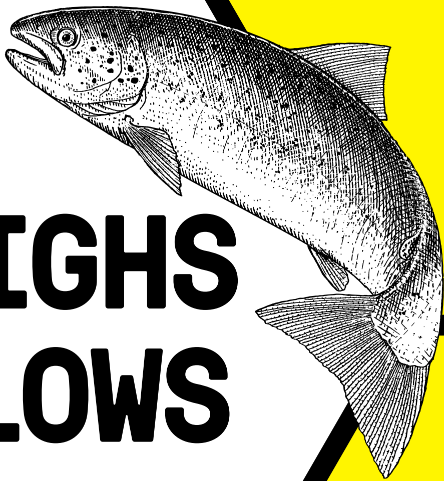
PROGRAMME AND ABSTRACT BOOK

LESSONS FROM TWO HIGH CO_2 WORLDS – FUTURE OCEANS AND INTENSIVE AQUACULTURE

10-12 APRIL 2018

LAGOA, SÃO MIGUEL, AZORES



CO_2 HIGHS AND LOWS

SOCIETY FOR EXPERIMENTAL BIOLOGY

LESSONS FROM TWO HIGH CO_2 WORLDS – FUTURE OCEANS AND INTENSIVE AQUACULTURE

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DELEGATE INFORMATION

BADGES

Participants are required to wear name badges at all times for proof of registration, security purposes and catering identification.

CATERING

Lunch and refreshments during the symposium are included in your registration fee. Refreshment breaks will be served in the poster/breakout area and lunch will be held in Restaurante Q'énosso which is close to the venue.

CERTIFICATE OF ATTENDANCE

Delegates requiring a certificate of attendance should visit the SEB registration desk on their departure.

VENUE

NONAGON – São Miguel Science and Technology Park, Rua da Tecnologia K – Epsilon, N.º 2
9560-421 Rosário, Lagoa, São Miguel

The scientific sessions will be taking place in the auditorium at the venue.

COACH TRANSFERS TO VENUE

Return coach transfers to NONAGON have been arranged for the duration of the symposium. Please see programme for collection times and drop off times in Ponta Delgada. There will also be a coach arranged to transport delegates to the conference dinner on 11 April.

Meeting Point
Portas da Cidade – City Gate, Av. D. Joao III, 9500-035, Ponta Delgada

LIABILITY

Neither the Society for Experimental Biology nor the FRCT will accept responsibility for damage or injury to persons or property during the symposium. Participants are advised to arrange their own personal health and travel insurance.

PHOTOGRAPHY

No photographs are to be taken of the speakers and their slides during the symposium unless consent is given by the speaker.

**Please note: The SEB will be taking photos during the event for promotional purposes. If you have any concerns, please visit the SEB registration desk.*

REGISTRATION

The registration desk will be open during the hours of the symposium and SEB staff will be on hand during the refreshment and lunch breaks should you require any assistance.

TWITTER

We're looking to increase the conversation at the symposium using Twitter so please get tweeting! Follow the conversation **#LFC02W**
SEB – **@SEBiology**

WI-FI INTERNET ACCESS

Internet access is available during the symposium and free of charge. Log in details will be available at the registration desk.

PROGRAMME

TUESDAY 10 APRIL 2018

08:20 DELEGATES PICK UP FROM PONTA DELGADA (MEETING POINT: PORTAS DA CIDADE)

08:50 REGISTRATION

09:25
FRCT Welcome
Dr Gui Menezes
Secretary of the Sea, Science and Technology, Regional Government of the Azores

09:35
Welcome and introduction
Prof Rod Wilson and Dr Rob Ellis
Symposium organising committee

CHAIR: MAURICIO URBINA

09:45
Prof Chris Harley
University of British Columbia, Canada
Ocean acidification impacts: confronting complexity and context-dependence
A18.1

10:15
Dr Sjannie Lefevre
University of Oslo, Norway
Are there CO_2 effects on oxygen uptake as predicted by the OCLTT hypothesis?
A18.2

10:30
Prof Timothy Ravasi
King Abdullah University of Science and Technology, Saudi Arabia
Genetic variation and phenotypic plasticity in the response to ocean acidification
A18.3

10:45
Dr Bayden D Russell
The Swire Institute of Marine Science, The University of Hong Kong, Hong Kong
Is elevated carbon dioxide the biggest concern for future aquaculture? Facing the temperature challenge
A18.4

11:00 REFRESHMENT BREAK/POSTERS

11:30
Prof Sam Dupont
University of Gothenburg, Sweden
From local adaptation to resilience – how to predict (and be prepared) for future global changes
A18.5

12:00
Ana M Faria
MARE-ISPA, Portugal
Reproductive trade-offs in the two-spotted goby under high pCO_2 levels
A18.6

12:15
Dr Kathryn E Smith
University of Exeter, United Kingdom
Individuals matter: Male-dependent shifts in sperm swimming and fertilisation success in response to high CO_2
A18.7

12:30
Dr Catriona M Clemmesen
GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany
The complexity of ocean acidification effects on larval cod *(Gadus morhua)*
A18.8

PROGRAMME

12:45 LUNCH/POSTERS

CHAIR: COLIN BRAUNER

14:00
Prof Philip Munday
James Cook University, Australia
Ocean acidification and marine fishes: the current state of knowledge, uncertainties, and future perspectives
A18.10

14:30
Alison A Monroe
King Abdullah University of Science and Technology, Saudi Arabia
Parental effects on heritability of high CO_2 tolerance in a coral reef fish
A18.11

14:45
Mr Blake L Spady
James Cook University, Australia
The effects of elevated CO_2 on the predatory behaviours of two species of tropical cephalopod
A18.12

15:00
Mr Michael Jarrold
James Cook University, Australia
Diel CO_2 cycles reduce severity of behavioural abnormalities in coral reef fish under ocean acidification
A18.13

15:15 REFRESHMENT BREAK/POSTERS

15:45
Prof Göran E Nilsson
University of Oslo, Norway
Neurophysiological mechanisms linking high-CO_2 with altered behaviour
A18.14

16:15
José Ricardo Paula
MARE – Marine and Environmental Sciences Centre, Portugal
Cognitive and neurobiological disruption of cleaning mutualisms under ocean acidification and warming
A18.15

16:30
Dr Fredrik Jutfelt
Norwegian University of Science and Technology, Norway
Temperate and coral reef fishes show negligible physiological and behavioural responses to elevated CO_2
A18.16

16:45
Dr Elliot Scanes
University of Sydney, Australia
Intertidal oysters reach their physiological limit in a future high-CO_2 world
A18.17

17:00
Dr Jodie L Rummer
James Cook University ARC Centre of Excellence for Coral Reef Studies, Australia
Physiological performance in a high CO_2 world – the role of maintaining oxygen transport in fish
A18.18

17:15 POSTER SESSION

19:00 DELEGATES TRANSFERRED TO PONTA DELGADA

PROGRAMME

WEDNESDAY 11 APRIL 2018

08:30 DELEGATES PICK UP FROM PONTA DELGADA (MEETING POINT: PORTAS DA CIDADE)

09:00 REGISTRATION

CHAIR: ROB ELLIS

09:15
Dr Christopher Good
The Conservation Fund's Freshwater Institute, United States
Consequences and control of dissolved carbon dioxide in intensive aquaculture systems
A18.19

09:45
Tom O Nilsen
Uni Research Environment, Norway
Effects of high environmental CO_2 levels on Atlantic salmon post-smolts
A18.20

10:00
Dr Kevin T Stiller
Nofima AS, Norway
The effect of carbon dioxide on fish growth performance in recirculating aquaculture systems
A18.21

10:15
Prof Sveinung Fivelstad
Western Norway University of Applied Sciences, Norway
Long term carbon dioxide experiments with salmonids – during 25 years
A18.22

10:30 REFRESHMENT BREAK/POSTERS

11:00
Prof Rod W Wilson
University of Exeter, United Kingdom
Using fundamental physiology to tackle high CO_2 associated problems in aquaculture
A18.23

11:30
Dr Colin J Brauner
University of British Columbia, Canada
Mechanisms and patterns of acid-base regulation in fish exposed to high environmental CO_2
A18.24

11:45
Dr Mark Bayley
Zoophysiology Aarhus University, Denmark
The effects of hypercapnia on intensively farmed air-breathing fish
A18.26

12:00
Dr Chris M Wood
University of British Columbia, Canada
What about the other high PCO_2 world – inside your fish?
A18.27

12:15 LUNCH/POSTERS

PROGRAMME

CHAIR: ROD WILSON

13:30
Dr Cory D Suski
University of Illinois, United States
Carbon dioxide and freshwater fish: Insights from barrier applications
A18.28

14:00
Dr Cosima S Porteus
University of Exeter, United Kingdom
The effects of water chemistry in recirculated aquaculture systems on the olfaction of European sea bass
A18.29

14:15
Dr Christina C Roggatz
University of Hull, United Kingdom
Modelling behaviour mediating cues in high CO_2 conditions
A18.30

14:30
Dr Alice Mirasole
University of Palermo, Italy
Slight differences in community structure and biodiversity of fish associated to a Cymodocea nodosa meadow in a shallow CO_2 vent
A18.31

14:45 REFRESHMENT BREAK/POSTERS

15:15
Dr David Bass
Cefas and Natural History Museum, United Kingdom
Disease as the major barrier to sustainable aquaculture production to 2050
A18.32

15:45
Dr Matthew B Sanders
Cefas, United Kingdom
Effect of ocean acidification on white spot syndrome virus (WSSV) replication in juvenile European lobster *(Homarus gammarus)*
A18.33

16:00
Dr Robert P Ellis
University of Exeter, United Kingdom
Elevated and variable CO_2 - a concern isolated to RAS or synonomus with intensive aquaculture globally?
A18.34

16:15
Dr Nia M Whiteley
Bangor University, United Kingdom
Energy budgets in edible crabs struggling to compensate for exposure to elevated CO_2 and reduced salinity
A18.35

16:30
Mr Will Davison
University of Exeter, United Kingdom
Cumulative impacts of high CO_2 and low salinity on the behaviour and physiology of shore crabs, *Carcinus maenas*
A18.36

16:45 END OF DAY 2

17:00 DELEGATES TRANSFERRED TO PONTA DELGADA

18:45 DELEGATES PICKED UP FOR DINNER (MEETING POINT: PORTAS DA CIDADE)

19:30 CONFERENCE DINNER LOCATION: RESTAURANTE ASSOCIAÇÃO AGRÍCOLA

PROGRAMME

THURSDAY 12 APRIL 2018

08:30 DELEGATES PICK UP FROM PONTA DELGADA (MEETING POINT: PORTAS DA CIDADE)

09:00 REGISTRATION

CHAIR: GÖRAN NILSSON

09:15
Dr Carol Turley
Plymouth Marine Laboratory, United Kingdom
CO_2 and the Ocean: an increasingly important issue on global to local scales for governments and society
A18.37

09:45
Dr Silvana N R Birchenough
Cefas, United Kingdom
Translating ocean acidification into practical applications to support aquaculture and food sustainability
A18.38

10:00
Mr Antonio Giacoletti
University of Palermo, Italy
The effect of climate change on a mussel-based Integrated Multi-Trophic Aquaculture (IMTA): insights from a mechanistic approach
A18.39

10:15
Rita F Patarra
CE3c - Centre for Ecology Evolution and Environmental Changes, University of Azores, Portugal
Effects of stocking density and water flow on the growth and bioremediation efficiency of the seaweed *Halopteris scoparia* (Ochrophyta)
A18.40

10:30 REFRESHMENT BREAK/POSTERS

11:00
Mr Bill Dewey
Taylor Shellfish Farms, United States
Impacts of ocean acidification on United States west coast shellfish aquaculture
A18.41

11:30
Dr Susan C Fitzer
University of Stirling, United Kingdom
Climate change driven sulphate soil acidification impacts oyster shell mineral structure
A18.42

11:45
Nicola Allison
University of St. Andrews, United Kingdom
Understanding the response of biomineralisation to rising seawater pCO_2
A18.43

12:00
Benjamin Mos
National Marine Science Centre, Southern Cross University, Australia
Biogenic acidification reduces sea urchin gonad growth and increases the susceptibility of aquaculture to ocean acidification
A18.44

12:15
Dr Stéphanie Auzoux-Bordenave
Sorbonne Université, France
Impact of ocean acidification on the early life-history stages of the European abalone *(Haliotis tuberculata)*
A18.45

12:30
Discussion, knowledge gaps & conclusions
Symposium organising committee

13:00 DELEGATES TRANSFERRED BACK TO PONTA DELGADA

14:00 DELEGATES PICKED UP FOR TOURS (MEETING POINT: PORTAS DA CIDADE)

POSTER SESSION TUESDAY 10 APRIL 2018

Dr Lynne U Sneddon
University of Liverpool, United Kingdom
CO_2 exposure in larval zebrafish: A painful issue?
A18.46

