Preface

Oxidative stress in aquatic ecosystems: Selected papers from the Second International Conference

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The Second International Conference on Oxidative Stress in Aquatic Ecosystems was held on November 11 – 14, 2015 in La Paz, Baja California Sur, Mexico. The Conference was hosted by the Centro de Investigaciones Biológicas del Noroeste (CIBNOR), S.C.. The conference was attended by 67 participants, representing 14 countries. The program included 18 symposium presentations from invited speakers, six presentations by students or postdoctoral associates, two virtual conferences, 44 poster presentations, and three working group sessions.

Symposium session themes included the role of oxidative stress in environmental adaptation and lifespan, redox signaling and adaptive responses, the application of “-Omics” to investigations of oxidative stress, and the utility of marine organisms as models for diseases.

This special issue of CBP-A comprises ten contributions from the conference, which fall into three general categories. Some of the contributions explore how oxidative stress develops in response to anthropogenic factors that are imposed singly or in combination. Other contributions examine the consequences of environmental factors such as plankton blooms and diurnal or seasonal patterns in temperature and water availability. Finally, some contributions examine oxidative stress within the context of life history stages, with a focus on the stress that can accompany reproductive activity.

One of the many challenges facing the responsible use of pesticides and herbicides is the ability of the chemicals to remain in soil and/or groundwater for weeks or even months, potentially contaminating nearby water bodies. When the chemicals impact the health of commercially important species, conflicts can arise between industries. Toledo-Ibarra et al. (2016a) report elevated oxidative damage to proteins and decreased total protein content in the livers and gills of Nile Tilapia (*Oreochromis niloticus*) that were acutely exposed to a widely-used organophosphorus pesticide (diazonin). The consequences for fish development are discussed.

Crude oil can enter water bodies through many routes. Although catastrophic events, like the 2010 *BP Deepwater Horizon* blowout garner much attention, crude oil also is released from natural seeps, from runoff near heavily populated areas, and from leakage along major shipping lines. Crude oil contains a mixture of compounds, including hydrocarbons, sulfur-containing compounds, and heavy metals, most of which have been implicated in inducing oxidative stress. Dzul-Zaamal et al. (2016a) evaluate biomarkers for oxidative stress in the skin mucus layer of dusky splitfin goodeid (*Goodea gracilis*), a freshwater fish that they exposed to

crude oil in acute, laboratory studies. The authors report an organ-specific pattern in the Integrated Biomarker Response. Given the elevated oxidative stress response in the skin and the un-invasive nature of sampling the skin mucus layer, as opposed to tissues like brain and liver, the authors advocate using the skin mucus layer for biomonitoring of habitats impacted by crude oil.

Many of the metals that are present in crude oil also can be found in aquatic habitats that are impacted by mining pollution. Given the established link between trace metal exposure and oxidative stress, [Schoonover et al. \(2016\)](#) focus on functional, or whole animal, traits in freshwater clams (*Musculium* spp.) that experienced chronic exposure to single metals or to a polymetal sediment from a polluted lake. Clams exposed to the polymetal mixture had decreased fecundity and climbing activity. The utility of the clams as sentinel species and as models for metabolic allocation studies are discussed.

While laboratory-based studies permit fine control over the experimental conditions, field studies enable the characterization of anthropogenic factor(s) within the context of the many environmental variables that are present in aquatic habitats. When the field studies incorporate minimally-invasive procedures, then the consequences of the anthropogenic factors can be determined for protected species. [Dzul-Caamal et al. \(2016b\)](#) explore the interacting effects of sex and of the mixture of eleven pollutants present in the Champoton River (Mexico) on oxidative stress markers in the Morelet's crocodile (*Crocodylus moreletii*). Comparisons across three tissue types, serum, peripheral blood cells, and snout scraping, collected from crocodiles from the polluted site and from a reference lake indicate that snout scraping samples are a useful, minimally-invasive method for assessing contaminant exposure

in a protected species. [Toledo-Ibarra et al \(2016b\)](#) use patterns in oxidative damage markers and enzyme activities in the gills of oysters (*Crassostrea corteziensis*) to evaluate the degree to which pollutants in the Boca de Camichin estuary (Mexico) are impacting oyster production. Although oysters from the estuary showed evidence of greater oxidative stress than did control organisms, the lack of correlation between oxidative stress markers and pollutants suggests that other environmental variables influence the stress physiology of the oysters.

