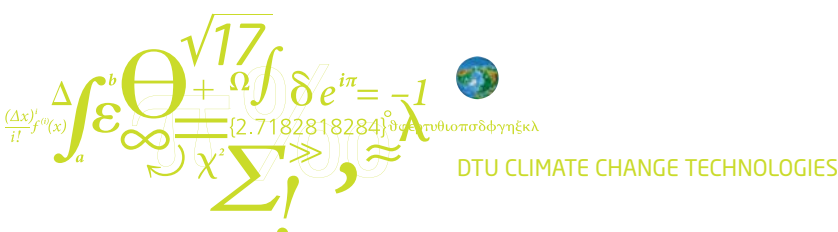
Climate change and fisheries interact both ways: Industrialised fisheries contribute to climate change through emission of greenhouse gasses. The fisheries sector must therefore take its share of contributing to mitigation. Fisheries are affected by climate change because the resource bases for fisheries, the marine ecosystems, change. The fisheries sector and public policy must therefore adapt to climate change.

Fisheries impacts on climate by being responsible for 1.2% of global oil consumption. The consumption of oil is very variable, dependent on the fishery. The global average is 0.45 kg fuel per kg fish landed (640 l/ton). European fisheries do however, amongst its many diverse fisheries, have some of the most oil consuming fisheries globally - it can be 4 kg fuel per kg fish landed in beam trawler fisheries. There have been low incentives for the industry to develop energy efficiency. On the contrary, the tax exemption for oil to fisheries can be considered a subsidy to the sector which has had the opposite effect of being a counterincentive for energy efficiency. However, more recently the high fuel prices have created a strong incentive for change.

Mitigation in this sector is primarily promoted through the general mitigation policy of the Community. Beyond this, energy saving technologies and practices are promoted by the Commission. There is considerable potential for reducing the emissions relative to landings. The policies we pursue for conservation reasons and to improve the economic performance of the fleet such as a reduction in fleet capacity together with healthier stocks will be the most important contribution to improved energy efficiency because a smaller fleet will harvest from larger fish stocks. The Commission is also facilitating information exchange on energy efficiency through a study and a web site with information available to operators in the sector.

The impacts of climate change on fisheries are expected to be very considerable and complex. The major features of relevance to fisheries management are not only northward changes in distribution but also changes in ecosystem productivity and that sustainable fisheries may need to exert lower fishing pressure when climate change is an added stress on fish populations and ecosystems. What is also new, with regard to earlier changes in the marine environment, is that the change predicted due to climate change is more rapid than earlier changes within the most recent several thousand years.

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It is a challenge to both industries and public policy to adapt to this.

From an industry perspective, more rapid changes in the resource base and cautious management, means that the industry needs to develop its flexibility even further in order to adapt to new conditions. The need for flexibility and a changing resource base may, on the other hand, discourage long term investments. We are trying to promote incentives for a longer investment horizon to encourage the industry to take a longer term responsibility so this may counteract these attempts. The industry may be facing new mechanisms to distribute access as the geographical distribution of stocks change. Existing access rights may change considerable in value as the volume (and thus value) of a stock changes as a result of climate change.

The adaptation of public policy is threefold: 1) maintain (or rebuild) resilience of marine ecosystems and fish stocks, 2) ensure that adequate measures will be taken as changes appear by developing a responsive and responsible decision framework and 3) Prepare response to distribution issues as fish stocks change distribution or new fishing opportunities appear.

1) Maintaining (or rebuilding) resilience of marine ecosystems and fisheries. This means that we should do effectively what we try to do anyway - to reduce the fishing pressure and fisheries impacts on ecosystem. Climate change is an added stress on marine ecosystems and fish stocks on top of fisheries, pollution etc. Climate change therefore makes the need to reduce fishing pressure even more urgent.

The first priority is therefore to do effectively what we try to do already to move to sustainable fisheries – to reduce overall fishing pressure and reduce capacity

2) Ensure that adequate measures will be taken as changes appear by developing a responsive and responsible decision framework. Climate change has highlighted that we have been operating within a false mindset of nature being constant - climate change and considerations of ecosystem linkages require management to be adaptive in a changing environment. Proper monitoring and scientific analysis needs to be in place which enables early warnings of changes and also of regime shifts. However, warnings about regime shifts are very difficult to get because science does not have good methods to identify such shifts in the early stages. Management plans must be made such that they are adaptive. This is what we already are trying to do with most recent plans. The discussion paper for the next cod recovery plan does specifically mention the changing environment as a reason to propose a new approach. We need to develop a responsible and responsive decision process which does not lead to complacency in times of little change and can react rapidly when required.