Dr Susana Galante-Oliveira
Biology Department CESAM, University of Aveiro, Portugal
Evidence of altered behaviour and reduced survival in *Nassarius reticulatus* (L.) veligers exposed to marine climate change projected scenarios
A18.47

Dr Andrea Y Frommel
University of British Columbia, Canada
Combined effects of ocean acidification and warming on organ health in larval kingfish
A18.48

Mrs Noha H Alsheikh
University of Hull, United Kingdom
The effects of low seawater pH on gene expression of the clam worm *Nereis succinea*
A18.49

Dr Jorg D Hardege
University of Hull, United Kingdom
Seawater pH impacts responses to marine info chemicals
A18.50

Mr Junho Eom
University of British Columbia, Canada
Direct PCO_2 measurements in the intestinal tract of the agastric goldfish
A18.51

Gudrun De Boeck
University of Antwerp, Belgium
Reduced salinity affects the capacity of juvenile European sea bass *(Dicentrarchus labrax)* to deal with additional stress
A18.52

Mr Will Davison
University of Exeter, United Kingdom
Are there conflicting acid-base impacts of feeding and living in a high CO_2 world? Alkaline tide v. Compensated respiratory acidosis
A18.53

LESSONS FROM TWO HIGH CO_2 WORLDS – FUTURE OCEANS AND INTENSIVE AQUACULTURE

A18.1 OCEAN ACIDIFICATION IMPACTS: CONFRONTING COMPLEXITY AND CONTEXT-DEPENDENCE

TUESDAY 10 APRIL 2018 09:45

CHRIS HARLEY (UNIVERSITY OF BRITISH COLUMBIA, CANADA)

@ HARLEY@ZOOLOGY.UBC.CA

Ocean acidification is a substantial threat to marine species and ecosystems, but its effects will range from subtle to substantial depending on the environmental context, the physiology and genetic diversity of the affected species, and the ecological relationships among species. I will present a framework for studying these complexities, and provide specific examples derived from research on benthic invertebrates including oysters, mussels, sea urchins, and abalone. Although ocean acidification effects may be difficult to generalize from one context to another for the purposes of scientific prediction or resource management, there are key attributes of systems that may make them more or less vulnerable and can serve as a starting point for anticipating future change.

A18.2 ARE THERE CO_2 EFFECTS ON OXYGEN UPTAKE AS PREDICTED BY THE OCLTT HYPOTHESIS?

TUESDAY 10 APRIL 2018 10:15

SJANNIE LEFEVRE (UNIVERSITY OF OSLO, NORWAY)

@ SJANNIE.LEFEVRE@IMBV.UIO.NO

The changing climate prompts a desire to understand and thereby the need to study and ultimately predict the outcome for marine ectothermic animals. The concept of “Oxygen and Capacity Limited Thermal Tolerance” (OCLTT) was inspired by the Fry paradigm of a bell-shaped “increase-optimum-decrease”-type response of absolute aerobic scope (AAS) to increasing temperature, but also include proposed negative and synergistic effects of elevated CO_2 levels in combination with warming. In my presentation, I will present some results of a meta-analysis examining the following questions: Does CO_2 in general cause an increase in resting oxygen demand (MO_{2rest}), and thereby reduce AAS? And is the combined effect of CO_2 and temperature on MO_{2rest} and AAS generally larger than expected from their sum, i.e. is the interaction synergistic? I calculated log response ratios to be able to compare result from a wide range of studies, including both fish and invertebrates. When examining the data as a whole, from the perspective of the above predictions, it becomes evident that there is a heterogeneity that is difficult to reconcile with the idea of a single unifying principle. While it is clear, that climate change can have severe physiological effects, and that AAS might be a useful variable for predicting the outcomes in some cases, malfunction of other physiological mechanisms must be considered and generalisations such as the OCLTT concept should be used with caution.

A18.3 GENETIC VARIATION AND PHENOTYPIC PLASTICITY IN THE RESPONSE TO OCEAN ACIDIFICATION

TUESDAY 10 APRIL 2018 10:30

TIMOTHY RAVASI (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA), CELIA SCHUNTER (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA), MEGAN WELCH (ARC CENTRE OF CORAL REEF STUDIES, JAMES COOK UNIVERSITY, AUSTRALIA), GORAN E NILSSON (UNIVERSITY OF OSLO, NORWAY), JODIE RUMMER (ARC CENTRE OF CORAL REEF STUDIES, JAMES COOK UNIVERSITY, AUSTRALIA), PHIL MUNDAY (ARC CENTRE OF CORAL REEF STUDIES, JAMES COOK UNIVERSITY, AUSTRALIA)

@ TIMOTHY.RAVASI@KAUST.EDU.SA

The impacts of ocean acidification will depend on the ability of marine organisms to tolerate, acclimate and eventually adapt to changes in ocean chemistry. We performed a unique transgenerational experiment with a common damselfish from the Great Barrier Reef to determine the molecular response of a coral reef fish to short-term, developmental and transgenerational exposure to near future elevated CO_2. This aids in teasing apart plastic responses due to developmental plasticity and reveals within-generation specific reactions to be driven by epigenetic regulators. Importantly, we find that altered gene expression for the majority of within-generation responses returns to baseline levels following parental exposure to elevated CO_2 conditions. However, gene expression involved in glucose homeostasis remains uncompensated across generations. Furthermore, we included different parental phenotypes measured by their level of behavioural tolerance to elevated CO_2 and found that responses of offspring varied largely with parental phenotype. We show that the transgenerational signal of tolerance is connected to the circadian rhythm and suggests adaptive potential of impaired behaviours from high CO_2 to be due to existing natural variation. Our aim is to further understand this tolerance to elevated levels of CO_2 which will aid in future predictions of resilience and population persistence in the light of rapidly increasing acidification of the oceans.

A18.4 IS ELEVATED CARBON DIOXIDE THE BIGGEST CONCERN FOR FUTURE AQUACULTURE? FACING THE TEMPERATURE CHALLENGE

TUESDAY 10 APRIL 2018 10:45

BAYDEN D RUSSELL (THE SWIRE INSTITUTE OF MARINE SCIENCE, THE UNIVERSITY OF HONG KONG, HONG KONG)

@ BRUSSELL@HKU.HK

It is increasingly recognised that ocean acidification is a threat to the function of coastal marine ecosystems. There is particular concern for calcifying molluscs in regions such as China, which produces >85% of the worlds oysters from aquaculture. However, the effects of ocean acidification can be transient, population specific, and are highly context-dependent. In contrast, recent years have seen an increasing incidence of heatwaves, or short-term temperature extremes, which have led to devastating shifts in some benthic ecosystems. Underlying these changes is the effect of elevated temperatures on the metabolic functioning of the organisms. In this talk, I will discuss the effects of elevated carbon dioxide and temperatures on the physiology of benthic coastal species. I will demonstrate how sublethal temperatures cause decline in function and, over the longer-term, elevated mortality, most likely because of a mismatch between metabolic demands and energy supplies (both reserves and intake). In less intensive coastal aquaculture systems, as found in much of Asia, rapidly rising temperatures may pose a greater threat than carbon dioxide by causing organisms to exhaust the energetic reserves.

A18.5 FROM LOCAL ADAPTATION TO RESILIENCE – HOW TO PREDICT (AND BE PREPARED) FOR FUTURE GLOBAL CHANGES

TUESDAY 10 APRIL 2018 11:30

SAM DUPONT (UNIVERSITY OF GOTHENBURG, SWEDEN)

@ SAM.DUPONT@BIOENV.GU.SE

Understanding species resilience is key to understand and address future global environmental changes such as ocean warming and acidification. Despite a growing body of evidence showing that these stressors will have a strong negative impact on marine species, variability in responses between species as well as between populations of the same species have strongly limited our ability to project future changes. Part of this variability can be explained by local adaptation and/or adaptive phenotypic plasticity. This talk will discuss how a mechanistic understanding of species and ecosystem responses (physiology, ecology, evolution) to environmental changes can help identifying resilient species and ecosystems. I will discuss how this approach can be used to re-evaluate existing literature, help design better experiments and develop the needed unifying theory for large scale projections.

A18.6 REPRODUCTIVE TRADE-OFFS IN THE TWO-SPOTTED GOBY UNDER HIGH pCO_2 LEVELS

TUESDAY 10 APRIL 2018 12:00

ANA M FARIA (MARE-ISPA, PORTUGAL), ANA F LOPES (MARE-ISPA, PORTUGAL), CÁTIA S E SILVA (MARE-IPL, PORTUGAL), SARA C NOVAIS (MARE-IPL, PORTUGAL), MARCO F LEMOS (MARE-IPL, PORTUGAL), EMANUEL J GONÇALVES (MARE-ISPA, PORTUGAL)

@ AFARIA@ISPA.PT

Fishes are currently facing novel types of anthropogenic stressors that have never experienced in their evolutionary history, such as ocean acidification. Under these stressful conditions, energetically costly processes, such as reproduction, may be sacrificed for increased chances of survival. This trade-off not only affects the organism itself but may result in reduced offspring fitness. In the present study, the effects of exposure to high pCO_2 levels were tested on the reproductive performance of a temperate species, the two-spotted goby, *Gobiusculus flavescens*. Breeding pairs were kept under control (~ 600 µatm, pH~ 8.05) and high pCO_2 levels (~ 2300 µatm, pH~ 7.60) conditions for a 4-month period. Additionally, oxidative stress and energy metabolism-related biomarkers were measured. Results suggest that reproductive activity is stimulated under high pCO_2 levels. Parental pairs in the simulated ocean acidification conditions exhibited increased reproductive output, with 50% more clutches and 44% more eggs per clutch than pairs under control conditions. However, there was an apparent trade-off between offspring number and size, as larvae of parental pairs under high pCO_2 levels hatched significantly smaller, suggesting differences in parental provisioning, which could be related to the fact that these females produce more eggs. Moreover, results support the hypothesis of different energy allocation strategies used by females under high pCO_2 conditions. These changes might, ultimately, affect individual fitness and population replenishment.

A18.7 INDIVIDUALS MATTER: MALE-DEPENDENT SHIFTS IN SPERM SWIMMING AND FERTILISATION SUCCESS IN RESPONSE TO HIGH CO_2

TUESDAY 10 APRIL 2018 12:15

KATHRYN E SMITH (UNIVERSITY OF EXETER, UNITED KINGDOM), MARIA BYRNE (UNIVERSITY OF SYDNEY, AUSTRALIA), DIONE DEAKER (UNIVERSITY OF SYDNEY, AUSTRALIA), CAMERON M HIRD (UNIVERSITY OF EXETER, UNITED KINGDOM), CERI LEWIS (UNIVERSITY OF EXETER, UNITED KINGDOM)

@ K.E.SMITH@EXETER.AC.UK

Global oceans are currently changing at a faster rate than at any other time over the last 300 million years, exposing marine fauna to multiple stressors and increasing extinction risks. Rising atmospheric carbon dioxide levels are being absorbed by the oceans, causing shifts in seawater carbonate chemistry and driving down ocean pH, a phenomenon known as ocean acidification (OA). OA is expected to become one of the greatest drivers of global ocean biodiversity change in the coming decades. When studying the impacts of OA on organism function, individual variability in responses is often overlooked. In reality, however, responses are rarely unidirectional, and what is deemed detrimental to most of the population may be beneficial to some. We examined the impact of OA (control, pH 7.9, pH 7.7) on sperm swimming and fertilisation success of males in two species of sea urchin: *Heliocidaris erythrogramma* and *Lytechinus pictus*. Following controlled spawning, sperm was analysed using Computer Assisted Sperm Analysis and the fertilisation success of each male was assessed using eggs pooled from multiple females. In both species we found that for some males fertilisation success and sperm swimming characteristics (e.g. velocity) declined under low pH conditions, but for others, these parameters increased. Typically, the response seen at pH 7.9 was amplified at pH 7.7, and the direction of the response (increase/decrease) remained the same. Here, we discuss our findings and identify sperm swimming characteristics that may predict the fertilisation success of individuals under both current and future ocean scenarios.

