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EDITORIAL

Organisms in a changing world

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Since its foundation in 1999 by Lawrence Hightower, the Cell Stress Society International (CSSI) has actively promoted international collaboration in the field of stress research. Over the years, the Society has gone from strength to strength, with one of its main, and highly, visible outputs being the journal 'Cell Stress & Chaperones'. Although initially, the full title of the journal was 'Cell Stress & Chaperones: An Integrative Journal of Stress Biology and Medicine' with an emphasis on the medical field, original scientific articles were always welcomed from a wide range of organisms and different aspects of stress molecular biology. However, in 2020, the sub-title was expanded to 'An Integrative Journal of Stress Biology, Medicine and the Environment', in acknowledgement of the increasing importance of understanding the cellular stress response in non-model environmental species in the context of the current climate crisis. Initial plans to celebrate the change in subtitle with a special environmental issue were somewhat stymied by the COVID-19 pandemic. However, finally, 3 years later, we are proud to present this special issue 'Organisms in a Changing Environment', which highlights the wide variety of stress response research being carried out in environmental species. In particular, these studies demonstrate how important it is to understand not only the environmental cellular stress response but also their integration with higher levels of biological organisation to understand future biodiversity, and inform conservation measures and policy in our changing world.

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This special issue starts with a *Perspective and Reflection* article, in which Gershoni discusses the 'Transgenerational transmission of environmental effects in livestock in the age of global warming' (Gershoni 2023). Estimates suggest that annual losses of up to $2.4 billion occur in the US livestock industry due to the effects of global warming on farm animals. Whilst the immediate effects of heat stress on livestock, for example on meat and milk production, animal health and welfare and reproduction, have been well documented, much less is known about the longer-term transgenerational effects of heat stress and epigenetic inheritance. These multigenerational studies require detailed animal pedigrees and environmental metadata, which are much more difficult to obtain in livestock compared with the standard epigenetic lab models of rats and mice, due to longer generation times and greatly increased housing and feed costs. In this perspective, Gershoni reviews the available data and discusses how the results can be used to optimise breeding strategies to overcome the potential negative effects of warming entrained by epigenetic factors during critical periods in livestocks' life histories, and to protect livestock-based food security.

The next two articles are both reviews addressing the core subject area of the Cell Stress & Chaperones journal, namely heat shock proteins. The first by Storey and Storey 'Chaperone proteins: universal roles in surviving environmental stress' (Storey and Storey 2022) quite rightly points out that only humans can bend their environment to suit themselves, all other organisms have had to develop mechanisms to enable them to adapt their basic metabolism to their particular habitat and associated environmental stresses. Storey and Storey (2022) describe recent advances in our understanding of how chaperone proteins are regulated in response to adverse conditions, when animals resort to a variety of survival strategies including torpor/hibernation, anaerobic metabolism, estivation and cold/freeze tolerance. Out of all the articles in this special issue, this review particularly demonstrates that even a relatively simple environmental question, such as 'How do organisms survive adverse conditions?' may require a gamut of highly diverse species to answer it. Storey and Storey showcase an impressive variety of experimental data from species ranging from goldenrod gall insects, through sea cucumbers, African lungfish and land snails to red-eared slider turtles, ground squirrels and monito del monte (small South American marsupial). In contrast, the second review by Collins et al. 'The environmental cellular stress response: The intertidal as a multistressor model' (Collins et al. 2023) specifically focusses on three species as experimental models (the blue mussel, an amphipod and the tidepool sculpin). Whilst it is acknowledged that the most accurate data on the environmental cellular stress response (CSR) is obtained by combining lab and field experiments, this article argues that, to date, such studies on intertidal species are limited. Most studies have concentrated on heat as a single stressor, although up to 15 different stressors have been ascribed to the intertidal zone. Using the variety of outcomes produced from two stressor experiments as examples (including synergy and cross-talk), the argument that multifactorial experiments, in combination with studies in the field, are essential to our understanding of this complex and dynamic multistressor environment is strongly supported.

