Acidification Workshop - Program

Venue: All lectures and round-table discussions will be in the "Arktika" auditorium on the second floor of the Fram High North Research Centre for Climate and the Environment. Directions to the Fram Centre are provided on pages 23 + 24 of this Program.

Tuesday, 27 September 2011

08:30 – Welcome and introduction to the Fram Centre and its ocean acidification flagship– Jo Aarseth (Research Coordinator, Fram Centre) and Maria Fossheim (Leader, Ocean Acidification Flagship)

08:45 - Welcome and overview of the workshop – Howard Browman & Clara Manno

Session 1 – Biogeochemistry of acidification + naturally acidified environments

09:00 - Charles T. Driscoll, "*Effects of acid rain on sensitive forest and freshwater ecosystems: is the problem solved?*"

09:45 - Richard Bellerby, "*Ocean acidification: background, recent observations and future scenarios*"

10:30 – Coffee

11:00 - Jason Hall-Spencer, "*Use of natural CO2 gradients to evaluate effects of ocean acidification*"

11:45 – Session 1 round-table discussion of, for example, underlying natural spatiotemporal variability compared to future scenarios; scales and rates of change; need to integrate perturbation experiments with observations provided by sediment cores and sediment trap time series; how can biogeochemistry of acidified freshwaters inform ocean acidification? The round-table will be led and moderated by the Session lecturers.

12:30 – Lunch (at the Fram Centre cafeteria)

Session 2 – Effects of acidification on organisms

13:30 - M. Debora Iglesias-Rodriguez , "*Effects of ocean acidification on phytoplankton*"

14:15 - Anne Todgham, "*Predicting the impacts of ocean acidification: Using "omic" approaches to understand the physiological capacity of organisms to tolerate elevated CO_2*"

15:00 - Coffee

15:30 - Sam Dupont, "*Species-sensitivity and life-history strategies, from eco-physiology to evolution*"

16:15-17:00 – Session 2 round-table discussion of, for example, methodological weaknesses (e.g. acute experiments to test a change with a long onset time; are typical control conditions used in perturbation experiments appropriate?; do we adequately account for natural spatiotemporal fluctuations in pH?: how to account for variability in the density of water during an experiment?); knowledge gaps; (specific to phytoplankton and invertebrates); how can studies on organismal and ecological responses in acidified freshwaters inform ocean acidification studies? The round-table will be led and moderated by the Session lecturers.

19:00 onwards: ***Informal evening socializer*** – Pizza and beer socializer at the University of Tromsø's student house, sponsored by the Fram Centre and the Association of Polar Early Career Scientists (APECS). Walking directions are provided on the maps at the end of the Program.

Wednesday, 28 September 2011

Session 2 – Effects of acidification on organisms *(continued)*

09:00 - Jon Havenhand, "*Effects of OA on fertilization in marine invertebrates: a review and synthesis*"

09:45 - Norman Yan, "*Direct and indirect effects of Ca and P decline on the crustacean zooplankton populations of acid-sensitive, Shield lakes*"

10:30 - Coffee

11:00 – Session 2 round-table discussion of, for example, methodological weaknesses (e.g. acute experiments to test a change with a long onset time); knowledge gaps; (specific to phytoplankton and invertebrates); how can studies on organismal and ecological responses in acidified freshwaters inform ocean acidification studies? The round-table will be led and moderated by the Session lecturers.

12:00 – Lunch (at the Fram Centre cafeteria)

13:00 – Haruko Kurihara, "*The diverse response of marine organisms and ecosystems to ocean acidification*"

13:45- Frode Kroglund, "*Acid rain affects salmonid sea water survival: lessons learned from metal exposures in rivers and estuaries*"

14:30 – 16:30: Coffee with refreshments and student "idea fertilization" poster session

19:00 onwards – ***Conference dinner***. Location to be announced. Sponsored by the Fram Centre.

Thursday, 29 September 2011

09:00 - Philip Munday – *"How does ocean acidification affect marine fishes?"*

09:45 - Antoine O.H.C. Leduc, *"Freshwater acidification and the detection of chemical signals: a case study using wild Atlantic salmon (Salmo salar)"*

10:30 – Coffee

11:00- Session 2 round-table discussion of, for example, methodological weaknesses (e.g. acute experiments to test a change with a long onset time); knowledge gaps; (specific to fish and higher vertebrates). The round-table will be led and moderated by the Session lecturers.

Session 3 – Socioeconomic aspects of acidification

11:30 - William Cheung, *"Projecting effects of ocean acidification on fish and fisheries"*

12 :15 – Lunch (at the Fram Centre cafeteria)

13:15 - Katrin Rehdanz, *"Economic costs of ocean acidification: A look into the impacts on shellfish production"*

14:00 – 15:30 – Coffee and refreshments with ***Panel session "The socioeconomic costs of ocean acidification"***. Panel led by Jon Havenhand, Richard Bellerby and Katrin Rehdanz.

