The effects of stressor dominance at environmentally relevant levels on the freshwater gastropod, *Lymnaea stagnalis*

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Human activity is driving biodiversity loss at an alarming rate and multiple interacting stressors are recognised as driving many of these declines. However, due to the practical limitations associated with multifactorial experimental designs, a new approach to investigate the effects of environmental stressors is needed. Here we assess combined effects of three ubiquitous environmental stressors (pollutant mixture, invasive predator and global warming) utilising a novel testing paradigm based on the 'dominance' theory. The central tenet of this theory is that when one or more stressors are present at sufficiently high levels, this drives the observed effects. Under this scenario, the addition of co-stressors at lower levels will have little impact on the level of response. In order to test this theory, using previously collected single stressor data in our test system, stressors were combined with each stressor at a 'dominant – EC30' level, either alone or in combination with additional stressors at 'negligible – EC10' levels. The pollutant mixture consisted of 13 components at environmentally relevant concentrations (EC10: 0.015 µg/L, EC30: 0.041 µg/L), a temperature-controlled approach was implemented for the global warming exposure (EC10: 20.2 °C, EC30: 22.0 °C) and the predator cue dilutions were prepared from the invasive signal crayfish, Pacifastacus leniusculus (EC10: 10%, EC30: 57.5%). Exposure occurred starting from embryos < 24 hours old (n = 10 per replicate, 5 replicates) until adults (~ 5 months). Snails were maintained in artificial freshwater with a 16:8 photoperiod. Water changes (50 %) were carried out three times per week. Endpoints measured were survival (hatching, post-hatch mortality), growth (total biomass, shell length), reproduction (fecundity, onset of egg laying, embryo viability) and avoidance behaviour. Upon single stressor exposure at the 'dominant' EC30 exposure level, negative effects on reproduction (embryo viability) were observed in response to pollution, avoidance behaviour was observed in response to predator cue and stimulatory effects on reproduction (accelerated egg production) was observed in response to higher temperature. Supporting our 'dominance' hypothesis, there were no differences for these endpoints when compared with the co-exposure scenarios where the remaining two stressors were present at negligible EC10 levels. However, negating our 'dominance' hypothesis, additional endpoints were impacted for all stressors under the multiple stressor exposure scenario (EC30+EC10+EC10) when compared with their respective single EC30 exposure. Therefore, additional stressors at low levels elicited additional effects on measured endpoints. Interestingly, observed effects were similar between the different multiple stressor exposure scenarios, and therefore, the overall stressor levels appeared to have more importance than the individual stressor identities. This could be due to a general stress response leading to changes in energy budget allocations. Findings from this study will provide crucial information on how combinations of stressors interact to affect aquatic organisms, reflecting how human activities are contributing to biodiversity loss within natural systems.

Acknowledgements: We thank Sarah Dalesman (Aberystwyth University) for providing snails to start a breeding colony at the University of the West of Scotland, the Galloway Fisheries Trust for help in obtaining signal crayfish. This research was funded internally by the University of the West of Scotland.

Occurrence of alkylphenols and alkylphenol ethoxylates in North Sea sediment samples collected across oil and gas fields

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Alkylphenol ethoxylates (APEs) have been used in several offshore oil and gas production applications including as emulsifiers in drilling mud formulations, which may have resulted in their disposal to sea. Both NP, OP and their ethoxylates are toxic to aquatic organisms and are endocrine disrupters due to their ability to mimic natural hormones. Nonylphenol and octylphenol are listed by the Oslo and Paris Commission (OSPAR) (2009) as chemicals for priority action and concerns over the endocrine disruption potential led to the replacement of these compounds with less toxic products for offshore drilling and production in the North Sea (Neff, 2005). Despite concern over the endocrine disrupting potential of their alkylphenol (AP) degradation products, information on the presence of AP/APEs in marine sediments in the vicinity of oil and gas production facilities is scarce.

The concentrations of nonylphenol, octylphenol and their mono- and diethoxylates were determined in marine sediment from 29 environmental surveys carried out in the North Sea between 2011 and 2020. Relationships between the concentrations of AP/APEs with total hydrocarbon content, drilling fluid type present and infrastructure age were examined.

The environmental risk of nonylphenol and octylphenol was assessed by a comparison to relevant environmental threshold criteria and trends in the concentrations of APs/APEs examined using linear mixed modelling techniques.

The concentrations of octylphenol, nonylphenol and their ethoxylates near offshore installations were broadly comparable to, or higher than those of coastal and estuarine point source discharges. When compared to environmental assessment criteria, the Norwegian Pollution Control Authority Class V (extensive toxic effects) threshold values for octylphenol and nonylphenol were exceeded within 100 m and 500 m of infrastructure respectively. Predicted no effect concentration values were exceeded for nonylphenol and octylphenol up to 5000 m from infrastructure, suggesting that a potential increased risk to biota was present at a considerable distance from point source inputs.