A18.8 THE COMPLEXITY OF OCEAN ACIDIFICATION EFFECTS ON LARVAL COD *(GADUS MORHUA)*

TUESDAY 10 APRIL 2018 12:30

CATRIONA M CLEMMESEN (GEOMAR HELMHOLTZ CENTRE FOR OCEAN RESEARCH KIEL, GERMANY), MARTINA H STIASNY (DEPARTMENT OF ECONOMICS SUSTAINABLE FISHERIES, UNIVERSITY OF KIEL, GERMANY), FELIX H MITTERMAYER (GEOMAR HELMHOLTZ CENTRE FOR OCEAN RESEARCH KIEL, GERMANY), NALANI K SCHNELL (INSTITUT DE SYSTÉMATIQUE ÉVOLUTION BIODIVERSITÉ, MUSÉUM NATIONAL D'HISTOIRE NATURELLE., FRANCE), THORSTEN BH REUSCH (GEOMAR HELMHOLTZ CENTRE FOR OCEAN RESEARCH KIEL, GERMANY)

@ CCLEMMESEN@GEOMAR.DE

In a series of experiments using eggs and larvae of different cod stocks and a variation of parental treatments (1) directly from the wild, 2) acclimated for 6 weeks, 3) acclimated for 5 months, 4) F4 aquaculture generation - the effect of end-of-the-century CO_2 levels ~(1100 µatm ppm) on cod larvae survival, growth and development was analysed. Additionally, the effect of different food levels was studied to evaluate potential buffering effects of surplus energy supply. In eight out of nine experimental trials survival of cod larvae was negatively affected by increased CO_2 levels. 6 week parental acclimation to ~1100 µatm buffered larval mortality led to an increase in survival compared to the control group, but only if the larvae were not energy limited. Indications of trade-offs between growth of the larvae and ossification of the skeletal structure and gill formation, but only under a limited food supply, were observed. Larger larval size, longer ossified gill arches, and a decrease in the ratio of gill filament/gill arch length as a result of increased CO_2 levels indicated a decoupling of larval size and gill size with potential effects on larval fitness. The lack of a direct CO_2 effect on survival, growth and skeletal ossification of larval cod, observed when the parental fish from the wild had been acclimated to the aquaculture facilities for 5 months, led to the conclusion that husbandry effects on the parental generation as well as population should be considered when looking at ocean acidification effects in future experiments.

A18.10 OCEAN ACIDIFICATION AND MARINE FISHES: THE CURRENT STATE OF KNOWLEDGE, UNCERTAINTIES, AND FUTURE PERSPECTIVES

TUESDAY 10 APRIL 2018 14:00

PHILIP MUNDAY (JAMES COOK UNIVERSITY, AUSTRALIA)

@ PHILIP.MUNDAY@JCU.EDU.AU

It is a decade since research commenced into the effects of anthropogenic ocean acidification on marine fishes. In that time, we have learned that projected end-of-century CO_2 levels can affect the growth, development and survival of early life stages of some species, but not others. There are also wide-ranging effects on behaviour that could alter performance and survivorship of some species in the wild. Yet, there is also enormous variation in the sensitivity of marine fishes to elevated CO_2, both among and within species, and we are learning that the effects of elevated CO_2 on fish can be context specific. In this talk, I will briefly outline the history of ocean acidification research on marine fishes, explore our current understanding of the field, including major knowledge gaps and uncertainties, and discuss new studies that are testing the potential of marine fish to adapt to ocean acidification.

A18.11 PARENTAL EFFECTS ON HERITABILITY OF HIGH CO_2 TOLERANCE IN A CORAL REEF FISH

TUESDAY 10 APRIL 2018 14:30

ALISON A MONROE (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA), MEGAN J WELCH (JAMES COOK UNIVERSITY, AUSTRALIA), CELIA SCHUNTER (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA), MICHAEL L BERUMEN (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA), PHILIP L MUNDAY (JAMES COOK UNIVERSITY, AUSTRALIA), TIMOTHY RAVASI (KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA)

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In fish, response to alarm cue can be impaired by ocean acidification. For the common damselfish, *Acanthachromis polyacanthus*, individual variation in this behaviour and in the brain transcriptional program were previously observed: some individuals displayed higher tolerance to elevated CO_2 than others which was also passed to their offspring. However, little is known about maternal and paternal influences of this variation on CO_2 tolerance. To investigate this, we crossed CO_2 tolerant fathers with CO_2 sensitive mothers and CO_2 tolerant mothers with CO_2 sensitive fathers. We then reared their offspring at current day (414 µatm) or end-of-the century (754 µatm) CO_2 levels for 6 weeks, as well as acutely exposed them to elevated CO_2 (754 µatm) at 6 weeks of age. To investigate the effects of parental phenotype on the transcriptional program of the offspring 68 brain transcriptomes were sequenced and differential gene expression was analysed. Our analysis revealed a distinct expression profile in offspring from different parental pairs across all offspring treatments. Interestingly, we found similar numbers of differentially expressed genes (~200-400) in offspring with different parental combinations and also in offspring under different treatments. This suggests strong parental influence on gene expression and shows similar magnitudes of transcriptional changes in response to the environment and/or parental phenotype. Our findings add to the knowledge of the capacity of coral reef fish to acclimate to rising CO_2 levels in the ocean and the underlying molecular mechanisms of parental influence on this acclimation.

A18.12 THE EFFECTS OF ELEVATED CO_2 ON THE PREDATORY BEHAVIOURS OF TWO SPECIES OF TROPICAL CEPHALOPOD

TUESDAY 10 APRIL 2018 14:45

BLAKE L SPADY (JAMES COOK UNIVERSITY, AUSTRALIA), SUE-ANN WATSON (ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, TOWNSVILLE, AUSTRALIA), PHILIP L MUNDAY (ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, TOWNSVILLE, AUSTRALIA)

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There is increasing evidence that projected near-future carbon dioxide (CO_2) levels can alter predator avoidance behaviour in marine invertebrates, yet little is known about the possible effects on predatory behaviours. Here we tested the effects of elevated CO_2 on the predatory behaviours of two ecologically distinct cephalopod species, the pygmy squid, *Idiosepius pygmaeus*, and the bigfin reef squid, *Sepioteuthis lessoniana*. Both species exhibited an increased latency to attack and altered body-pattern choice during the attack sequence at elevated CO_2. *I. pygmaeus* also exhibited a 20% decrease in predation rate, an increased striking distance, and reduced preference for attacking the posterior end of prey at elevated CO_2. Elevated CO_2 increased activity levels of *S. lessoniana* comparable to those previously shown in *I. pygmaeus*, which could adversely affect their energy budget and increase their potential to be preyed upon. The effects of elevated CO_2 on predatory behaviours, predation strategies and activity levels of cephalopods reported here could have far-reaching consequences in marine ecosystems due to the ecological importance of cephalopods in the marine food web.

A18.13 DIEL CO_2 CYCLES REDUCE SEVERITY OF BEHAVIOURAL ABNORMALITIES IN CORAL REEF FISH UNDER OCEAN ACIDIFICATION

TUESDAY 10 APRIL 2018 15:00

MICHAEL JARROLD (JAMES COOK UNIVERSITY, AUSTRALIA), CRAIG HUMPHREY (AUSTRALIAN INSTITUTE OF MARINE SCIENCE, AUSTRALIA), MARK MCCORMICK (JAMES COOK UNIVERSITY, AUSTRALIA), PHILIP MUNDAY (ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, AUSTRALIA)

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Elevated CO_2 levels associated with ocean acidification (OA) have been shown to consistently alter behavioural responses in coral reef fish. However, all studies to-date have used stable pCO_2 treatments, not considering the substantial diel pCO_2 cycles that occur on shallow reef habitats. Here, we reared juvenile damselfish, *Acanthochromis polyacanthus*, and clownfish, *Amphiprion percula*, in are series of stable (500, 750 and 1000 µatm) and diel fluctuating (750 ± 300, 1000 ± 300 and 1000 ± 500 µatm) pCO_2 treatments in two experiments. As expected, lateralization of *A. polyacanthus* and response to predator cue of *Am. percula* were negatively affected in fish reared at stable, elevated pCO_2 in both experiments. However, diel pCO_2 fluctuations alleviated the negative effects of OA on behaviour, although, the extent of alleviation was dependent on the magnitude of fluctuation, mean pCO_2 level experienced and the behavioural trait. Importantly, in experiment two, behavioural abnormalities that were present in fish reared at 750 µatm CO_2 were absent in fish reared at 750 ± 300 µatm CO_2. Overall, we show that diel pCO_2 cycles can substantially reduce the severity of behavioural abnormalities caused by elevated CO_2. Thus, past studies may have over-estimated the impacts of OA on the behavioural performance of coral reef fishes. Furthermore, our results suggest that diel pCO_2 cycles will delay the onset of behavioural abnormalities in natural populations.

A18.14 NEUROPHYSIOLOGICAL MECHANISMS LINKING HIGH-CO_2 WITH ALTERED BEHAVIOUR

TUESDAY 10 APRIL 2018 15:45

GÖRAN E NILSSON (UNIVERSITY OF OSLO, NORWAY)

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Several species of fish, including damselfishes, wrasses, salmonids, gobies, stickleback, rockfish, and sharks, show maladaptive behaviours when exposed to projected future CO_2 levels. The altered behaviours include olfactory and auditory responses, swimming activity, lateralization, cleaning, retinal function and learning. Where it has been examined, the behavioural changes have been linked to an altered function of the major inhibitory neurotransmitter receptor in brain: the $GABA_A$ receptor. It has been suggested that pH regulatory mechanisms lead to altered gradients of chloride and bicarbonate over neuronal membranes, which drives the $GABA_A$ receptor in the direction of becoming excitatory. It is the carbonation, rather than the acidification, that is likely to be the culprit, since gills are highly permeable to CO_2 while essentially impermeable to H^+. Recently, it has been revealed that elevated CO_2 exposure in damselfish leads to altered transcription of most genes involved in regulating GABA function, with the changes being in the direction of increased GABAergic signaling. This could add to the initial ion disturbance by initiating a vicious cycle where homeostatic mechanisms in neuronal circuits strive to counteract the reduced inhibitory input by up-regulating GABA signaling, which due to the altered ion gradients unfortunately leads to more excitation rather than inhibition. It is tempting to suggest that the increase in cellular metabolism needed to fuel these over-excited circuits will lead to increased CO_2 and bicarbonate production that could further alter the ion gradients. This could explain how a relatively minor initial disturbance can lead to major changes in neural function.

A18.15 COGNITIVE AND NEUROBIOLOGICAL DISRUPTION OF CLEANING MUTUALISMS UNDER OCEAN ACIDIFICATION AND WARMING

TUESDAY 10 APRIL 2018 16:15

JOSÉ RICARDO PAULA (MARE - MARINE AND ENVIRONMENTAL SCIENCES CENTRE, PORTUGAL), REGINA BISPO (MARE - MARINE AND ENVIRONMENTAL SCIENCES CENTRE, PORTUGAL), SVANTE WINBERG (DEPARTMENT OF NEUROSCIENCE PHYSIOLOGY UNIT BIOMEDICAL CENTRE (BMC), UPPSALA UNIVERSITY, SWEDEN), PHILIP L MUNDAY (ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, JAMES COOK UNIVERSITY, AUSTRALIA), RUI ROSA (MARE - MARINE AND ENVIRONMENTAL SCIENCES CENTRE, PORTUGAL)

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Cleaning mutualisms are the textbook example of animal cooperation. On coral reefs, the iconic cleaning relationship between cleaner fish and their clients is essential for maintaining community diversity and abundance. However, cleaners can choose to collaborate or cheat, as they prefer eating mucus from their clients where possible. Cleaners are known for their remarkable cognitive abilities and sophisticated behaviour, that they use for manipulation, partner control and tactical deception of their partners. However, the ecological conditions where cleaners were able to evolve their cognitive abilities are changing due to human-induced environmental changes. Here we show that acclimation to ocean acidification and warming conditions decreased cleaning motivation and the quality of interactions between cleaners and clients. Moreover, using a well-known cognitive task derived from the biological market theory, we observed a substantial impairment in cleaner wrasse cognition abilities when exposed to elevated CO_2. At the molecular level, dopamine, serotonin and norepinephrine concentrations (and respective turnovers) were significantly affected by these stressors. Elevated CO_2 interacted with dopamine impairing the cleaners' and clients' perception and with serotonin and norepinephrine modulating motivation for interaction. On the other hand, warming affected synaptic activity in both mutualist partners. We advocate that the breakdown of cleaning mutualisms will affect the maintenance of local community structures on coral reefs.

A18.16 TEMPERATE AND CORAL REEF FISHES SHOW NEGLIGIBLE PHYSIOLOGICAL AND BEHAVIOURAL RESPONSES TO ELEVATED CO_2

TUESDAY 10 APRIL 2018 16:30

FREDRIK JUTFELT (NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY, NORWAY), TIMOTHY D CLARK (DEAKIN UNIVERSITY, AUSTRALIA), GRAHAM D RABY (UNIVERSITY OF WINDSOR, CANADA), SANDRA BINNING (UNIV. OF MONTRAL MONTREAL, CANADA), DOMINIQUE G ROCHE (UNIV. OF NEUCHÂTEL, SWITZERLAND), BEN SPEERS-ROESCH (UNIV. OF NEW BRUNSWICK SAINT JOHN, CANADA), JOSEFIN SUNDIN (NORWEGIAN UNIV. OF SCIENCE AND TECHNOLOGY TRONDHEIM, NORWAY)

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Much of the anthropogenically released carbon dioxide dissolves in the ocean, causing ocean acidification. Exposure to predicted end-of-century CO_2 levels has been reported to affect the physiology and behaviour of marine fishes, which could have detrimental consequences for population viability in the future. However, a growing number of studies report no physiological or behavioural changes, suggesting species- or experiment-specific effects and a far from complete understanding of the true impacts of ocean acidification. We investigated the possible effect of both short- and long-term exposure to ~1000 µatm CO_2 on fish physiology and behaviour, using in total 13 different species of wild-caught temperate and tropical fishes. We filmed all trials and used automated measurements to ensure objectivity and transparency. We did not detect any significant impairments in the physiology or behaviour of any of the species, revealing that all species were resilient to CO_2 exposure. Further, we found no evidence to suggest a role of ocean acidification in the interference of GABA-A neurotransmitter function. Our findings highlight the need for independent replication before we can reach a consensus on the ecological and physiological effects of ocean acidification on fishes.