Some issues that can be debated:

- Is OA a problem for society (if so, why)?
- What should/could be done?
- Who should be held responsible?
- Is climate engineering a solution?
- There will be winners and losers as a result of OA (both ecologically and economically). How will that affect the politics of discussions about OA?

15:30 – Closing of the workshop

Lecture abstracts

Ocean acidification: background, recent observations and future scenarios

Richard Bellerby

Consequent to the increase in the atmospheric load of carbon dioxide (CO_2), due to anthropogenic carbon release, there has been an increase in the oceanic carbon reservoir. At the air-sea interface, the productive, euphotic surface ocean is a transient buffer in the process of ocean-atmosphere CO_2 equilibrium, a process retarded by the slow mixing of the surface waters with the intermediate and deep ocean. As such, the greatest changes to the CO_2 system are occurring in the surface waters. This build up of CO_2 is already altering the speciation of carbonate chemistry of the oceans and projections on decadal to centennial timescales point to changes in seawater pH and carbonate species that may have ramifications for the success of organisms or whole marine ecosystems. This presentation will introduce the concept of ocean acidification, including an analysis of the latest results on empirical evidence of change of the marine carbonate system. We will also examine results from regional and global modelling exhibiting scenarios of change over the next decades.

Projecting effects of ocean acidification on fish and fisheries

William Cheung

Recent theories and empirical evidence suggest that ocean acidification (OA) may impacts on some marine fishes and the effects are likely to be exacerbated by other aspects of global changes such as warming. Biological responses to OA may affect population dynamics through changes in growth and mortalities at different life stages. This would have implications for the fisheries that depend on these species. However, the level of impacts and the mechanisms of biological effects appear to vary considerably between species. Although long-term biological impacts of OA are not fully understood, it is important to develop scenarios of how OA may affect marine fisheries. In this talk, I will present a series of quantitative scenarios on the potential impacts of OA and other ocean changes on marine fisheries and human wellbeing. These scenarios are generated from the Dynamic Bioclimatic Envelope Model (DBEM) that simulates changes in population dynamics, species distributions and maximum catch potential of >600 species of exploited demersal fishes in world. The DBEM incorporates main hypotheses of biological responses to OA and other ocean changes. The model is driven by projected changes in ocean conditions from global-scale Earth System Models. The results suggest the potential of large-scale redistributions of fisheries catch as a result of OA and other ocean changes, with many tropical countries losing substantially from their potential fisheries benefits. Marine ecosystems and fisheries may further impacted through changes in the life history of fishes caused by ocean changes. OA may potentially increase the rate of changes and reduce fisheries catch. I will also present how these changes are expected to affect fisheries economics and food security.

Effects of acid rain on sensitive forest and freshwater ecosystems: is the problem solved?

Charles T. Driscoll

Elevated emissions of air pollutants can impact ecosystems. Until recently air quality management in the U.S. has focused on human health, largely ignoring ecosystem effects. However, ecosystems provide essential services and functions. Since the early 1970s the U.S. has implemented controls on emissions of air pollutants, through the Clean Art Act and air quality rules. Air pollutants of particular concern include sulfur dioxide and nitrogen oxides. These pollutants result from fossil fuel emissions, including coal fired electric utilities, and are transported long distances. Sensitive ecosystems include high elevation forests, streams and lakes. A variety of approaches have been used to investigate ecosystem effects of acid rain, including time-series measurements, whole ecosystem experiments, spatial surveys or gradient studies, paleoecological reconstructions, synthesis activities and modeling. The Adirondack region of New York is among the regions most highly impacted by acidic deposition the U.S., with effects on soil and surface waters and resulting effects on certain tree species and aquatic biota. Marked decreases in concentrations of sulfate and hydrogen ion have occurred in precipitation since the late 1970s. Decreases in nitrate deposition have been evident in recent years. These decreases are consistent with long-term controls on emissions from electric utilities. Adirondack lakes have shown decreases in concentrations of sulfate, which coincide with decreases in atmospheric sulfur deposition. Concentrations of nitrate have also decreased in several Adirondack lakes. Decreases in concentrations of sulfate plus nitrate have resulted in improvements in the acid-base status of some lakes, including increases in acid neutralizing capacity (ANC) and pH, and a shift in the concentrations of aluminum toward less toxic organic forms. These changes have coincided with recovery in the fisheries of some acid-impacted lakes. Soil surveys and watershed model calculations provide evidence of the long-term chemical changes that have occurred to soils and surface waters due to acidic deposition. Model calculations also provide information on how forest ecosystems might respond to future decreases in acidic deposition. The concept of critical loads has been advanced to guide the management and recovery of ecosystems from air pollution disturbance. Lessons learned from studies of acid rain on forests and freshwaters will be presented.