3) Prepare response to distribution issues as fish stocks change distribution or new fishing opportunities appear. Questions of distributions of access will be raised in international fora as the geographical distribution of stocks change. We need to discuss and get decision rules for this early on, preferably before the changes in the sea have taken place. We think that generally, access is based on historical precedence of catches rather than geography. Another case is 'new' stocks, when fish species occur in areas where they did not occur before. This creates the risk of the development of unregulated fisheries and early measures need to be taken to manage emerging fisheries – it is difficult to reverse overfishing. We must establish mechanisms which introduces regulation (and distribution of access) in such cases.

4<sup>th</sup> session: Feedback from terrestrial productivity changes to the climate

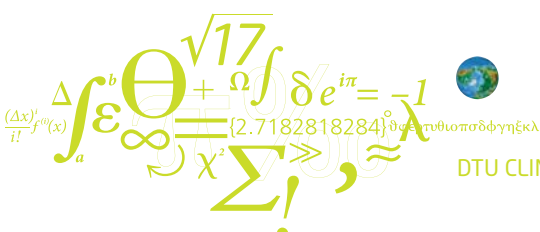
**Non-CO2 greenhouse gas exchange between land and atmosphere from a climate change perspective**

Keith Smith  
*University of Edinburgh*

The growth in world population, and the associated increased demand for food and feed, has resulted in large-scale land use change from natural forests and grassland to agricultural land, and a major intensification of agricultural production. The increasing popularity of a more meat-and milk-based diet internationally has added to the pressures on land, and now the demand of land for biofuels has added another dimension to the problem. These changes have resulted in a large increase in the release of CO<sub>2</sub> to the atmosphere from carbon previously stored in trees and soils, and also an increase in the emissions of methane because of increasing livestock populations, and an increase in N<sub>2</sub>O emissions resulting from increased N fertilizer use.

Activities associated with land use account for 25 – 45% of all anthropogenic CH<sub>4</sub> emissions. Reductions in emissions from rice and from manure management are feasible, but only a fall in ruminant populations is likely to make a real difference in methane emissions. The additional reactive nitrogen introduced into the biosphere from the vastly expanded production of synthetic nitrogen fertilizers over the last 50 years has increased the emissions of N<sub>2</sub>O, and agriculture is now the major anthropogenic source of this gas. Practices which improve overall N use efficiency in agriculture are capable of reducing emissions per unit of N used significantly, but the projected increases in fertilizer use in coming decades suggest that the overall trend will continue upwards for some time.

Potential mitigation measures in the short-term include improvements in agricultural knowledge transfer and “carrot & stick” monetary policies to reduce N<sub>2</sub>O, by reducing over-fertilization with N; adopting other procedures known to improve N use efficiency; and using nitrification inhibitors. Better water management in rice paddies can reduce CH<sub>4</sub> emissions and possibly modifying rumen metabolism in the remaining livestock herd will also contribute. Longer-term, both CH<sub>4</sub> and N<sub>2</sub>O emissions could be reduced by a significant move back to more vegetarian diets.



## Crop production in a changing climate

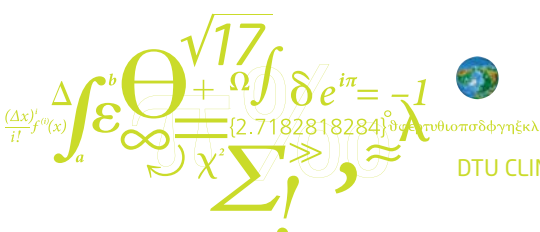
Jørgen E. Olesen

*Aarhus University, Dept. of Agroecology and Environment*

Climate change affect cropping systems through a wide range of direct and indirect pathways. The effects may be positive or negative depending on current climate and soils, and depending on the direction of change. It should be stressed that the effects of climate change on crops are mediated through the farmer's management of the genotype x environment interactions, which is crucially dependent on available resources, including climate, soil, water, nutrients and genetic diversity. So far, research on climate change impacts in agriculture has given little emphasis on changes in frequency of extreme events. However, the impacts of increased climate variability on plant production are likely to increase yield losses above those estimated from changes in mean climate only. This is primarily linked with changes in the frequency of extreme heat waves and changes in rainfall patterns, including more intensive precipitation events and longer drought periods. Changes in climate variability may be particular difficult for many farmers to adapt to, and adaptation strategies to cope with variability may be different than from those dealing with changes in mean climate. Strategies for adapting to increased variability may include measures to avoid periods of high stress or measures that increase resilience of the system by adding diversity in the crop rotation and improving soil and water resources.