A18.17 INTERTIDAL OYSTERS REACH THEIR PHYSIOLOGICAL LIMIT IN A FUTURE HIGH-CO_2 WORLD

TUESDAY 10 APRIL 2018 16:45

ELLIOT SCANES (UNIVERSITY OF SYDNEY, AUSTRALIA), LAURA M PARKER (UNIVERSITY OF SYDNEY, AUSTRALIA), WAYNE A O'CONNOR (NSW DEPARTMENT OF PRIMARY INDUSTRIES, AUSTRALIA), LAURA STAPP (ALFRED WEGENER INSTITUTE HELMHOLTZ INSTITUTE FOR POLAR AND MARINE RESEARCH, GERMANY), PAULINE M ROSS (UNIVERSITY OF SYDNEY, AUSTRALIA)

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Marine molluscs living in the intertidal zone experience internal acidosis when exposed to air (emersion) at low tide. Relative to other marine organisms, molluscs have been identified as vulnerable to future ocean acidification; however, paradoxically it has also been shown that molluscs exposed to high CO_2 environments are more resilient compared with those molluscs naive to CO_2 exposure. Two competing hypotheses were tested using a novel experimental design incorporating tidal simulations to predict the future intertidal limit of oysters in a high-CO_2 world; either high-shore oysters will be more tolerant of elevated PCO_2, or elevated PCO_2 will cause high-shore oysters to reach their limit. Sydney rock oysters, Saccostrea glomerata, were collected from the high-intertidal and subtidal areas of the shore and exposed in an orthogonal design to either an intertidal or a subtidal treatment at ambient or elevated PCO_2, and physiological variables were measured. The combined treatment of tidal emersion and elevated PCO_2 interacted synergistically to reduce the extracellular pH (pH_e) of oysters, and increase the PCO_2 in the haemolymph ($P_e CO_2$) and standard metabolic rate. Oysters in the intertidal treatment also had lower condition and growth. Oysters showed a high degree of plasticity, and little evidence was found that intertidal oysters were more resilient than subtidal oysters. It is concluded that in a high-CO_2 world the upper vertical limit of oyster distribution on the shore may be reduced. These results suggest that previous studies on intertidal organisms that lacked tidal simulations may have underestimated the effects of elevated PCO_2.

A18.18 PHYSIOLOGICAL PERFORMANCE IN A HIGH CO_2 WORLD – THE ROLE OF MAINTAINING OXYGEN TRANSPORT IN FISH

TUESDAY 10 APRIL 2018 17:00

JODIE L RUMMER (JAMES COOK UNIVERSITY ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, AUSTRALIA), KELLY D HANNAN (JAMES COOK UNIVERSITY ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, AUSTRALIA), JACOB L JOHANSEN (NEW YORK UNIVERSITY, ABU DHABI MARINE BIOLOGY LABORATORY, UNITED ARAB EMIRATES), RASMUS ERN (UNIVERSITY OF TEXAS MARINE SCIENCE INSTITUTE, UNITED STATES), PHILIP L MUNDAY (JAMES COOK UNIVERSITY ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES, AUSTRALIA), ANDREW J ESBAUGH (UNIVERSITY OF TEXAS MARINE SCIENCE INSTITUTE, UNITED STATES)

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The physiological responses of model fish species to elevated CO_2 have been investigated for decades. Yet, target pCO_2 levels (>10,000 µatm) often reach far beyond predicted for mid- and end-of-century (500-1,200 µatm) climate change scenarios. Recently, a mechanism involving Root effect haemoglobins that are unique to teleost fishes and plasma-accessible carbonic anhydrase (CA) was characterized in salmonids, whereby oxygen release to red muscle was enhanced when fish were exposed to elevated CO_2 conditions (>15,000 µatm). This may explain why fish species that have been tested under climate change relevant CO_2 conditions exhibit either maintained or even enhanced physiological performance. We tested this hypothesis in two coral reef fish species where – as with other reef fishes – oxygen uptake rates and aerobic scope have either been unaffected or positively affected under elevated CO_2. Though inhibiting CA (via C18 injection) had no effect on swimming performance, fish maintained under elevated pCO_2 for at least 14 d exhibited higher critical swimming speeds (Ucrit) than control counterparts, and CA gene expression patterns increased five- to six-fold in red muscle and heart, respectively. Both tissues are thought most relevant to maintaining or enhancing aerobic performance. Interestingly, gene expression patterns in the heart may have been responding earlier than those in the red muscle, with a three-fold increase within 8 h exposure to elevated CO_2. The daily fluctuations in pCO_2 that reef fishes experience due to photosynthesis/respiration patterns of the coral and the benthos may play a role in the temporal aspects of this response with relevance to energy savings.

A18.19 CONSEQUENCES AND CONTROL OF DISSOLVED CARBON DIOXIDE IN INTENSIVE AQUACULTURE SYSTEMS

WEDNESDAY 11 APRIL 2018 **09:15**

CHRISTOPHER GOOD (THE CONSERVATION FUND'S FRESHWATER INSTITUTE, UNITED STATES), JOHN DAVIDSON (THE CONSERVATION FUND'S FRESHWATER INSTITUTE, UNITED STATES), BRIAN VINCI (THE CONSERVATION FUND'S FRESHWATER INSTITUTE, UNITED STATES), STEVEN SUMMERFELT (THE CONSERVATION FUND'S FRESHWATER INSTITUTE, UNITED STATES)

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Previous research has demonstrated that elevated dissolved carbon dioxide (CO_2) in aquaculture settings is associated with reduced fish growth performance and feed conversion efficiency, lower survival, and higher incidence of pathologies such as nephrocalcinosis. Many of these negative outcomes are consequences of alterations in blood pH and ion concentration, as well as decreased haemoglobin oxygen binding and carrying capacity. In water recirculation aquaculture systems (RAS) with high feed loadings and utilizing pure oxygen, CO_2 production is increased, and CO_2 will accumulate to detrimental levels unless efficient gas conditioning technologies are applied, and water recirculation flows are sufficient to maintain reasonably low culture tank hydraulic retention times. This presentation will describe the physiological consequences of fish exposed to both short- and long-term elevated CO_2, as well as methods employed to maintain CO_2 at safe levels in intensive aquaculture facilities. Results from on-site research, focusing on Atlantic salmon *Salmo salar* and rainbow trout *Oncorhynchus mykiss*, will be presented, and will be compared to findings from similar, previously published studies, as well as observations from industry. While elevated CO_2 can be an issue in any aquaculture setting, given the recent growth of land-based fish production this presentation will focus on salmonids grown to market size in modern facilities utilizing RAS technologies.

A18.20 EFFECTS OF HIGH ENVIRONMENTAL CO_2 LEVELS ON ATLANTIC SALMON POST-SMOLTS

WEDNESDAY 11 APRIL 2018 **09:45**

TOM O NILSEN (UNI RESEARCH ENVIRONMENT, NORWAY), BENDIK F TERJESEN (NOFIMA, NORWAY), JELENA KOLAREVIC (NOFIMA, NORWAY), ELISABETH YTTEBORG (NOFIMA, NORWAY), LARS O E EBBESSON (UNI RESEARCH ENVIRONMENT, NORWAY), SIGURD O HANDELAND (UNI RESEARCH ENVIRONMENT, NORWAY), VASCO C MOTA (NOFIMA, NORWAY)

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Atlantic salmon has demonstrated the capacity to physiologically acclimate when exposed to increased P_{CO_2} levels in aquaculture flow-through systems. Less is known about tolerance to increased P_{CO_2} in Recirculation Aquaculture System (RAS). In the present study, Atlantic salmon post-smolt in a RAS in Sunndalsøra, Norway, were kept at 12 ppt (12°C) and exposed to six different P_{CO_2} levels ranging from <5 mg/L (P_{CO_2} <1.83 mm Hg), 12 mg/L (P_{CO_2} =4.40 mm Hg), 19 mg/L (P_{CO_2} =6.94 mm Hg), 26 mg/L (P_{CO_2} =9.50 mm Hg), 33 mg/L (P_{CO_2} =12.06 mm Hg) and 40 mg/L (P_{CO_2} =14.61 mm Hg). After 12 week treatments fish were transferred to full strength seawater with the lowest tested P_{CO_2} level. We found that post-smolts demonstrated a classic transient physiological compensatory response to cope with elevated P_{CO_2}, despite a clear and persistent decrease in growth rate when reared above 19 mg/L CO_2. After twelve weeks of variable P_{CO_2} exposures post-smolt were challenged with rapid changes from high (40 mg/L) to low (5 mg/L) P_{CO_2} levels and vice-versa. Here we also will present physiological compensatory responses 1 and 24 hours and up to 6 days following rapid changes in CO_2 exposure.

A18.21 THE EFFECT OF CARBON DIOXIDE ON FISH GROWTH PERFORMANCE IN RECIRCULATING AQUACULTURE SYSTEMS

WEDNESDAY 11 APRIL 2018 **10:00**

KEVIN T STILLER (NOFIMA AS, NORWAY), TOM O NILSEN (UNI RESEARCH AS, NORWAY), VASCO C MOTA (NOFIMA AS, NORWAY), JASCHA GERWINS (NOFIMA AS, NORWAY), MICHELE GALLO (WAGENINGEN UNIVERSITY, NETHERLANDS), ELIZABETH YTTEBORG (NOFIMA AD, NORWAY), GRETE BAEVERFJORD (NOFIMA AS, NORWAY), JELENA KOLAREVIC (NOFIMA AS, NORWAY), STEVEN T SUMMERFELT (THE CONSERVATION FUND'S FRESHWATER INSTITUTE, UNITED STATES), BENDIK F TERJESEN (NOFIMA AS, NORTHERN MARIANA ISLANDS)

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Long term saltwater dissolved CO_2 exposure experiments in recirculating aquaculture (RAS) settings are rare and the reported growth and health effects can be vague. The used measuring equipment and differences in water chemistry induced by CO_2 as an on-ideal gas make a comprehensive effect assessment difficult. Most studies are usually test three CO_2 concentrations, which limits a detailed concentration vs. growth relationship analysis. Nofimas CO2RAS project was designed to evaluate the CO_2 effects on Atlantic salmon post-smolts in RAS. The first experiment investigated a chronic CO_2 exposure over 12-weeks using concentrations of 5(2500), 12(6000), 26(13000), 33(16000) and 40(20000) mg/L(µatm) (Salinity=12 ppt, Temperature=12,5 °C). Growth results fit nicely in a linear model whereas a reduction in growth started already at 12 mg/L. Based on these findings, a reduced growth of >10% can be predicted between 5 and 20 mg/L (typical RAS production conditions). Cataract formation, kidney nephrocalcinosis and morphological damage did not differ between the treatments. However, skin analysis showed that fish exposed to high CO_2 concentrations had a significantly thinner dermis layer. For a more comprehensive understanding of the multifactorial CO_2 effects on teleosts an interspecies comparison of similar experimental setups will be presented to pinpoint common, species specific or experimental CO_2 effects. It could be that even the current Atlantic salmon production recommendation at ≤15 mg/L CO_2 had a negative influence on welfare and growth. Contrasting results from long-term studies indicate that there is a need for including CO_2 feedback reactions with the rearing environment to provide threshold recommendations.

A18.22 LONG TERM CARBON DIOXIDE EXPERIMENTS WITH SALMONIDS – DURING 25 YEARS

WEDNESDAY 11 APRIL 2018 **10:15**

SVEINUNG FIVELSTAD (WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES, NORWAY), CAMILLA HOSFELD (WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES, NORWAY)

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During the last 25 years several long-term carbon dioxide experiments on Atlantic salmon parr, smolts and postsmolts have been performed at Western Norway University of Applied Sciences. The experiments are divided into experiments in soft water, experiments in hard fresh water and in seawater. In low alkalinity fresh water carbon dioxide has adverse effects on fish in combination with labile Al/pH at concentrations around 8-10 mg L^{-1} carbon dioxide, and the smolts are not acclimated to such conditions. In a recent experiment on postsmolts, specific growth rate (SGR) decreased linearly as a function of carbon dioxide partial pressure in the range 0.6 – 12 mmHg ($p < 0.05$), during the last part of the experiment. This period lasted only for 12 days and stress related to weight sampling and blood sampling (although cautious catching of the fish), may have added to the effect of carbon dioxide, indicating that fish exposed to increased carbon dioxide, is more susceptible to other factors and vice versa. Postsmolts exposed to carbon dioxide levels above 8 mmHg had increased incidence of nephrocalcinosis ($p < 0.05$). This means that how experiments are performed may strongly influence the conclusions in carbon dioxide research, and also that nephrocalcinosis may be an important parameter.