Species-sensitivity and life-history strategies, from eco-physiology to evolution

Sam Dupont

Ocean acidification (OA) is believed to be a major threat for near-future ecosystems and that amongst the most sensitive taxa will be calcifying organisms and the free-living larval stages produced by many benthic marine species. This presentation, we will give a brief overview on how elevated seawater pCO2 impacts animal physiology through alterations in body fluid acid-base chemistry, energy budget and how calcification can suffer in a secondary fashion. I will try to point out similarities and dissimilarities in physiological response to ocean acidification in different marine phyla. A special emphasis will be placed on the role of life-history strategy. For example, the impact of OA on planktotrophic larvae is globally negative while lecithotrophic larvae appear to benefit from OA. Within a species, egg size and spawning time are also of tremendous importance; for example, in northern hemisphere, late spawners appear to be more at risk than early spawners. Other "rescue" strategies such as larval cloning can also play a major role and life-history strategies should be included in any large scale predictions of the impact of OA and climate change and that some of the original paradigms (e.g. OA will negatively impact marine calcifiers) should be reconsidered. The role of acclimation, phenotypic plasticity and selection will be discussed.

Use of natural CO2 gradients to evaluate effects of ocean acidification

Jason Hall-Spencer

Areas with naturally high CO2 (and/or low pH and low calcium carbonate saturation states) are being used to investigate which organisms can tolerate the long-term consequences of ocean acidification and reveal how ecosystems respond. For example; differences in aragonite saturation state appear to affect the strength of coral reefs between ocean basins, upwelling areas can have sessile communities that tolerate periods of high CO2, estuaries have pH gradients that cause mollusc shells to dissolve. Volcanic vents are also proving to be particularly useful 'natural laboratories' for the study of ocean acidification as they reveal tipping points in calcification, recruitment, growth, survival and species interactions along pCO2 gradients. Many species of macroalgae, seagrass, foraminiferans, corals, polychaetes, crustaceans, molluscs and bryozoans are remarkably tolerant of long-term exposures to high and variable carbon dioxide levels at tropical and temperate vents. However, a fall in mean pH 8.1 to mean pH 7.8 has detrimental effects on benthic recruitment from the plankton (Cigliano et al., 2010) and decreases the biodiversity associated with sedimentary habitats (Dias et al., 2010), rocky shores (Porzio et al., 2011), coral reefs (Fabricius et al. 2011) and seagrass beds (Martin et al., 2008) with around 30% fewer species in adult populations at mean pH 7.8 than in adjacent areas at mean pH 8.1. Transplant experiments show that unusually high sea surface temperatures can act synergistically with ocean acidification at these sites (Rodolfo-Metalpa et al. 2010), strengthening evidence for the CO2 emissions targets required to avoid declines in coastal marine biodiversity and shifts in ecosystem structure.

Cigliano M et al. (2010) Marine Biology 157, 2489-2502.
Dias B et al. (2010) Journal of the Geological Society, London. 167, 843-846.
Fabricius K et al. (2011) Nature Climate Change 1, 165-169.
Porzio L et al. (2011) Journal of Experimental Marine Biology and Ecology 400, 278-287.
Rodolfo-Metalpa R et al. (2010) Marine Ecology 31, 447-456.

Effects of OA on fertilization in marine invertebrates: a review and synthesis

Jon Havenhand

Recent reviews of the effects of ocean acidification on fertilization success and early development of marine invertebrates conclude that fertilization is largely insensitive to OA. While this is an accurate summary of the literature, closer analysis shows that many published studies were designed in such a way that negative effects may not have been detectable in the assays used, and that positive effects of OA could never have been detected. In this presentation I will summarise the available data that allow an objective assessment of the effects of fertilization success on OA, and show that there is considerable variation in sensitivity of fertilization success to OA both within and between species, and show examples of negative, no, and positive effects of OA on fertilization.

Effects of ocean acidification on phytoplankton

M. Debora Iglesias-Rodriguez

Ocean acidification has caused changes in carbonate chemistry in the oceans including an increase in seawater carbon dioxide and bicarbonate ions, and a decline in pH and the concentration of carbonate ions. These chemical alterations can have profound effects on the efficiency of the photosynthetic acquisition of carbon and the synthesis of organic and inorganic carbon compounds by marine organisms. However, modelling these processes is complex and requires an understanding of the mechanisms controlling the sinks (e.g., photosynthesis) and the sources (calcification, respiration) of carbon dioxide. Among eukaryotic phytoplankton, diatoms and coccolithophores appear to enhance photosynthetic carbon fixation, and prokaryotic nitrogen fixers show an overall increasing trend in nitrogen fixation. However, observations in the lab and in the field revealed that the calcification response of coccolitophores is variable between and even within the species concept. Novel tools such as proteomics and transcriptomics reveal that the protein signature associated with high carbon dioxide levels is comparable to that associated with present-day conditions. While looking at the past geological record of coccolithophores can aid in understanding past trends in abundance and diversity, interpreting the environmental controls on these changes is not always easy because alterations in carbon chemistry are often associated with changes in other chemical or physical variables including temperature, and calcium and magnesium levels. This talk will discuss the physiological responses of biogeochemically important phytoplankton groups to ocean acidification in an ecological and evolutionary context using molecular, physiological and biogeochemical information.