Many management-level adaptation options have been proposed and analysed. Most of these are extensions of current practices to cope with climatic variation or adverse environmental conditions. Several of these adaptation measures may be used to increase resilience to climate change in cropping systems. However, when it relates to soil and water resources, building resilient systems may require long-term planning and changes already now in anticipation of climate change. An example of this is can be illustrated by the link between climate change and soil degradation, which is one of the greatest threats to global food production. Most of the processes causing soil degradation are enhanced by climate change, being promoted by higher temperatures, more intense rainfall and longer drought periods, which lead to lower soil carbon stocks, increased soil erosion and salinization. Yet, higher soil carbon contents and better soil structure will be critical for cropping systems to cope with increased climate variability. There is clearly a need within research, advice and policy to focus more on those aspects of agricultural systems that build resilience.

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Many of the options available for adapting agricultural activities will influence the emissions of greenhouse gases either by enhancing or reducing the fluxes. However, it should be kept in mind that agricultural activities affect several greenhouse gases simultaneously, and it is the net effect on the global warming potential of all gases that should be considered. There may also be differences between short- and long-term responses to introduction of system and management changes, in particular for measures that involve changes in soil management and input of carbon and nitrogen to the soil. There are very few studies linking adaptation and mitigation in agriculture, and further studies are warranted.

### **Solutions/opportunities**

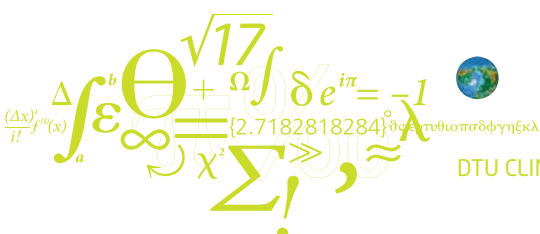
To cope with climate change, agriculture needs to build more climate resilient systems. This involves strategies that protect soil quality and promote the better water and nutrient use efficiencies.

## Model predictions of greenhouse gas emission at a regional scale

Klaus Butterbach-Bahl

*Institute for Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Forschungszentrum Karlsruhe, Kreuzackbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany*

Biosphere-atmosphere exchange of greenhouse gases is largely affected and driven by a series of environmental factors such as meteorology (climate) or soil and vegetation properties as well as human management (irrigation, fertilization, tillage etc.). Especially with regard to soil N<sub>2</sub>O emissions, this is resulting in a well known huge spatial and temporal variability of emissions on field as well as on regional scales. To address this variability, to improve existing estimates and to explore options to mitigate GHG emissions from terrestrial ecosystems or to better understand biosphere feedbacks to climate change several groups worldwide have started to develop and to use biogeochemical models for the simulation of GHG exchange. Even though the models are still having a considerable uncertainty due to parametric uncertainty or uncertainties in input parameters (e.g. regional soil properties) they do allow to identify trends in emissions, characterization of regional hotspots and exploration of likely climate change feedbacks. The presentation will summarize some recent results on applications of biogeochemical models on site to regional and global scales and lessons we have learned from these studies.



4<sup>th</sup> session: Feedback from terrestrial productivity changes to the climate

**Soil carbon stocks**

**Changes in relationship to global change factors and soil management strategies**

Per Ambus

*Biosystems Division, Risø DTU*

Soil bound organic carbon (C) constitutes 1500 Gt on global scale, which is almost twice as much C as present in the atmosphere (730 Gt) and three time as much as present in plants (500 Gt). On a European scale, the soil C stock is c. 75 Gt. Gross fluxes of C between atmosphere and soils are large (120 Gt compared to 5-6 Gt from fossil fuels and cement production) and driven by various biotic and abiotic parameters, including photosynthetic C accumulation, litter-fall, decomposition and runoff. Even small changes in these large and opposing fluxes may have a significant influence on the total atmospheric CO<sub>2</sub> pool, and thus for future climatic perturbations. If carbon is released from soil to the atmosphere, climate change will be exacerbated. In contrast, if soil accumulates more carbon and emission decrease, climate change will be retarded. The importance of current global changes in atmospheric CO<sub>2</sub>, temperature and precipitation for soil C stocks is largely unknown, or at the best associated with large uncertainties. Most important for soil C stocks is land use and land use changes combined with soil management. It has been estimated that 20 – 50 % of the current increase in atmospheric burden of C is caused by changes in land use strategies during the industrial development. Generally grasslands and forest soils accumulate carbon; however, soil carbon losses occur when these ecosystems are converted into croplands. Options for proper management strategies to increase soil C sequestration are several; they are immediately available and do not require development of new and unproven technologies.

This presentation gives a brief overview on current knowledge concerning important controls on soil C stock changes in relationship to expected future climatic conditions. Opportunities to increase soil C through proper management is also discussed touching opportunities and potentials of cropping strategy and incorporation black carbon into the soil.