A18.23 USING FUNDAMENTAL PHYSIOLOGY TO TACKLE HIGH CO_2 ASSOCIATED PROBLEMS IN AQUACULTURE

WEDNESDAY 11 APRIL 2018 **11:00**

ROD W WILSON (UNIVERSITY OF EXETER, UNITED KINGDOM)

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Elevated CO_2 levels, far higher than end-of-century climate change predictions for natural ecosystems, are typical for intensive aquaculture. Intensive aquaculture and the water management processes often used (especially in recirculating aquaculture systems or RAS) result in further atypical water chemistry variables (e.g. alkalinity, calcium, salinity) for fish and invertebrates. Several decades of fundamental physiology research, and more recent climate change research, have shown how CO_2 can affect acid-base regulation and blood oxygen transport. Calcium has a powerful modulatory influence on gill permeability and ion/acid-base regulatory functions, whilst environmental sodium and chloride act as the main counter-ions for excreted H^+ and HCO_3^-, respectively, during active acid-base regulation such as during exposure to elevated CO_2. In calcifying invertebrates, environmental calcium and alkalinity (i.e. HCO_3^- and CO_3^{2-}) are also key variables determining the rate of calcification, which needs to be especially rapid in post-moult crustaceans. One major issue that is relevant to high CO_2 conditions in aquaculture but not sufficiently considered, is the post-feeding blood alkalosis that occurs in fish that have an acid-secreting stomach. This may create a conflict between the retention of bicarbonate (required to compensate acidosis in a high CO_2 environment) and excretion of bicarbonate (required during recovery from the post-feeding "alkaline tide"). This may have repercussions for digestive function, energy expenditure, growth efficiency and pathologies sometimes found in aquaculture. I will discuss how physiology can play a potentially important role in improving growth (moulting in crustaceans), health and welfare in the high CO_2 world of aquaculture.

A18.24 MECHANISMS AND PATTERNS OF ACID-BASE REGULATION IN FISH EXPOSED TO HIGH ENVIRONMENTAL CO_2

WEDNESDAY 11 APRIL 2018 **11:30**

COLIN J BRAUNER (UNIVERSITY OF BRITISH COLUMBIA, CANADA), RYAN B SHARTAU (UNIVERSITY OF BRITISH COLUMBIA, CANADA)

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Acid-base regulation is one of the most tightly regulated physiological processes and pH disturbances are rapidly corrected to restore homeostasis and animal function. In most fish investigated to date, acute (up to 96 h) exposure to elevated environmental CO_2 (hypercarbia) results in a rapid reduction in both blood pH (pHe) and tissue intracellular pH (pHi). pHe recovers in association with an elevation in plasma HCO_3^- which is matched by an equimolar reduction in plasma Cl^-, a pattern observed in both freshwater and marine fishes. pHi recovers in association with pHe recovery but the latter is generally limited to about 2 kPa CO_2 by an "apparent HCO_3^- threshold". Many natural freshwater environments (as well as in aquaculture) routinely experience CO_2 levels far in excess of this value (up to 6-8 kPa). In some fish, severe hypercarbia (>6 kPa) results in a large, sustained reduction in pHe (> 1 pH unit) but, remarkably, there is no change in pHi of crucial tissues such heart, brain, liver or muscle, termed preferential pHi (ppHi) regulation. ppHi regulation is rapid (within minutes) and appears to be associated with CO_2 tolerance in fishes. In a recent survey, of 20 species that span a broad phylogeny containing temperate and tropical species, as well as water and air-breathing fishes, 18 exhibited ppHi regulation and thus, we hypothesize this trait may be wide spread among fishes. By conferring hypercarbia tolerance, ppHi regulation may have been a key exaptation that facilitated important evolutionary transitions in vertebrate evolution.

A18.26 THE EFFECTS OF HYPERCAPNIA ON INTENSIVELY FARMED AIR-BREATHING FISH

WEDNESDAY 11 APRIL 2018 **11:45**

MARK BAYLEY (ZOOPHYSIOLOGY AARHUS UNIVERSITY, DENMARK), MIKKEL THOMSEN (ZOOPHYSIOLOGY AARHUS UNIVERSITY, DENMARK), DO T T HUONG (CAN THO UNIVERSITY, VIETNAM)

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Levels of CO_2 in freshwater systems can be elevated far above atmospheric equilibrium as a result of the geology or soil drainage of the river basin. Further, in the tropics, PCO_2 in freshwater systems can be greatly enhanced as a result of organic loading, plant coverage and sluggish water mixing with numerous recordings in excess of 80,000 µatm. In the intensive tropical aquaculture of air-breathing fish of the Mekong delta, PCO_2 >30,000 µatm is a common occurrence in the latter half of the growth cycle. Concentrating on the economically important *Pangasianodon hypophthalmus*, the effects of CO_2 on gill ventilation and air-breathing, acid base status, fish behavior, oxygen uptake and growth will be presented. Elevations in PCO_2 to 30,000 µatm have little influence on ventilation, standard metabolic rate, maximum oxygen uptake or aerobic scope. This fish is an excellent regulator of extracellular pH resulting in very high plasma bicarbonate levels towards the end of the growth cycle in aquaculture ponds. Growth is unaffected by exposure to constant 30,000 µatm but preliminary data indicate that fluctuating CO_2 levels may have a negative impact. The data will be discussed in the context of tropical freshwater environments and in an evolutionary perspective.

A18.27 WHAT ABOUT THE OTHER HIGH PCO_2 WORLD – INSIDE YOUR FISH?

WEDNESDAY 11 APRIL 2018 **12:00**

CHRIS M WOOD (UNIVERSITY OF BRITISH COLUMBIA, CANADA), JUNHO EOM (UNIVERSITY OF BRITISH COLUMBIA, CANADA)

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There is concern about the increased ambient PCO_2 levels (0.1 kPa, 0.75 torr) that fish may face in a future world, and the higher levels (1 kPa, 7.5 torr) often seen in intensive aquaculture. However it has been overlooked that they may routinely encounter even greater PCO_2 levels in their own digestive tracts. Indeed in humans, the PCO_2 of flatus averages 35 kPa, about 6-fold higher than normal blood PCO_2 levels. This occurs because of the generation of CO_2 in the chyme by bacterial metabolism, and by the neutralization of secreted H^+ by secreted HCO_3^- and basic components of the meal. Is the same true in fish, and if so, what are the consequences for blood perfusing the highly vascularised digestive tract? We are aware of no previous direct measurements in fish chyme, but PCO_2 values ranging from 1-13 kPa (7.5-95 torr) may be estimated from published studies on four species. However these are based on applying the Henderson-Hasselbalch equation to pH and HCO_3^- levels in chyme sampled from fish after sacrifice. With this background in mind, we are presently undertaking a series of direct PCO_2 and pH measurements in the digestive tracts, blood, and peritoneal cavities of live rainbow trout and goldfish, both fasted and fed a common pellet diet, to test these ideas using a new generation of prototype needle-tip optical PCO_2 sensors and esophageal pH electrodes. The trout is a carnivore with an HCl-secreting stomach and the goldfish is an agastric omnivore (NSERC Discovery, Presens GmbH).

A18.28 CARBON DIOXIDE AND FRESHWATER FISH: INSIGHTS FROM BARRIER APPLICATIONS

WEDNESDAY 11 APRIL 2018 **13:30**

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Carbon dioxide levels (CO_2) in freshwater have the potential to increase in the future due to several mechanisms. Our group has been quantifying the impacts of elevated CO_2 on freshwater fishes, mainly in the context of the intentional generation of CO_2 plumes to deter the movements of invasive fishes (e.g., Bigheaded Carp). Results from these studies indicate that some of the impacts of elevated CO_2 observed in marine fishes also occur in freshwater fishes, including an impaired alarm cue response, impaired activity patterns, and a suite of physiological disturbances. However, some responses seen in the marine environment (e.g., loss of lateralization) were not observed in freshwater fishes following extended exposure to elevated CO_2, and impairments observed often abated when animals were returned to baseline CO_2 levels. We have also found that extended exposure to elevated carbon dioxide results in improved tolerance, and that tolerance to CO_2 exposure is repeatable and related to aspects of metabolic phenotype. These results are further discussed in the context of CO_2 in freshwater environments and the application of CO_2 as a management tool.

A18.29 THE EFFECTS OF WATER CHEMISTRY IN RECIRCULATED AQUACULTURE SYSTEMS ON THE OLFACTION OF EUROPEAN SEA BASS

WEDNESDAY 11 APRIL 2018 **14:00**

COSIMA S PORTEUS (UNIVERSITY OF EXETER, UNITED KINGDOM), ROBERT P ELLIS (UNIVERSITY OF EXETER, UNITED KINGDOM), ROD W WILSON (UNIVERSITY OF EXETER, UNITED KINGDOM)

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Fish exposed to end-of-the-century levels of CO_2 show altered sensory behaviour that is likely to affect survival of both individuals and populations in the wild. Recently we have found that elevated CO_2 /low pH seawater (~1000 µatm/pH 7.85) can have a direct negative effect on the olfactory sensitivity of European sea bass *(Dicentrarchus labrax)*, an economically important species, including a reduced response to certain odorants by up to 50%. The aquaculture production of European sea bass has been steadily increasing from 4,000 to 157,000 tonnes between the 1990s and 2014. Aquaculture production of sea bass ranges from coastal net-pens to land-based tank systems, all of which maintain fish at high densities. The water chemistry in recirculated aquaculture systems (RAS) can have much higher pCO_2 than is predicted for natural environments (3,000-17,000 µatm) while maintaining pH to relatively normal levels (~7.95) by buffering with added alkalinity. An impaired sense of smell has the potential to pose a welfare concern for farmed fish. Therefore, we have explored the effects of this altered water chemistry on olfaction in sea bass using nerve recording in anaesthetised fish.

A18.30 MODELLING BEHAVIOUR MEDIATING CUES IN HIGH CO_2 CONDITIONS

WEDNESDAY 11 APRIL 2018 **14:15**

CHRISTINA C ROGGATZ (UNIVERSITY OF HULL, UNITED KINGDOM), JÖRG D HARDEGE (UNIVERSITY OF HULL, UNITED KINGDOM), DAVID M BENOIT (UNIVERSITY OF HULL, UNITED KINGDOM)

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Many interactions of aquatic organisms rely on chemical signalling molecules. Behaviours, such as brood care, settlement or foraging, are mediated by these chemical cues and depend on their successful reception by the organism. Most biological molecules with signalling function possess functional chemical groups that are sensitive to changes in pH. High CO_2 conditions in aquatic environments, however, lead to a reduction in pH and could therefore impact the functional groups of the signalling cues, causing significant molecular changes. Here we present an overview of the functional groups affected by pH and illustrate them by a number of examples including amino acids and peptides known to mediate key behaviours of aquatic organisms. We describe a set of systematic approaches to assess the molecular effects of changing pH using NMR spectroscopy and computational chemistry, which enable us to predict the cues' properties essential for successful recognition by the receptor in high CO_2 conditions, such as conformation and charge distribution. We further highlight the challenges associated with the realistic modelling of signalling cues and compare our results to bioassay data in order to illustrate their biological relevance. We conclude that modelling the pH-sensitivity of signalling cues can provide new mechanistic insights into the effects of pH at molecular level. As high CO_2 conditions pose a threat to a range of aquatic environments and frequently occur in the aquaculture industry, our approach provides a toolbox with numerous potential applications for biological questions.

A18.31 SLIGHT DIFFERENCES IN COMMUNITY STRUCTURE AND BIODIVERSITY OF FISH ASSOCIATED TO A CYMODOCEA NODOSA MEADOW IN A SHALLOW CO_2 VENT

WEDNESDAY 11 APRIL 2018 **14:30**

ALICE MIRASOLE (UNIVERSITY OF PALERMO, ITALY), GERALDINA SIGNA (UNIVERSITY OF PALERMO, ITALY), PAOLA GIANGUZZA (UNIVERSITY OF PALERMO, ITALY), CHIARA BONAVIRI (UNIVERSITY OF PALERMO, ITALY), ANTONIO MAZZOLA (UNIVERSITY OF PALERMO, ITALY), SALVATRICE VIZZINI (UNIVERSITY OF PALERMO, ITALY)

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Naturally acidified environments are used to test ecological hypotheses about the effects of ocean acidification on complex communities. Here, we used a shallow Mediterranean CO_2 vent to study the coastal fish assemblages associated to Cymodocea nodosa seagrass meadows, long-term exposed to high pCO_2 / low pH conditions. In particular, by using underwater visual census method, we assessed the structure and the biodiversity of fish assemblages living in a low pH site and in two control sites, in two periods of the year featured by dissimilar seagrass structure. The aim of this study was to test the effect of different pH on fish assemblages mediated by the habitat-forming structural species C. nodosa. Contrary to expectations, fish assemblages exposed to acidified conditions did not reveal striking differences, both in the community structure and in biodiversity, compared with both controls. Furthermore, a general higher abundance of small-sized individuals was found in the low pH site. Spatial and temporal patterns indicated that these differences cannot be addressed to C. nodosa meadow structure at different pH conditions. Moreover, current findings suggest that fish may exploit the vent area above all for its enhanced food resources and that detrimental effects of acidification can be overcome by fish mobility, using the closer control area as a 'recovery zone'. Therefore, although fish may be able to withstand the projected lowering of pH, indirect effects of acidification (i.e. food resources alteration) could exacerbate changes in fish assemblages.