Acid rain affects salmonid sea water survival: lessons learned from metal exposures in rivers and estuaries

Frode Kroglund

The water quality in lakes and rivers depends on several factors including catchment geology (chemical composition and weathering rates), vegetation (base cation depletion), rainfall and rainfall pattern (chemical weathering and dilution), climatic zone (snow in winter and snowmelt episodes in spring), temperature (weathering rates), degree of influence from seawater (ion contribution), the level of local pollution (industry, agricultural, and sewage etc.) and on long-range transported air pollutants ('acid rain' and various persistent organic and inorganic micropollutants). Several of these factors are also influenced by climate and will respond to climate change. In addition, water quality (as pH) will be influenced by biological processes (CO_2; respiration & photosynthesis). There is thus no simple relationship between acid rain, water quality and biology.

Acidification can be anthropogenic (acid rain), but can also wholly or partly be due to natural process (organic acids). Acidification implies a pH reduction (H^+ increase), but it is the pH-related mobilization of aluminum (Al) that is the prime cause for deteriorating fish health. Differences in acid deposition, geology and weathering rates between Europe and North America e.g. results in differences in both Al mobilization, pH/Al relationships and on what form Al is present on in water, where concentration and speciation to a large extent can be related to water pH and organic content. Toxicity however, is only related to cationic (positively charged) species of Al, where the concentration of cationic Al will increase with a reduction in pH and decrease with increased organic content. Al must therefore be fractionated to determine the biologically relevant concentration. Sensitivity and response to Al exposure varies with fish species, population characteristics and with which life stages are present at any given time. Atlantic salmon smolt is regarded as the species & life stage most sensitive to acid rain and Al. While smolt exposed to a pH 5.0 without Al is unaffected, this same pH value will, when Al is present, be highly toxic. Toxicity is caused by Al binding to the fish gill, where high doses will kill the fish in freshwater, where low doses can have the same ecological effect by affecting various salt-regulating enzymes impairing body electrolyte regulation in sea water. Smolt with impaired body electrolyte regulation can die, lack fright response (and are eaten), spend more energy on maintaining body functions (grow poorly) and have reduced tolerance to secondary stressors acting in seawater (increased sensitivity to salmon lice).

Active measures have been implemented in Sweden and Norway to protect Atlantic salmon while waiting for water quality to recover following emission reductions. While acid emissions have been reduced, water quality will remain impaired for decades to come due to soil processes. Liming was initiated during the 1980's and 1990's to protect salmon and other acid sensitive organisms. It became early clear that there was an urgent need to define what biological traits need protection and to define water criteria that provide a satisfactory level of protection. While improving water quality to a level where fish "lived" was a satisfactory target in the 1980's, it became clear that properties like seawater tolerance had to be included as a biological response criterion during the 1990's. While a pH following liming of 6.0 was regarded as satisfactory in the 1980's, the current pH-target is set to pH 6.4 (in spring). This increase in pH was needed to reduce Al-related toxicity to a level where we could not detect affects on smolt survival in seawater. As a result of these actions, around 12% of all salmon landed in rivers in Norway are at present caught in a limed river.

While salmon catches have increased in most limed rivers, some rivers have not responded as expected. Several of these feed into fjords dominated by brackish water. Major fish kills within salmon rearing pens linked this to floods in the 1980's and to Al in the 1990's. Acidification has not only increased Al in freshwater but has also increased the transport of Al into the estuaries. As sea water has very low Al concentrations, total Al will decrease linearly with increased salinity. Al toxicity in brackish water will however increases as salinity increases from 1 to around 5 psu to decrease with a further increase in salinity. Here enhanced toxicity is not due to reduced pH but to seasalts liberating Al from organic and colloidal Al-complexes increasing the presence of cationic Al in the estuaries. Currently we are investigating whether

Al in estuaries have or don not have an affect on the survival of anadromous fish. What started as a freshwater topic in the 1970's has today become an estuarine topic.