Interestingly, the first research article in this special issue by Wang et al. addresses points discussed in both reviews. In 'Coping with harsh heat environments: molecular adaptation of metabolic depression in the intertidal snail *Echinolittorina radiata*' (Wang et al. 2022), the CSR, including evaluation of heat shock proteins (HSPs) and oxidative stress response genes, was examined in two different populations of *E. radiata* found along the Chinese coastline. They showed that although metabolic depression is used as a survival mechanism under extreme heat stress, the response varied with population/local conditions and that there was not a predictable, universal CSR. Similarly, González-Ruiz et al. used a candidate gene approach to evaluate 'The combination of hypoxia and high temperature affects heat shock, anaerobic metabolism and pentose phosphate pathway key components responses in the white shrimp (*Litopenaeus vannamei*)' (González-Ruiz et al. 2022). This farmed shrimp is tolerant of a wide variety of stressful conditions, but little is known about the cellular mechanisms underpinning this resilience. This study investigated the CSR associated with each individual stress, and also combined stressors. They demonstrated significant cross talk between stress response pathways, which clearly enhances survival of this shrimp species in complex aquaculture conditions. The importance of cross talk is reiterated in 'Crosstalk between endoplasmic reticulum and cytosolic unfolded protein response in tomato', in which Löchli et al. concentrate on identifying transcription factors associated with the endoplasmic reticulum unfolded protein response (ER-UPR) and heat stress (Löchli et al. 2022). They elegantly demonstrated cross talk between the ER-UPR and the cytosolic unfolded protein response (CPR), identifying key regulators that co-ordinate protein homeostasis in different cellular compartments when tomato plants are under heat stress. The UPR is also examined in 'Regulation of the unfolded protein response during dehydration stress in African clawed frogs, *Xenopus laevis*' by Malik et al. In the wild, these frogs live in ponds that often dry up in the summer, with survival of the frogs dependant on them burrowing into the mud and entering a hypometabolic state to survive desiccation. Using Western blot analysis of candidate genes, Malik et al (2022) showed that the UPR helps adapt *X. laevis* tissues to dehydration stress and that upregulation of glucose-regulated proteins (GPRs) is also protective, with both pathways helping to maintain ER function under stressful conditions.

The next three research articles use three highly diverse species to explore different aspects of the impact of stressful conditions on reproduction and immune function. We start with the study of Benoit et al. warning that 'Reduced male fertility of an Antarctic mite following extreme heat stress could prompt localised population declines' (Benoit et al. 2023). The Antarctic mites *Alaskozetes antarcticus*, although present in large numbers (hundreds to thousands per site) have very limited distributions and dispersal capabilities. Furthermore, they take 4–5 years to become reproductive. Interestingly this study showed that not only did experimentally applied heat stress reduce male fertility, but also that males from warmer microhabitats were less fertile. This reduction in fertility was associated with increased expression of HSPs, indicative of cellular stress. These results prompted concerns highlighted in the title that this species could come under threat in the future as Antarctica warms. For the second of these studies, we move to much larger animals; grey seals. In 'Fitness correlates of blubber oxidative stress and cellular defences in grey seals (*Halichoerus grypus*): support for the life-history-oxidative stress theory from an animal model of simultaneous lactation and fasting' Armstrong et al. tested the CSR, including HSP abundance in foraging versus lactating female seals (Armstrong et al. 2023). The results showed that elevated energy costs during reproduction reduces the allocation to defences and increases cellular stress. Hence lactating females may be more vulnerable to environmental factors (such as the effects of climate change) that further exacerbate their cellular stress. In the final study of this trio, seasonal plasticity and melatonin production is examined in the northern palm squirrel 'Seasonal plasticity in immunocompetent cytokines (IL-2, IL-6 and TNF-α), myeloid progenitor cell (CFU-GM) proliferation, and LPS-induced oxido-inflammatory aberrations in a tropical rodent *Funambulus pennanti*: Role of melatonin' (Rastogi and Haldar 2022). These animals are seasonal breeders, in which photoperiod plays a significant role in the production of melatonin, a well-described immunomodulator. This study demonstrates the complex cross-talk between seasonality, photoperiod and melatonin, which is essential for the maintenance of animal health, but also plays a key role in fertility and reproductive success, with a healthy immune system significantly affecting the abilities of these animals to cope with environmental stress. All three studies emphasise the need to study multiple life history stages to accurately assess vulnerability of the species under study to cellular stress, as reproductive success is key to future recruitment and population resilience.

This special issue concludes with a more traditional study screening the diversity of heat shock proteins in a rotifer 'A genome-wide screening of the 70 kDa heat shock protein (HSP70) genes in the rotifer *Brachionus plicatilis sensu stricto* with a characterization of two heat-inducible HSP70 genes' (Grewal et al. 2022). *B. plicatilis* is proposed as an emerging model in evolutionary genetics for the study of stress responses and ageing. It has the advantage that it is easy to culture, reproduces asexually, has a short life span and has a very diverse environmental distribution. Preliminary genome screens are always useful to evaluate the potential complexity of the stress response. This is clearly complex in the rotifer, which possesses 15 HSP70-like genes, of which almost 50% are distant family members. This screen is the first stage in understanding the function of these chaperones in this species and how they contribute to the CSR.

To summarise, this special issue comprises eleven articles that show case the wide biodiversity in environmental stress research, in terms of both species and approaches. We hope that it will inspire more ecological molecular researchers to submit their environmental articles to Cell Stress & Chaperones and contribute to our growing environmental community. In the interim, for further environmental articles, please browse the collection, also entitled 'Organisms in a changing environment'.

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