A18.32 DISEASE AS THE MAJOR BARRIER TO SUSTAINABLE AQUACULTURE PRODUCTION TO 2050

WEDNESDAY 11 APRIL 2018 **15:15**

DAVID BASS (CEFAS AND NATURAL HISTORY MUSEUM, UNITED KINGDOM), GRANT STENTIFORD (CEFAS, UNITED KINGDOM)

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By 2050, global production from aquaculture is set to double as yield from fisheries flatlines. Aquaculture will make an increasingly important contribution to the future global diet. Disease in aquaculture is considered widely as the number one barrier to achieving this growth. Infectious microbial diseases continue to impose major yield-limiting effects on production with overall impact of these diseases exceeding $6bn per annum. In specific sectors (e.g. shrimp), losses may exceed 40 % of global capacity with emergent diseases having potential to collapse national/ regional production. Even more so than terrestrial systems, aquatic environments impose a constant risk of exposure to disease-causing pathogens. An historic poor knowledge of background microbial 'diversity' in aquatic farm systems leads to frequent emergence of previously unknown diseases, surprising farmers and creating shock in the wider value chain. Some remain restricted to specific geographies while others rapidly spread to distant regions with trade and, impose long term (often decadal) economic and social effects, often in the world's poorest farming communities. To break the cycle of emergence, spread, persistence and effect, new thinking is needed. Recent work from our team has challenged the current paradigm, proposing that focus should be increasingly placed on the interaction between host-pathogen-environment nexus for managing infectious diseases. In particular, understanding the specific conditions (e.g. water quality, CO_2) which drive microbial changes in the aquaculture environment and host, facilitating development of disease. By re-focussing efforts to this 'pre-emergent' phase, we envisage an era of reduced impact of infectious disease in global aquaculture.

A18.33 EFFECT OF OCEAN ACIDIFICATION ON WHITE SPOT SYNDROME VIRUS (WSSV) REPLICATION IN JUVENILE EUROPEAN LOBSTER *(HOMARUS GAMMARUS)*

WEDNESDAY 11 APRIL 2018 15:45

MATTHEW B SANDERS (CEFAS, UNITED KINGDOM), KELLY S BATEMAN (CEFAS, UNITED KINGDOM), ROSE C KERR (CEFAS, UNITED KINGDOM), CRAIG STENTON (CEFAS, UNITED KINGDOM), NICK GH TAYLOR (CEFAS, UNITED KINGDOM), GRANT D STENTIFORD (CEFAS, UNITED KINGDOM)

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Since the industrial revolution, CO_2 from anthropogenic activity has altered seawater carbonate chemistry. These changes will affect species that rely on carbonate saturation states to maintain their structures. This will impact aquaculture. Ocean acidification (OA) is known to have adverse effects on the physiology and biochemistry of some cultured species. Increasing global demand means that by 2030 more than 60% of global seafood will need to be supplied by aquaculture. However, there is limited evidence on the likely impacts of OA on diseases. This limits our ability to make informed decisions. This study shows preliminary results for how changes in pH and temperature can influence disease profiles in the commercially important European lobster; a species targeted for aquaculture. White Spot Syndrome Virus (WSSV) is a lethal, highly infectious viral disease normally associated with shrimp farming in Asia. Increasing water temperature and acidity resulting from climate change, combined with the higher stocking densities found in mariculture, may facilitate the introduction and spread of the WSSV. Results from this study indicate that water temperature remains a major factor influencing WSSV replication *in vivo*. Additional treatments, based on elevated atmospheric CO_2 concentrations, also influenced the replication of WSSV *in vivo*. Lower pH tended to produce higher viral loads *in vivo* but did not result in a concurrent increase in mortality. The results from this study suggest that OA could influence the prevalence, spread and pathogenicity of certain diseases. This could have significant socio-economic impacts and wider repercussions for food security.

A18.34 ELEVATED AND VARIABLE CO_2 – A CONCERN ISOLATED TO RAS OR SYNONOMUS WITH INTENSIVE AQUACULTURE GLOBALLY?

WEDNESDAY 11 APRIL 2018 16:00

ROBERT P ELLIS (UNIVERSITY OF EXETER, UNITED KINGDOM), ROD W WILSON (UNIVERSITY OF EXETER, UNITED KINGDOM)

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Exponentially rising CO_2 is a global concern (currently 400 µatm), driving climate change and causing acidification of both marine and freshwater environments. Physiologists have long known that CO_2 directly affects acid-base and ion regulation, respiratory and metabolic function. More recently, many studies have demonstrated that elevated CO_2 projected for end of this century (e.g. 800-1,000 µatm) has additional, previously unforeseen, effects on sensory and nervous system functions of fish and invertebrates, negatively impacting behaviour, fitness, and survival. Increasing alongside the human population, rising CO_2 levels not only threaten aquatic ecosystems but also global food security. Elevated CO_2 is also synonymous with intensive aquaculture. The high stocking densities commonly used in intensive production settings often elevate CO_2 levels beyond 10,000 µatm. Whilst such conditions are traditionally considered to be isolated to intensive RAS production and fin fish in particular, we demonstrate adverse carbonate chemistry is perhaps more symptomatic of aquaculture globally. Highlighting the conditions experienced across a range of production settings, and species, we discuss the importance of understanding carbonate chemistry within aquaculture ecosystems for optimising production efficiency and minimising adverse health outcomes.

A18.35 ENERGY BUDGETS IN EDIBLE CRABS STRUGGLING TO COMPENSATE FOR EXPOSURE TO ELEVATED CO_2 AND REDUCED SALINITY

WEDNESDAY 11 APRIL 2018 16:15

NIA M WHITELEY (BANGOR UNIVERSITY, UNITED KINGDOM), COLEEN C SUCKLING (BANGOR UNIVERSITY, UNITED KINGDOM), BENJAMIN J CIOTTI (PLYMOUTH UNIVERSITY, UNITED KINGDOM), JAMES BROWN (BANGOR UNIVERSITY, UNITED KINGDOM), IAN D MCCARTHY (BANGOR UNIVERSITY, UNITED KINGDOM), CHRIS HAUTON (UNIVERSITY OF SOUTHAMPTON, UNITED KINGDOM), LUIS GIMENEZ (BANGOR UNIVERSITY, UNITED KINGDOM)

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Exposure of the edible crab, *Cancer pagurus*, to near-future elevations in CO_2 levels and reduced salinity have been used to explore whether this commercial species can cope with future ocean change. Edible crabs inhabit European rocky shores from the low intertidal down to 50-100m, and prefer habitats with little variation in salinity. Predictions of future reductions in both ocean pH and salinity suggest that this species may be exposed to both changes simultaneously. We exposed juvenile crabs to four treatments (normal and elevated pCO_2; full strength and dilute seawater) in a fully factorial design, for six months. Our studies demonstrated that juvenile edible crabs were unable to compensate for CO_2-induced changes in haemolymph pH, but disruptions were less marked in crabs exposed to diluted seawater (salinity = 25). In addition, edible crabs did not engage in active, energy consuming mechanisms during exposure to either elevated CO_2, or dilute seawater, because they were unable to increase Na^+/K^+ ATPase activities in the gills. On further investigation of the energetic repercussions, we were able to demonstrate transient changes in energy budgets caused by both CO_2 and salinity, due to alterations in carbohydrate and lipid levels, while protein levels remained unchanged. The data arising from this study helps to link physiological capacities to performance in sub-littoral crustacean species normally buffered from environmental change.

A18.36 CUMULATIVE IMPACTS OF HIGH CO_2 AND LOW SALINITY ON THE BEHAVIOUR AND PHYSIOLOGY OF SHORE CRABS, *CARCINUS MAENAS*

WEDNESDAY 11 APRIL 2018 16:30

WILL DAVISON (UNIVERSITY OF EXETER, UNITED KINGDOM), GEORGIE WALKER (UNIVERSITY OF EXETER, UNITED KINGDOM), ROBERT ELLIS (UNIVERSITY OF EXETER, UNITED KINGDOM), MAURICIO URBINA (UNIVERSIDAD DE CONCEPCIÓN, CHILE), ROD WILSON (UNIVERSITY OF EXETER, UNITED KINGDOM)

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Rising atmospheric CO_2 causing ocean acidification is projected to negatively impact >50% of benthic marine invertebrate species by 2100. However, whilst negative impacts of rising CO_2 levels (hypercapnia) on organismal growth, feeding, reproduction and behaviour have been increasingly documented over the past decade, there is a dearth of research investigating the impact of hypercapnia in conjunction with other marine stressors. The green shore crab, *Carcinus maenas*, is a keystone organism on rocky shores and estuaries and has a broad range of environmental tolerances. Crabs living in the intertidal zone are periodically (tidally) exposed to air and they also voluntarily show emersion behaviour (i.e. move into air). However, the physiological triggers of this emersion behaviour are currently not known. We studied the impact of declining salinity and/or increasing CO_2 over a 6 hour period on the emersion behaviour and acid-base physiology of *C. maenas*, aiming to elucidate the physiological basis of this emersion behaviour. We found that falling salinity (from 35 down to 10 PSU), rising CO_2 (from 400 up to 4000 µatm) or their combination, all tended to increase emersion behaviour (by about 2-fold), but this was only statistically significant for salinity alone below 15 PSU. Six hours exposure to low salinity alone (7 PSU) caused a significant metabolic alkalosis while high CO_2 (4000 µatm) induced a significant respiratory acidosis. When applied together haemolymph pH was maintained at a level analogous to organisms submerged under ambient control conditions, suggesting an antagonistic action of these two stressors on blood acid-base chemistry.

A18.37 CO_2 AND THE OCEAN: AN INCREASINGLY IMPORTANT ISSUE ON GLOBAL TO LOCAL SCALES FOR GOVERNMENTS AND SOCIETY

THURSDAY 12 APRIL 2018 **09:15**

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A sustained effort of knowledge exchange by scientists around the world has resulted in a growing understanding by policy makers of the vital and major role of the ocean in the Earth system; in absorbing >90% of the heat energy from global warming, ~27% of the CO_2 emissions to the atmosphere and all the water from melting ice. These are resulting in rapid change to ocean physics and chemistry with increasingly high risk to ocean ecosystems and those dependent on them. This has resulted in major decisions to include the ocean and its ecosystems in UN goals and agreements for the first time. Here I will discuss some of them and why they are important.

A18.38 TRANSLATING OCEAN ACIDIFICATION INTO PRACTICAL APPLICATIONS TO SUPPORT AQUACULTURE AND FOOD SUSTAINABILITY

THURSDAY 12 APRIL 2018 **09:45**

SILVANA N R BIRCHENOUGH (CEFAS, UNITED KINGDOM), CRISTIAN A VARGAS (CENTRO PARA EL ESTUDIO DE FORZANTES MULTIPLES SOBRE SISTEMAS SOCIO-ECOLOGICOS MARINOS (MUSELS). UNI, CHILE), STEFAN GELCICH (CENTRO DE ECOLOGIA APLICADA Y SUSTENTABILIDAD. FACULTAD DE CIENCIAS BIOLOGICAS POTIFICA UNIVERSIDA, CHILE)

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Aquaculture is a key activity to support development goals of food provision for the increasing global population. The rise of production has grown steadily over the past decades, surpassing the rate of global population growth and being an effective food production alternative. Aquaculture activities cover several species, including fish (66.6 million tons/yr), algae (23.8 tons/yr) and molluscs (15.1 tons/yr). This overall trend may account for 60% of seafood by 2030. Aquaculture production (~53%) now comes from the ocean's coasts and estuaries. As a large fraction of the world's population inhabits the coastal zones and these are highly exposed to anthropogenic impacts. However, one of the major changes affecting the oceans is due to the increase in CO_2 in the atmosphere over the past century. These increased atmospheric CO_2 concentrations are absorbed by the ocean, resulting in changes of the carbonate chemistry of the seawater (referred as Ocean Acidification). Commercial shellfish species, chiefly bivalves and crustaceans are exposed to these changes exhibiting different sensitivities. This work has synthesised all the available experimental OA evidence for shellfish commercial species. The information was then used to develop adaptation options for the aquaculture sector under OA effects. The potential adaptation options were then evaluated with a socio-ecological questionnaire. The respondents suggested that whilst OA could a threat there will be other more pressing co-stressors. Similarly, more issues associated with licensing, meeting market and demand as well as seed production could have more detrimental effects over the shorter time-scales for the industry sector.