The diverse response of marine organisms and ecosystems to ocean acidification

Haruko Kurihara

Increase of the atmospheric CO_2 is now quickly acidifying and changing the seawater carbonate chemistry of the whole ocean, with profound ramification on the marine organisms. Invertebrates that produce calcium carbonate shells and skeletons are suggested to be particularly vulnerable to the ocean acidification. However, current studies revealed that the tolerance capacity to the acidification is highly species and stage specific. Additionally, impacts on non-calcifiers and vertebrates such as fishes have also been demonstrated. In this presentation, I will summarize available data for the impacts of ocean acidification on survival, growth, reproduction, early development, physiology, calcification, behavior and species interaction of a wide range of organisms, and evaluate some physiological traits that might be related on the diverse response of the organisms to the ocean acidification. Additionally, some model ecosystem such as coral reefs, coastal region and Southern ocean will be focused for understanding the effect of ocean acidification at ecosystem level and consequences of the ocean acidification on fisheries and ecology will be discussed.

Freshwater acidification and the detection of chemical signals: a case study using wild Atlantic salmon (Salmo salar)

Antoine Leduc

Many organisms use chemical cues to find partners and food, but also to sense the presence of natural enemies and to avoid predation. One such type of chemical cues is typically released following mechanical damage to the skin of an injured prey fish, as would likely occur following a predation event. When detected by conspecifics, these "damage-released chemical alarm cues" may trigger innate behavioural responses involved in the mediation of local predation risks. Such responses may include overall reductions in activities and increased cautious responses that confers higher survival probabilities to prey. To investigate if ambient acidity had the potential to affect the detection and/or response to chemical cues, we performed a series of field observations using damage-released chemical alarm cues in 6 Atlantic salmon (*Salmo salar*) nursery streams that ranged in pH from 5.71 to 7.49 (3 acidic streams and 3 neutral streams) over the course of 6 years. We monitored and quantified several behavioural modalities in juvenile salmon to assess if the detection of these chemical alarm cues was dependent on the ambient pH. Salmon present in any acidified streams did not respond to alarm cues while those in neutral streams exhibited species-typical alarm responses. We further examined potential mechanisms involved in the apparent behavioural impairment to determine whether differences in salmon populations between acidic and neutral streams could explain the loss of response to chemical alarm cues observed under acidic conditions. In a reverse-transplant experiment between acidic and neutral streams, we showed that salmon of any stream had the ability to produce and to detect chemical alarm cues and no significant difference between the origin of salmon could explain the loss of chemical alarm function. Finally, under laboratory condition, we determined at which pH value the loss of alarm function occurs and if a survival cost (increased mortality from predation) exists for juvenile salmonids exposed to acidified alarm cues in the presence of a predator (largemouth bass; *Micropterus salmoides*). Laboratory results showed that between 6.4 and 6.2 (pH unit), a steep decrease in alarm behaviour occurred despite the introduction of chemical alarm cues, suggesting for a graded loss of response with increasing acidity. In staged-encounters between prey and predator, prey individuals exposed to acidified alarm cues under the threshold of pH 6.2 had significantly shorter survival time when compared to individuals exposed to neutral alarm cues. Altogether, these results suggest that even subtle chemical changes in ambient acidity may interfere with the detection and use of chemical signals in otherwise pristine conditions.

How does ocean acidification affect marine fishes?

Philip L. Munday

ARC Centre of Excellence for Coral Reef Studies, and School of Marine and Tropical Biology, James Cook University, Australia. Phone +61 7 47815341. Email: philip.munday@jcu.edu.au

In general, marine fishes are thought to be relatively tolerant to increased CO_2 and reduced pH because they have well developed physiological mechanisms for acid-base regulation. Adults of some marine fishes can tolerate CO_2 concentrations several orders of magnitude greater than predicted to occur under climate change scenarios, and the few studies that have investigated the effects of ocean acidification on early life history traits have found little evidence for negative impacts. In contrast, recent studies have demonstrated dramatic effects of elevated CO_2 on sensory and behavioral attributes of coral reef fish. Larval fish exposed to near-future CO_2 concentrations exhibit impaired ability to identify chemical and auditory cues that help them locate suitable adult habitat and avoid predators at the end of their pelagic phase. Juvenile fish also exhibit riskier behavior in natural coral-reef habitat, leading to markedly higher rates of mortality. Although impairment of sensory behavior has been described in fishes from acidified freshwater systems, the mechanisms responsible are fundamentally different. Acidification by mineral acids alters the chemical structure of relevant cues. In contrast, exposure to elevated CO_2 causes neurological dysfunction that affects a broad suite of behaviours. In this talk I will describe the behavioural attributes affected and why marine fishes are so sensitive to these impacts.