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Effects of concurrent temperature and nitrate gradients on diatom multitrait phenotypes over two timescales

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Two hallmarks of environmental change in oceans is that first, many aspects of the environment change concurrently. For example, while oceans will warm, the nutrients available for phytoplankton growth in many regions will drop. Second, projections of future environments carry high uncertainty. For example, projections of global average sea surface temperature changes in the coming decades span ~4°C, with uncertainties in local projections being even higher. Because of these two characteristics of ocean change, our understanding of organismal responses to it must be applicable over a wide range of multidriver environments. I will present experimental results of the plastic (short term) and evolutionary (long term) growth of a model diatom in 20-25 different temperature x nitrate environments, with each driver present as a gradient at each level of the other driver, also known as a fully factorial experiment. We show that the ability to respond to warming on all time scales is a function of nitrate availability, with the optimum temperature for growth (T_{opt}) being a saturating function of nitrate availability in the short term. In the longer term, the ability to adapt to high temperatures by increasing growth and shifting T_{opt} upwards depends on nitrate availability, and we identify the critical concentration of nitrate needed for adaptation to warming in otherwise ideal environments. Finally, we demonstrate that adaptation is linked to changes in common markers of stress, such as internal pools of reactive oxygen. We also discuss trends in changes in ecologically-important traits such as cell size across the full range of multidriver environments. The resourcing and logistics of fully-factorial multidriver experiments can appear substantial, but we strongly advocate for doing them where possible. Because of this, I will go over the advantages and limitations of laboratory experiments with enough environments to generate "response surfaces" relative to experiments that use a smaller number of environmental scenarios, with the aim of dispelling some of the myths around carrying out experiments that generate response surfaces.

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The abstract should be submitted to masts@st-andrews.ac.uk, in an editable format, by 16:00 Friday 19th August 2022.

Aqueous Exposure to Benzo[a]Pyrene (BaP) Induced Behavioural Ecotoxicity in a Model Marine Amphipod, *Parhyale hawaiensis*

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Abstract

Marine and intertidal benthic organisms can be exposed to chemicals released from oil and gas-related activities, negatively affecting their survival. Among these substances are polycyclic aromatic hydrocarbons (PAHs) that include Benzo[a]Pyrene (BaP), which is neurotoxic and can affect aquatic organism behaviour. The objective of this ecotoxicity study was to assess the effects of chronic-aqueous exposure to BaP in the circumtropical marine amphipod, *Parhyale hawaiensis*. This amphipod is especially environmentally relevant in marine and estuarine ecosystems vulnerable to pollution and has emerged as a prominent model organism with considerable information on genomics, development, and physiology to support ecotoxicology investigations. Adult male and female *P. hawaiensis* (total carapace length 5-9 mm) were selected and exposed to 500µg/L BaP for 21 d to assess effects on feeding rate, precopula pairing, geotaxis and phototaxis, and locomotory response to food presence. These behavioural responses to BaP exposure were also investigated according to the amphipod gender. Relative to unexposed controls, the feeding rate, moulting frequency, and geotaxis activities were reduced by more than 50% in BaP-treated *P. hawaiensis*. No mortality was recorded, but both males and females presented significant differences ($p \leq 0.05$) in feeding rate and moulting frequency. A significant difference was also observed in the geotaxis and phototaxis activities of male but not female amphipods. Ongoing investigations include assessment of PAH exposure on changes in target gene expression profiles, haematology, and pathophysiology. Many tropical marine and estuarine ecosystems are vulnerable to anthropogenic pollution. Thus, developing ecotoxicology methods and understanding *P. hawaiensis* responses to oil-related pollutants will assist in protecting these critical ecosystems.

Tweetable abstract (Tweeter handle: @ibnlawan2010)

Our ecotoxicity work sponsored by @PTDF_Nigeria and presented at #MASTSasm2022, Glasgow, shows how aqueous exposure to an #oil_pollutant, Benzo[a]Pyrene, affects the behaviour of a marine model organism, #*Parhyale hawaiensis*, in ways that could contribute to population decline.

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Predicting changes in the spatial distribution of UK grey and harbour seals using a random forest algorithm and climate model projections

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The North Sea is entering a period of unprecedented change in the seascape with installation of windfarms and removal of oil and gas. During this period, sea surface temperatures are set to increase with climate change impacting primary productivity, which will in turn affect marine top predators. Thus, predicting the impacts of the changing seascape on top predators and associated effective marine management is predicated on incorporating the potential impacts of climate change. Here we quantify the current at-sea thermal envelope of the two UK seal species and predict which areas will remain within that envelope in the next 30 years.

Specifically, this study investigates the suitable thermal at-sea habitat and foraging areas for grey and harbour seals in the western North Sea and the potential impacts of climate change on their spatial distribution using a machine learning algorithm, random forests. Random forest models have been shown to be one of the best performing species distribution model approaches and to be particularly useful when comparing the effects of multiple environmental variables on species distribution.

We use GPS tracking data from grey and harbour seals tagged on the east coast of the UK and the northern coast of France, sea surface temperature data, along with static covariates to characterise areas which seals inhabit. We also use Hidden Markov Models to identify foraging areas to enable characterization of the suitable thermal foraging habitat for both species. To predict suitable thermal habitat for seals in the future, both for presence and for foraging, climate model predictions for sea surface temperature data are obtained from the Met Office HadGEM3 model and incorporated into the random forest model.

Here, we present our findings from the random forest modelling and highlight the changes in at-sea spatial distribution of seals that may occur due to climate change. This thermal habitat suitability modelling will provide valuable information on the species environment relationship for two important marine mammal species in the UK.