A18.39 THE EFFECT OF CLIMATE CHANGE ON A MUSSEL-BASED INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA): INSIGHTS FROM A MECHANISTIC APPROACH

THURSDAY 12 APRIL 2018 **10:00**

ANTONIO GIACOLETTI (UNIVERSITY OF PALERMO, ITALY), MARIA CRISTINA MANGANO (UNIVERSITY OF PALERMO, ITALY), GIANLUCA SARÀ (UNIVERSITY OF PALERMO, ITALY)

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A pressing need for a mechanistic approach to predict the effects of CC on coastal aquaculture productivity is now urgent. Nevertheless, there is not a well-tested mechanistic framework being able to help stakeholders to spatially-tailor the aquaculture management options need to increase the societal economic incomes. By integrating experimental outcomes and a Dynamic Energy Budget (DEB) model is now possible to generate that kind of information increasing the understanding of CC effects on cultured biota. Here, we studied the effects of low pH, increasing temperature and augmented amount of food due to Integrated Multi-trophic Aquaculture Trophic (IMTA) on functional traits of the cultured mussel *Mytilus galloprovincialis*. Experimental data fed the DEB model to predict the effects of these stressors on life-history traits contextualised along the Sicilian coasts (Mediterranean Sea). Main results showed that there was a significant depressing effect of hypercapnia on functional performances of experimental animals: the metabolic rates decreased, the assimilation lowered. A DEB-based sensitivity analysis, performed to test the effect of lower pH (7.5), temperature increase (up to 2°C – COP21) and IMTA conditions on the time needed to reach commercial size, showed that low pH resulted in a ~25% longer time to reach the commercial size. Nevertheless, the negative effect of lower pH was buffered by the increasing temperature and by augmented food density. Results showed that a mechanistic approach can be useful to assess CC effects and to generate quantities to feed aquaculture management strategies under future CC scenarios.

A18.40 EFFECTS OF STOCKING DENSITY AND WATER FLOW ON THE GROWTH AND BIOREMEDIATION EFFICIENCY OF THE SEAWEED *HALOPTERIS SCOPARIA* (OCHROPHYTA)

THURSDAY 12 APRIL 2018 **10:15**

RITA F PATARRA (CE3C - CENTRE FOR ECOLOGY EVOLUTION AND ENVIRONMENTAL CHANGES, UNIVERSITY OF AZORES, PORTUGAL), MARIA H ABREU (ALGAPLUS PROD. E COMERC. DE ALGAS E SEUS DERIVADOS, PORTUGAL), RUI PEREIRA (ALGAPLUS PROD. E COMERC. DE ALGAS E SEUS DERIVADOS, PORTUGAL), ALEJANDRO H BUSCHMANN (CENTRO I-MAR CEBIB UNIVERSIDAD DE LOS LAGOS, CHILE), ANA I NETO (CE3C - CENTRE FOR ECOLOGY EVOLUTION AND ENVIRONMENTAL CHANGES, UNIVERSITY OF AZORES, PORTUGAL)

Cultivating algae using nitrogen-rich water effluents from fish aquaculture have proven to be an alternative to produce these organisms in land-based culture systems. The cultivation potential of *Halopteris scoparia* (L.) Sauvageau using seabream effluents in a land-based tank systems was investigated for the first time. This species is promising to the seaweed industry due to its biological activities (e.g. anti-ageing/anti-wrinkle) that are already being used in personal care products. An orthogonal experimental design was used to test the effect of stocking density (SD; 2 and 5 g L-1) and water flow (WF; CF - closed by night flow, OF - open flow) which both influence CO_2 levels, on *H. scoparia* relative growth rate (RGR), productivity and biofiltration capacity, using 230 L seaweed culture tanks over a 4-week period. Stocking density significantly affected growth performance being >2-fold higher at the lowest SD (RGR = 5.52±1.84 % day−1), which translated into a biomass production of 13.28±4.43 g dw m−2 wk−1, independently of the WF combination tested. Carbon and nitrogen contents (% dry wt) increased during the experiment, indicating nutrient storage by *H. scoparia*. Total ammonium nitrogen was found to be the main N source for *H. scoparia*, with uptake efficiencies around 60% in all treatments and removal rates of 3.63±0.47 g m-2 day-1. Overall, *H.scoparia* may be a good candidate species to be cultivated in land-based IMTA systems. The exploitation of this species using cultivated biomass is possible and seaweed farmers can now foresee upscaling its production.

A18.41 IMPACTS OF OCEAN ACIDIFICATION ON UNITED STATES WEST COAST SHELLFISH AQUACULTURE

THURSDAY 12 APRIL 2018 **11:00**

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The Northwest corner of the United States supports a vibrant mollusc culture industry growing a variety of species with a wide range of culture systems. Much of the stock for the farms is generated by a few large privately-owned hatcheries. Seasonal upwelling of deep, CO_2-enriched ocean water off the coasts of Washington and Oregon combines with the influence of anthropogenic CO_2 emissions to compound changes in seawater chemistry. Two of the major hatcheries experienced significant declines in oyster larvae production that has been linked to coastal upwelling of these high CO_2, low pH corrosive waters. The impacts on hatchery production coupled with failures in natural seed recruitment resulted in serious shortages of oyster seed for U.S. West Coast oyster farmers between 2007 and 2010. Outstanding collaboration between industry, academic and government scientists has resulted in water monitoring and treatment systems for hatcheries. These systems boost carbonate ion concentrations in hatchery water improving shell building capacity. This adaptation measure has

restored oyster seed production and given shellfish growers a temporary workaround for changing ocean chemistry. In anticipation of worsening conditions, the shellfish industry in collaboration with University scientists is also exploring rearing oysters bred to survive the corrosive conditions and culturing shellfish in conjunction with seaweed or seagrass to improve water chemistry conditions on their farms. Growers are also speaking out about their experiences hoping their story will help policy makers and others who are concerned about the health of our oceans understand the consequences of unchecked carbon emissions on them.

A18.42 CLIMATE CHANGE DRIVEN SULPHATE SOIL ACIDIFICATION IMPACTS OYSTER SHELL MINERAL STRUCTURE

THURSDAY 12 APRIL 2018 **11:30**

SUSAN C FITZER (UNIVERSITY OF STIRLING, UNITED KINGDOM), SERGIO TORRES GABARDA (UNIVERSITY OF SYDNEY, AUSTRALIA), LUKE DALY (UNIVERSITY OF GLASGOW, UNITED KINGDOM), BRIAN HUGHES (HUNTER LOCAL LAND SERVICES, AUSTRALIA), MICHAEL DOVE (NEW SOUTH WALES DEPARTMENT OF PRIMARY INDUSTRIES, AUSTRALIA), WAYNE O'CONNOR (NEW SOUTH WALES DEPARTMENT OF PRIMARY INDUSTRIES, AUSTRALIA), MARIA BYRNE (UNIVERSITY OF SYDNEY, AUSTRALIA)

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Ocean acidification is occurring globally through increasing CO_2 absorption into the oceans creating particular concern for calcifying species. In addition to ocean acidification, near shore marine habitats are exposed to the deleterious effects of runoff of acid sulphate soils which also decreases environmental pH. This coastal acidification is being exacerbated by climate change driven sea-level rise and catchment-driven flooding. In response to reduction in habitat pH by ocean and coastal acidification molluscs are predicted to produce thinner shells of lower structural integrity and reduced mechanical properties threatening mollusc aquaculture. Here we present the first study to examine oyster biomineralisation under sulphate soil acidification in a region where growth of commercial bivalve species has declined in recent decades. Examination of the crystallography of the shells of the Sydney rock oyster, *Saccostrea glomerata*, by electron back scatter diffraction analyses revealed that the signal of environmental acidification is evident in the structure of the biomineral. *Saccostrea glomerata*, shows phenotypic plasticity, as evident in the disruption of crystallographic control over biomineralisation in populations living in coastal acidification sites. Our results indicate that reduced sizes of these oysters for commercial sale may be due to the limited capacity of oysters to biomineralise under acidification conditions. As the impact of this catchment source acidification will continue to be exacerbated by climate change with likely effects on coastal aquaculture in many places across the globe, management strategies will be required to maintain the sustainable culture of these key resources.

A18.43 UNDERSTANDING THE RESPONSE OF BIOMINERALISATION TO RISING SEAWATER pCO_2

THURSDAY 12 APRIL 2018 **11:45**

NICOLA ALLISON (UNIVERSITY OF ST. ANDREWS, UNITED KINGDOM), CATHERINE COLE (UNIVERSITY OF ST. ANDREWS, UNITED KINGDOM), CHRIS HINTZ (SAVANNAH STATE UNIVERSITY, UNITED STATES), KENNETH HINTZ (GEORGE MASON UNIVERSITY, UNITED STATES), KIRSTY PENKMAN (UNIVERSITY OF YORK, UNITED KINGDOM), ROLAND KROGER (UNIVERSITY OF YORK, UNITED KINGDOM), DAVID EVANS (UNIVERSITY OF ST. ANDREWS, UNITED KINGDOM), JAMES RAE (UNIVERSITY OF ST. ANDREWS, UNITED KINGDOM), ADRIAN FINCH (UNIVERSITY OF ST. ANDREWS, UNITED KINGDOM)

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We investigated the effect of seawater pCO_2 (180, 400 and 750 µatm) on biomineralisation in different genotypes of the massive tropical zooxanthellate coral Porites spp. We used skeletal boron geochemistry to infer the pH and dissolved inorganic carbon (DIC) of the coral fluid used for calcification. Corals actively increase the pH of the calcification fluid above that of seawater, shifting the DIC equilibrium in favour of CO_3^{2-} at the expense of CO_2 and HCO_3^-. This creates a gradient favouring the diffusion of CO_2 from the surroundings into the fluid and serves as a mechanism to concentrate DIC for biomineralisation. Calcification fluid pH was generally lower in corals cultured at high seawater pCO_2. These low calcification fluid pH corals had low fluid [CO_3^{2-}] and [HCO_3^-], the DIC species implicated in aragonite precipitation, and, usually, low calcification rates. We do not observe the large variations in [co-precipitating DIC]

which we expect if the calcification fluid maintains an equilibrium with seawater CO_2. Rather our data suggests that the overlying [CO_2], available to diffuse into the calcification site, is broadly comparable between all pCO_2 treatments implying that metabolic activity (respiration and photosynthesis) generates a similar [CO_2] in the vicinity of the calcification site, regardless of seawater pCO_2. Different coral genotypes exhibit significantly different relationships between calcification fluid DIC chemistry and calcification rate, indicating that other factors also affect skeletal precipitation. We observe differences in the amino acid compositions of the skeletal organic matrix, both between genotypes and between pCO_2 treatments which may explain this.

A18.44 BIOGENIC ACIDIFICATION REDUCES SEA URCHIN GONAD GROWTH AND INCREASES THE SUSCEPTIBILITY OF AQUACULTURE TO OCEAN ACIDIFICATION

THURSDAY 12 APRIL 2018 **12:00**

BENJAMIN MOS (NATIONAL MARINE SCIENCE CENTRE SOUTHERN CROSS UNIVERSITY, AUSTRALIA), MARIA BYRNE (NATIONAL MARINE SCIENCE CENTRE SOUTHERN CROSS UNIVERSITY, AUSTRALIA), SYMON A DWORJANYN (NATIONAL MARINE SCIENCE CENTRE SOUTHERN CROSS UNIVERSITY, AUSTRALIA)

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Changes in the uptake of CO_2 by oceans (ocean acidification) has emphasised the importance of seawater carbonate chemistry on growth of calcifying organisms. However, calcifiers can also alter carbonate chemistry through respiration and calcification, a potential limitation for the aquaculture of these organisms. This study examined how seawater exchange rate and density of the sea urchin *Tripneustes gratilla* affected carbonate chemistry of their culture water and in turn drove variation in growth and gonad production. Growth, relative spine length, gonad production and consumption rates were reduced by up to 67% by increased density (9 to 43 individuals.m^{-2}) and reduced exchange rates (3.0 to 0.3 exchanges.hr^{-1}), but survival and food conversion efficiency were unaffected. Analysis of the influence of seawater parameters indicated that reduced pH and calcite saturation state were the primary factors limiting gonad production and growth. Uptake of bicarbonate and release of CO_2 by *T. gratilla* changed the carbonate chemistry of culture water. Importantly total alkalinity (A_T) was reduced, likely due to calcification by the urchins. Low A_T limits the capacity of culture water to buffer against acidification. This study demonstrates the importance of carbonate chemistry and biogenic acidification in inhibiting the productivity of calcifiers in culture. Furthermore, it highlights the vulnerability of aquaculture to predicted increases in atmospheric CO_2 concentrations and acidification of source water, which are likely to exacerbate changes in carbonate chemistry in culture water due to reduced buffering capacity. Direct management to counter biogenic acidification will be required to maintain productivity of marine calcifiers.