Economic costs of ocean acidification: A look into the impacts on shellfish production

Daiju Narita, Katrin Rehdanz, and Richard S.J. Tol

Ocean acidification is increasingly recognized as a major global problem. Yet economic assessments of its effects are currently almost absent. Unlike most other marine organisms, mollusks, which have significant commercial value worldwide, have relatively solid scientific evidence of biological impact of acidification and allow us to make such an economic evaluation. By performing a partial-equilibrium analysis, we estimate global and regional economic costs of production loss of mollusks due to ocean acidification. Our results show that the costs for the world as a whole could be over 100 billion USD with an assumption of increasing demand of mollusks with expected income growths. The major determinants of cost levels are the impacts on the Chinese production, which is dominant in the world, and the expected demand increase of mollusks in today's low-income countries, which include China, in accordance with their future income rise.

Predicting the impacts of ocean acidification: Using "omic" approaches to understand the physiological capacity of organisms to tolerate elevated CO_2

Anne E. Todgham

Of critical importance to assessing the vulnerability of organisms to ocean acidification (OA) is a comprehensive understanding of the physiological "weak links" that underlie an organism's inability to tolerate increases in CO_2. With ocean conditions expected to change considerably in the next 90 years, there is an urgency to address these questions in the most efficient manner. In the post-genomic era, we have increasing access to a number of sensitive genomics-enabled techniques (i.e. transcriptomics and proteomics). Leveraging these "omic" approaches provides us with the capability of investigating the response of many cellular pathways simultaneously to stressors, such as elevated CO_2. Gene regulation, and the process of increasing mRNA transcripts for the synthesis of new proteins, is one of the most rapid and versatile ways in which organisms can respond to an environmental stressor. Since the ability of an organism to adjust to a changing environment will be driven by complex changes in gene regulatory networks and subtle changes in numerous cellular pathways, the use of "omic" tools will be particularly useful and efficient in elucidating the cellular-level responses to OA. Furthermore, responses to multiple stressors are complex. Organisms may be able to adjust their physiology to cope with elevated levels of CO_2 but this compensatory response could result in less energy available for mounting a stress response to further environmental change. Suites of differentially regulated genes and proteins can provide a physiological signature of organismal condition and uncover the trade-offs between physiological processes that ultimately define resilience of a population faced with a multistressor environment. The ultimate goal is to apply these techniques to organisms in their natural setting, thus matching the "omics" with questions and experimental designs relevant to the ecology of the organism.

Direct and indirect effects of Ca and P decline on the crustacean zooplankton populations of acid-sensitive, Shield lakes

Norman D. Yan, H. Riessen, C. Laforsch, I. Altshuler, A. Jeziorski, A. Paterson, N. Kim, A. Cairns, and J.P. Smol

While the classic effects of lake acidification on crustacean zooplankton in soft-water lakes were predictable from the inherent differences among taxa in sensitivity to acidity and to invertebrate predators, the contemporary situation cannot be so simply explained. Taxa differ dramatically in both P and Ca requirements Lake P levels are declining likely because of ongoing soil acidification, while lake Ca levels are declining because of the acidification of soils, forestry practices, and climatic change, all coincident with rising lake pH. The net effect for the dominant, Ca-rich daphniids is reduced growth rates, survival and clutch size, and delayed maturation, coupled with reduced production of normal structural defenses against native and introduced predators. Overall the fitness of many daphniids is falling in comparison with competitors with lower Ca and P requirements, and better defenses, and species assemblages are changing in consequence. We will provide paleoecological, spatial and temporal evidence for these changes, supported by both field and lab experimental proof of the causes. One lesson for students of ocean acidification is that relatively modest changes in lakewater chemistry are resulting in large changes in zooplankton community composition in Shield lakes, most simply characterized as a replacement of nutrient-rich, pelagic herbivores by their jelly-clad competitors.

Student posters

1) **Ocean acidification will have winners and losers – but what does this mean for ecosystem functioning?** Samantha L. Garrard, Maria Cristina Buia

2) **Influence of increased acidification on physiology and gene expression in marine invertebrate calcifiers.** Amit Kumar, P.Murugan, M.Anand

3) **A biomarker approach to evaluate adverse effects caused by coal fired thermal plants in Chile.** Aguirre-Martínez, G.V., Del Valls, T. A. and Martín-Díaz, M. L.

4) **Effect of rising CO2 levels and eutrophication on plankton community structure and transparent exopolymer particles (TEP) production in the St- Lawrence estuary ecosystem**. Annane S., Ferreyra G. A., Pelletier E., Demers S.

5) **Long-term CO_2 enrichment experiments on marine phytoplankton.** Anders Torstensson, My Mattsdotter

6) **Effects of ocean acidification on benthic metabolism and dynamics of nutrient fluxes in sediment-water interface.** Alves, Betina Galerani R.; Sumida, P.Y.G.

7) **Iimpact of ocean acidification on microbial loop meiofauna.** Ape Francesca, Pusceddu A., Danovaro R.