Much of the early work that linked oxidative stress and thermal stress physiology to environmental variables was conducted in rocky intertidal habitats. The well-delineated spatial organization of environmental variables and of organisms in these habitats allowed for the development of straightforward hypotheses and experimental designs. As a general rule, the lower intertidal and subtidal zones are considered to be more benign than are the higher intertidal zones. This pattern is not upheld in some Antarctic habitats, where the Antarctic Circumpolar Current carries water that has relatively high levels of dissolved and total Fe. [González and Puntarulo \(2016a\)](#) show that subtidal limpets (*Nacella concinna*) accumulate more Fe and have more lipid damage than do intertidal limpets. In contrast, the two limpet populations had similar nitrosative metabolism and antioxidant enzyme activities, indicating that not all cellular-level metrics are impacted by Fe exposure.

While it is clear from the contributions in this special issue that a wide array of chemical factors can induce oxidative stress in aquatic organisms, other features of aquatic habitats, particularly O₂ availability and thermal extremes, also influence the balance between free radical production and damage/repair processes. [Moreira et al. \(2016\)](#) present a meta-analysis of the “preparation for oxidative stress” phenomenon across 102 species from eight phyla.

These species experience anoxia and/or hypoxia within the context of freezing, dehydration, estivation, and aerial exposure. Upregulation of antioxidant enzymes and/or glutathione in preparation for the stress was present in more than half of the species, and was dependent upon the type of stress.

Many components of oxidative stress physiology vary across seasons, reflecting seasonal patterns in life history traits such as reproduction, patterns in whole-animal activity levels and habitat selection, and patterns in environmental variables. [González and Puntarulo \(2016b\)](#) examine the consequences of seasonal exposure to planktonic toxins in the bivalve *Mytilus edulis platensis*. During the spring, mussels in the Argentinean Sea are exposed to toxins from plankton blooms that occur in response to increased nitrate, phosphate, and Fe in the seawater. Seasonal patterns in Fe content, free radical production, lipid damage, antioxidant enzyme activity, and nitrosative metabolism reflect the effects of planktonic toxins and temperature changes.

Many life history traits have the potential to influence and/or be influenced by oxidative stress. Mechanisms underlying the complex relationship between oxidative stress and reproduction include the role of steroid hormones such as cortisol and the costs of immune responses. [Taylor et al \(2016\)](#) evaluate associations between steroid hormone concentrations and oxidative stress markers in adult female sockeye salmon (*Oncorhynchus nerka*) and in several developmental stages of offspring. The authors did not detect evidence that maternal stress, even when simulated with high levels of cortisol, impacts steady-state oxidative stress in the offspring. [Crocker et al \(2016\)](#) explore alterations to oxidative stress parameters, immune function and steroid hormones in Northern elephant seals (*Mirounga angustirostris*) during

periods of breeding, extended fasting, and breath-holds. The authors use a combination of metabolomics and functional studies to evaluate the manifestation of oxidative stress during the three conditions. Using transcriptomics, the authors characterize the expression pattern of 67 genes involved in oxidant generation or antioxidant function in response to experimental elevation of plasma cortisol.

The ten contributions in this special issue illustrate several trends in the field of oxidative stress biology. First, it is clear that oxidative stress influences many levels of biological organization in aquatic animals, from gene expression and enzyme activity to reproductive success and locomotion. Second, many of the contributions incorporate an element of biomarker development, with emphases on uninvase or minimally-invasive techniques and whole-animal traits. Third, while the necessity of measuring cellular-level biomarkers, particularly the “-Omics” tools, in multiple tissues and across multiple seasons is well-established, the links between these cellular-level traits and whole animal traits are poorly understood. Finally, several of these contributions highlight the importance of considering oxidative stress, particularly the stress associated with anthropogenic factors, within the context of natural stressors and life history patterns. On the final day of the conference we held a working group session in which we discussed one of the major challenges facing this field: the difficulty of studying multiple stressors. The complexities and limitations of lab-based experimental approaches, the interactive and even antagonistic relationships among stressors, and the lack of appropriate statistical tools all contribute to our inability to model all features of aquatic habitats. A blend of laboratory-based and field-based studies that merge high-throughput and data-rich techniques with (more) traditional measurements of cellular

physiology and whole-animal traits may be the best approach to characterizing oxidative stress in aquatic animals.

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