A18.45 IMPACT OF OCEAN ACIDIFICATION ON THE EARLY LIFE-HISTORY STAGES OF THE EUROPEAN ABALONE *(HALIOTIS TUBERCULATA)*

THURSDAY 12 APRIL 2018 **12:15**

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Ocean acidification is a major global stressor that leads to substantial changes in seawater carbonate chemistry, with potential significant consequences for calcifying organisms. Marine shelled molluscs are ecologically and economically important species providing essential ecosystem services and food sources. Because they use calcium carbonate ($CaCO_3$) to produce shells, molluscs are among the most vulnerable invertebrates to ocean acidification, with early developmental stages being particularly sensitive to pH change. The European abalone *Haliotis tuberculata* is a commercially important gastropod species for which the whole life cycle is controlled in aquaculture. Early development and shell formation have been extensively studied in *H. tuberculata*, showing that the primary shell is mostly composed of amorphous $CaCO_3$, followed by a gradually crystallization under aragonite. Since aragonite is more susceptible to dissolution compared

to calcite, the abalone shell provides a relevant model to study the impact of ocean acidification. Larval and juveniles abalones obtained from controlled fertilization held at the hatchery France-Haliotis were submitted to a range of decreased pHs (8.1 to 7.6) over the development cycle. Biological responses were evaluated by measuring survival, development, growth index and shell calcification. Polarized and SEM microscopy were used to assess whether lowering the pH had an influence on shell morphology and microstructure. Our results evidenced that ocean acidification negatively impacted abalone development and disrupted the shell formation process. Since these biological effects were observed for pH values expected by 2100, ocean acidification may have potential negative consequences for larval recruitment and population persistence in a near future.

POSTER SESSION TUESDAY 10 APRIL 2018

A18.46 CO_2 EXPOSURE IN LARVAL ZEBRAFISH: A PAINFUL ISSUE?

TUESDAY 10 APRIL 2018

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Fish are known to respond to a wide range of irritant chemicals, displaying clear behavioural changes after exposure to potentially noxious stimuli. Recent evidence shows that these noxious agents can have an impact on the behaviour of larval forms of zebrafish. However, very little information is available on the effects of carbon dioxide (CO_2) on larval zebrafish. In adult fish, topical application of CO_2 preparations such as CO_2 infused water and soda water activates nociceptors. Stimulation of nociceptors gives rise to the sensation of pain in mammals. To determine if CO_2 exposure is nociceptive in larval fish, five days post-fertilisation zebrafish were exposed to a preparation containing CO_2 (10% soda water, 7.53 mmol/l CO_2) for 10 minutes and the behavioural response of the fish (percentage time spent active) recorded. If CO_2 is nociceptive, administering drugs with analgesic properties should prevent any behavioural change. Commonly used pain-relieving drugs, aspirin, lidocaine, morphine and flunixin, were tested via immersion. Zebrafish larvae exhibited a significant reduction in activity (18.9%) after exposure to soda water, whereas lidocaine at 5 mg/l and morphine at 48 mg/l ameliorated this response (activity reduced by only 0.1 and 0.8%, respectively). These results show for the first time that CO_2 induced behavioural effects on larval zebrafish can be reduced using analgesics providing evidence for the nociceptive properties of CO_2. These findings have implications for the use of high concentrations of CO_2 as an agent for anaesthesia, stunning or euthanasia in the welfare of captive fishes.

A18.47 EVIDENCE OF ALTERED BEHAVIOUR AND REDUCED SURVIVAL IN *NASSARIUS RETICULATUS* (L.) VELIGERS EXPOSED TO MARINE CLIMATE CHANGE PROJECTED SCENARIOS

TUESDAY 10 APRIL 2018

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Ubiquitous in intertidal coastal communities of the NE Atlantic, *Nassarius reticulatus* perpetuation relies also on the fitness of planktonic early life stages, whose sensitivity to the climatic change projected for a near-future is unknown. To assess the impact of the concurrent “acidification” and “warming” in their swimming ability and survival, nearly-hatched veligers obtained in the NW Portuguese coast were exposed for 14 days to climate change simulated scenarios resulting from 4 temperature (T) levels –16, 18, 20, 22°C– and 2 pCO_2 levels –ambient, targeting seawater pH≈8.1, ≈750 µatm targeting pH≈7.8– considering reference conditions at the sampling site during the spawning season (16-20°C, pH≈8.1) and the Intergovernmental Panel on Climate Change projections (+0.2°C/decade, -0.3 units in seawater pH) for the year 2100. The developmental stage and

mortality were assessed after 2 (D_2), 8 (D_8) and 14 (D_{14}) days, and the activity and distance travelled by veligers at D_{14} , by analysing Zebrabox® video recordings. Larvae at 16°C-treatments returned high signal interference and could not be analysed. Except for development, constrained only by T and significantly accelerated at 22ºC, data revealed a synergic effect of T and pCO_2 as follows: mortality increased with acidification and warming, reaching >90% at D_{14} under pH 7.8 and T ≥20°C; surviving veligers showed reduced activity and travelled distance under pH 7.8 and T ≥20°C. This work demonstrates drastic consequences of near-term acidification and warming projected scenarios on *N. reticulatus* veligers' competence and, thus, the eminent threat that these phenomena represent to this species survival.

A18.48 COMBINED EFFECTS OF OCEAN ACIDIFICATION AND WARMING ON ORGAN HEALTH IN LARVAL KINGFISH

TUESDAY 10 APRIL 2018

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Kingfish *(Seriola lalandi)* are an important commercial and recreational fish species off the coast of New Zealand. To test the combines effects of ocean acidification and warming, larval kingfish were raised from egg stage to 21 days post hatch under control (21°C) and elevated (25°C) temperatures and control (450uatm) and elevated (1000uatm) CO_2 concentrations in a full factorial design. The condition and health of the larvae were evaluated through histological section of internal organs, as well as eyes, gills and fins.

A18.49 THE EFFECTS OF LOW SEAWATER pH ON GENE EXPRESSION OF THE CLAM WORM *NEREIS SUCCINEA*

TUESDAY 10 APRIL 2018

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The rising levels of atmospheric CO_2 in the recent decades has caused a drastic increase in oceanic carbon dioxide levels and led to a significant reduction in the ocean water pH values because water absorbs the CO_2 and forms carbonic acid, causing an increase in H^+ ions thus reducing pH values. This decrease in pH affects the oceans' ecosystems and poses the need for marine life to adapt to increasing acidity, phenotypically or genotypically in order to counter the negative effects on their physiology. The changes may be phenotypic for short-term acclimation or genotypic for long-term adaptation. This study investigated the effects of ocean acidity on polychaetes (*Nereis* family). This study aims to examine whether *(Nereis succinea)* show differences in the expression of various metabolites and genes when challenged by low pH and high carbon-dioxide. In addition, worms obtained from different populations should potentially show adaptive differences in pH tolerance that are manifested also in terms of behaviour and physiology. The worms were collected from at Cardiff Bay (United Kingdom) and individuals were exposed to low pH value environments in the laboratory for short time (one day-one week) and long-term durations (3 months), and compared to a control group that was kept in normal pH environment and samples stored and utilised for gene expression analysis. Data show up/down-regulation of gene expression pattern, differences between short and long term stress effects, changes in enzyme activity levels and impacts upon animal behaviour all of which implies significant effects of pH stress upon the worms.

A18.50 SEAWATER pH IMPACTS RESPONSES TO MARINE INFO CHEMICALS

TUESDAY 10 APRIL 2018

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Chemical signals coordinate marine animal behaviour, but little is known on how these are affected by human activities. High CO_2 concentrations absorbed from the atmosphere leads to reduced seawater pH, a process termed ocean acidification. Disruption of behaviour including feeding, predator–prey interactions, larval settlement or mating potentially have dramatic effects threatening important aquaculture species. We provide an overview of studies that demonstrate impacts of seawater pH at neural, signal detection and signal response level. Using synthetic pheromones and feeding stimulants we examined responses when individuals are exposed to pH levels expected for 2100. Based on the acid dissociation constants (pK_a) of chemical cues we tested the theory that pH directly affects signalling compounds in the environment. For signal detection, ligands need docking to receptor sites, in low pH excessive hydrogen ions shift the equilibrium towards the protonation of the signals. The extent of which depends primarily on the cue's pK_a. A reduction in pH of ~0.4 i.e. reduces signal strength by 19.7% for the female sex pheromone UDP in shore crabs reducing signal bioavailability. Feeding stimulants including amino acids and small peptides are also impacted. We show evidence for signal disruption through structural changes of cues, reduced and changed detection by the organisms, and altered behavioural responses. We conclude that signal disruption associated with ocean acidification is likely to become a threat to marine aquaculture impacting upon an organism's fitness. Studies are needed to evaluate marine organisms' ability to acclimatise and adapt to this threat.

A18.51 DIRECT PCO_2 MEASUREMENTS IN THE INTESTINAL TRACT OF THE AGASTRIC GOLDFISH

TUESDAY 10 APRIL 2018

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High partial pressures of CO_2 are known to occur in the digestive tracts of mammals, due to bacterial metabolism and the neutralization of gastric H+ secretion by HCO_3- from the pancreas and liver, and by basic components of the meal. Does the same occur in fish? By applying the Henderson-Hasselbalch equation to published numbers for pH and HCO_3- levels in the chyme of terminally sacrificed fish, very high PCO_2 levels can be calculated (1-12%). However, direct PCO_2 measurements have never been made in the gastro-intestinal tracts of live fish. The goldfish is of interest as it is agastric and does not secrete HCl. Using prototype needle-tip optical PCO_2 sensors (PreSens, Regensburg, Germany), PCO_2 was directly measured from anterior intestine (2.36 ± 0.53%), mid intestine (1.91 ± 0.27%), and posterior intestine (2.17 ± 0.46%) of live, recently fed goldfish. These PCO_2 values in the chyme were higher than in the peritoneal cavity (1.43 ± 0.34%) or arterial blood (0.57 ± 0.18%). After ~ 13 days starvation, PCO_2 values tended to be lower (1.36 – 1.75%) in all three intestinal compartments, but none of the differences were significant. These data will be compared with comparable measurements from the gastro-intestinal tract of HCl-secreting rainbow trout. We conclude that even in the absence of gastric HCl secretion, elevated PCO_2 levels can occur in the digestive tracts of fish. (NSERC Discovery, PreSens GmbH).

A18.52 REDUCED SALINITY AFFECTS THE CAPACITY OF JUVENILE EUROPEAN SEA BASS *(DICENTRARCHUS LABRAX)* TO DEAL WITH ADDITIONAL STRESS

TUESDAY 10 APRIL 2018

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European sea bass is a euryhaline teleost, is widely distributed throughout the estuaries and open oceans of Europe and is extensively used for aquaculture. They migrate seasonally between the open sea and estuarine environments, thus they are often challenged with osmotic stress. Previous research showed that at low salinities, sea bass are experiencing difficulties to maintain homeostasis and any additional stress such as reduced food intake or ammonia exposure resulted in disturbed ion balance and oxidative stress. Plasma pH was reduced at lower salinities, and plasma Cl levels were increased. This was accompanied by an increase in Na^+/K^+-ATPase expression and activity, activation of H^+-ATPase and down-regulation of $Na^+/K^+/2Cl^-$ gene expression. In fasted fish, increased lactate and Cl levels indicate that fish switch to anaerobic metabolism more easily at lower salinities. Overall, this indicates that several players in acid-base regulation are affected by low salinity as well. Therefore, the effect of increased environmental pCO_2 was examined in juvenile sea bass at 32, 10 and 2.5 ppt.

A18.53 ARE THERE CONFLICTING ACID-BASE IMPACTS OF FEEDING AND LIVING IN A HIGH CO_2 WORLD? ALKALINE TIDE V. COMPENSATED RESPIRATORY ACIDOSIS

TUESDAY 10 APRIL 2018

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With the rapid growth of aquaculture in the last forty years and the need for even greater future growth, it is becoming increasingly important to optimize the conditions found within aquaculture for maximising productivity and improving sustainability. The high stocking densities within farms leads to elevated carbon dioxide levels, which are vastly higher than in the wild. Acute exposure to elevated environmental CO_2 (hypercarbia) leads to blood acidosis that is compensated by excreting excess acid to the water and accumulating bicarbonate in blood to restore normal pH; known as “compensated respiratory acidosis”. However, environmental hypercarbia is not the only acid-base disturbance experienced by farmed fish. High feeding rates lead to pronounced blood alkalosis (the “alkaline tide”), which should add to the already elevated blood bicarbonate levels as a consequence of living in a permanently high CO_2 world. We hypothesise this creates a conflict in terms of acid-base regulation – the need to actively retain bicarbonate whilst living in hypercarbia, and actively excrete bicarbonate while recovering from the post-feeding alkaline tide. Our research is assessing how simultaneous environmental hypercarbia and feeding impact transcriptional, digestive and physiological responses, in particular acid-base regulation and oxygen binding and delivery by red blood cells, at a time when metabolic demand is elevated by Specific Dynamic Action (SDA or energetic cost of digestion).

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