8) **Effects of CO_2 induced pH decrease on shallow benthic microbial communities.** A. Franzo, M. Celussi , T. Cibic , P. Del Negro , C. De Vittor

9) **Future efforts to elucidate the effects of pH on jellyfish blooms.** Mar B. Belmar, Elisa Fernández-Guallart, Alejandro Olariaga, Juancho Movilla, Verónica Fuentes, Carles Pelejero and Eva Calvo.

10) **Combined effects of ocean acidification, climate change and oil related discharges.** Maj Arnberg, Piero Calosi, Sam Dupont, Dan J. Mayor, Dag Hjerman, Renée K. Bechmann

11) **Impact of ocean acidification on *Corallium rubrum* (L. 1758): an experimental approach.** Cardini U., Pusceddu A., Cerrano C., Danovaro R.

12) **Ocean acidification: understanding ocean carbon cycling and the biological pump in a high CO_2 world.** Rachel Cooper, S. Leigh McCallister

13) **Molecular approaches to study the effect of high-CO_2 on the larval development of the commercial oyster *Crassostrea hongkongensis.*** R Dineshram, V Thiagarajan

14) **Harmful effects of ocean acidification on a commercially important fish species: Atlantic cod.** Andrea Y. Frommel, Rommel Maneja, David Lowe, Audrey Geffen, Arild Folkvord, Uwe Piatkowski and Catriona Clemmesen

15) **The effects of ocean acidification on the early life stages of marine invertebrates: current tolerances and the potential for future selection.** Ackley C. Lane

16) **Effects of ocean acidification n the species interactions of coralline algae across trophic levels.** Sophie J. McCoy, Catherine A. Pfister

17) **Effects of increased mobility and bioavailability of metals onmarine organisms because of dramatic rise in CO_2 concentration.** M D Basallote-Sanchez, A Rodriguez-Romero, J Blasco, T A DelValls and I Riba

18) **DNA damage in relation to aquatic acidification.** Neelam Mangwani

19) **Tools to provide possible response to ocean acidification.** P. Rumolo, M. Barra, M. DelCore, L. Prevedello, S. Gherardi, M. Vallefuoco

20) **Learning from the global oceans: the ecological impacts of carbon acidification of Lake Superior and Lake Michigan.** Jennifer C. Phillips

21) **The effects of CO_2-related seawater acidification on the mobility and availability of metals and on growth of marine microalgae.** De Orte, M. R, Sarmiento, A.M, Del Valls, A.

22) **Understanding ocean acidification impacts on tropical marine organisms in Philippine waters.** Rhia Odessa M. Gonzales

23) **Effects of ocean acidification on the ability of cod larvae to modify their foraging behaviour.** Rommel H. Maneja

24) **Physiological effects of ocean acidification on calcifying marine larvae.** R. Hunter, C. Lewis, R. Wilson

Student poster prize winner

Amit Kumar
c/o Dr. Punyasloke Bhadury
Dept. of Biological Sciences,
Indian Institute of Science Education and Research- Kolkata,
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for his poster, “Influence of increased acidification on physiology and gene expression in marine invertebrate calcifiers”.

Workshop participants (Total = 69; 18 countries)

Gabriela Aguirre-Martínez
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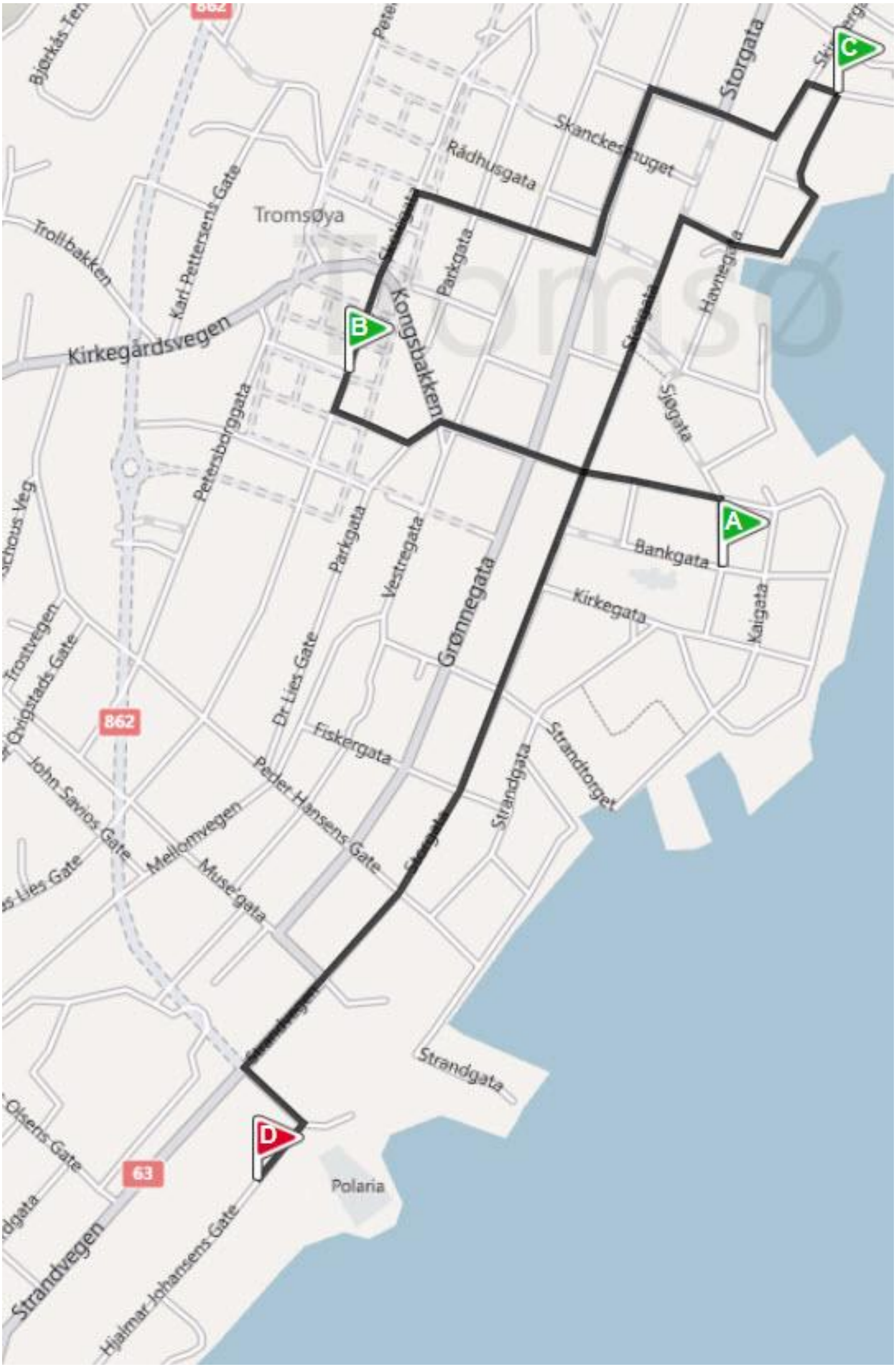
Getting to the Fram Centre

Follow the routes on the maps below. You will walk from the SAS Hotel at Sjøgata 7 (**A** on the map), or from the AMI Hotel at Skolegata 24 (**B** on the map) to the Fram Centre ("Fram Senteret" in Norwegian) at Hjalmar Johansens gate 14 (**D** on the map). These are both (A to D and B to D) about 15 minute walks (1 km). The University of Tromsø Student House (DRIV) is at Søndre Tollbodgate 3 (**C** on the map).

A
B
C
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Tromsø
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Skanckesmuget
Rådhusgata
Parkgata
Kongsbakken
Havnegata
Sjøgata
Bankgata
Kirkegata
Kaigata
Grønnegata
Vestregata
Dr Lies Gate
Fiskergata
Peder Hansens Gate
Strandgata
Strandtorget
Mellomvegen
Muségata
Petersborggata
Kirkegårdsvegen
Karl Pettersens Gate
Trollbakken
Bjørkås Terr
Trostvegen
Qvigstads Gate
John Savios Gate
Strandvegen
Hjalmar Johansens Gate
Polaria
862
63

Some restaurants in Tromsø

For those of you who have not been out to restaurants in Norway - be aware that a good three course meal will cost you 600- to 700- NOK, WITHOUT alcohol. There are, of course, many less expensive alternatives, including pizza, burgers and the usual fast food chains. An overview of restaurants (not an all-inclusive list) can be found here:

www.destinasjontromso.no/english/going_out_restaurants.html

Some recommendations from colleagues who live in Tromsø

All of these are in the central part of Tromsø within easy walking distance of the SAS Hotel.

Emma's drømmekjøkken. Rated the best restaurant in Tromsø. Very pricey. www.emmasdrommekjokken.no

4 Roser. The tasting menu is 5 courses with 4 different glasses of wine. Top quality food and clever choice of wines. Decoration may not be to everyone's taste. Very pricey. www.de4roser.no

Compagniet. Excellent meat and great selection of wines. www.compagniet.no

Fiskekompaniet. Excellent fish menu. Small portions. www.fiskekompani.no

Arctandria. Good fish menu. One floor above the legendary Skarven Pub. www.skarven.no

Skarven Pub. Famous Tromsø pub. Pub food. www.skarven.no/international

Lotus vin og mathus. Good sushi and many other things. In the center, by the harbour.

Aune garden. An old butcher shop transformed into a cafe-bar-restaurant. Good place for a beer, a coffee or a small meal (good fish soup). www.aunegarden.no

Steakers. Just what it sounds like. www.steakers.no/tromso/