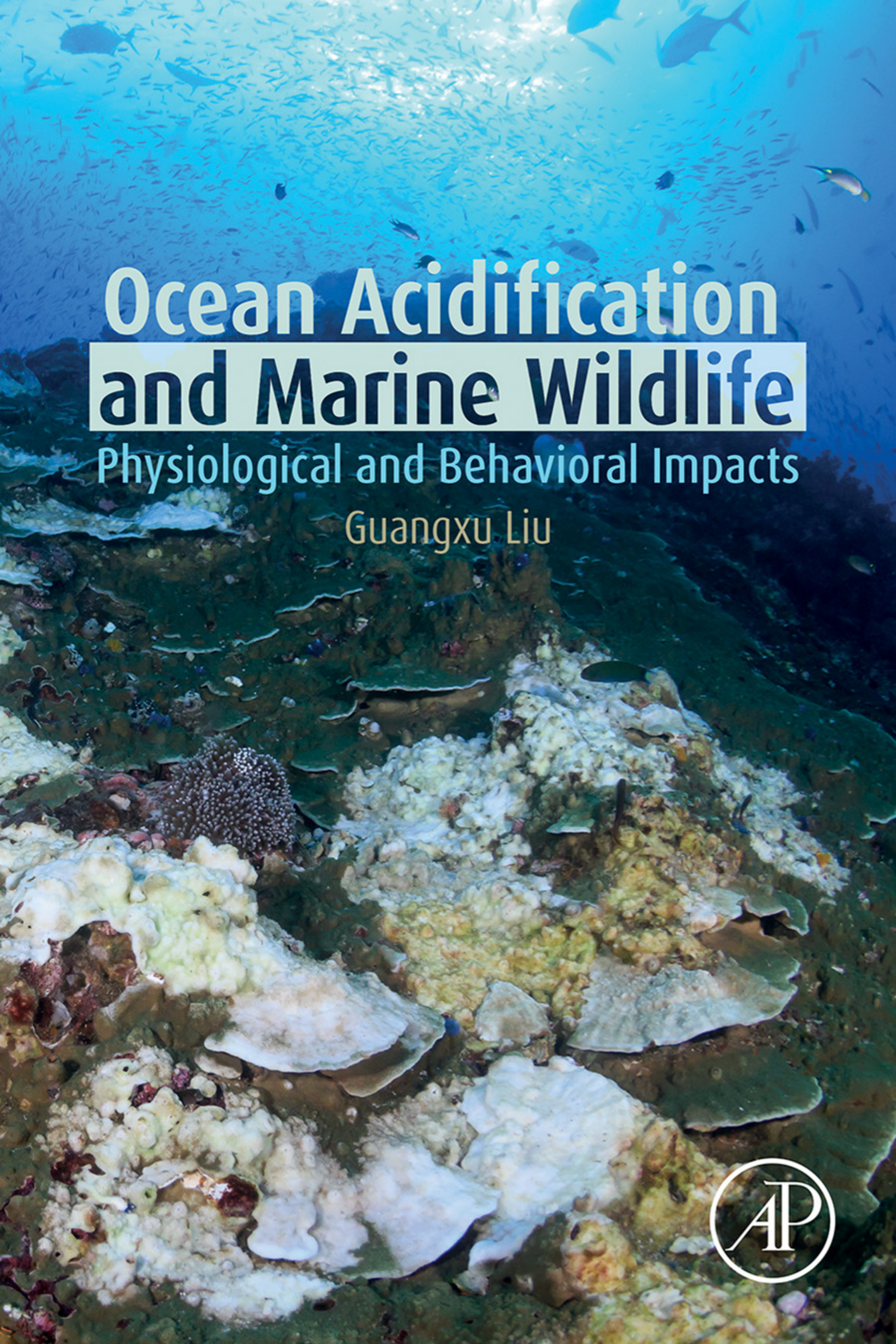

Ocean Acidification and Marine Wildlife

Physiological and Behavioral Impacts

Guangxu Liu

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525 B Street, Suite 1650, San Diego, CA 92101, United States
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom

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British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-822330-7

For Information on all Academic Press publications
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Publisher: Charlotte Cockle
Acquisitions Editor: Anna Valutkevich
Editorial Project Manager: Megan Ashdown
Production Project Manager: Maria Bernard
Cover Designer: Matthew Limbert

Typeset by MPS Limited, Chennai, India

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CHAPTER ONE

Physiological impacts of ocean acidification on marine invertebrates

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Introduction

Due to anthropogenic activities such as deforestation, fossil fuel utilization, cement production, and biomass burning since the Industrial Revolution in the mid-eighteenth century, the concentration of atmospheric carbon dioxide (CO_2) has increased approximately from 280 to 387 parts per million (ppm), which is higher now than it has been for more than 800,000 years (Booth et al., 2012; Caldeira & Wickett, 2003; Feely et al., 2004; Orr et al., 2005). Being the earth's largest carbon sink, the ocean plays an extremely important role in the global carbon cycle (Doney et al., 2009; Le Quéré et al., 2009). Approximately 30%–50% of the CO_2 released into the atmosphere has been absorbed by the earth's ocean, which thus resulted in reductions in seawater pH, a process termed "ocean acidification" (OA) (Caldeira & Wickett, 2003; Sabine et al., 2004). Over the past two centuries, the global average surface seawater pH has already decreased by more than 0.1 units, from approximately pH 8.21 to pH 8.10, which is equivalent to a 30% increase in the hydrogen ion (H^+) concentration in the seawater (Ellis et al., 2017; Sabine et al., 2004). According to the prediction made by the Intergovernmental Panel on Climate Change, if fossil fuel emissions and carbon-sequestration efforts continue at the present rate, the surface seawater pH will drop another 0.3–0.4 units by the end of the 21st century and by 0.7 units around the year 2300 (Pachauri et al., 2014). Besides, oceanic uptake of atmospheric CO_2 also lowers the carbonate concentration and reduces the saturation state of calcium carbonate in seawater, especially aragonite and

Ocean Acidification and Marine Wildlife.
DOI: https://doi.org/10.1016/B978-0-12-822330-7.00003-4

calcite, which are critical for many marine invertebrates in creating their skeletal structures or shells (Caldeira & Wickett, 2003; Fitzer et al., 2016; Thomsen et al., 2013; Zhao et al., 2017). Therefore theoretically, OA will affect a diversity of marine invertebrate species by altering seawater chemistry (Andersson & Gledhill, 2013; Gibson et al., 2011; Mollica et al., 2018).

Invertebrates, which make up about 95% of all animal species, are the largest group of animals on earth. In the ocean, marine invertebrates are not only functionally important in the marine ecosystem but also have significant commercial value worldwide (Marinelli & Williams, 2003). Since living in an acidified environment would constitute stress to marine inhabitants, OA could have profound ramifications on the physiological performance of marine invertebrates (Gallo et al., 2019; Gazeau et al., 2010; Kurihara, 2008; Shi, Han, et al., 2017; Shi et al., 2019). To date, OA is projected to impact marine invertebrates such as mollusks, crustaceans, and echinoderms present in various areas, from the open sea to estuaries and coastal areas (Bechmann et al., 2011; Holcomb et al., 2014). The present chapter focuses on the physiological impacts of OA on marine invertebrates, including gametic traits, fertilization success, embryonic development, biomineralization, metabolism, growth, and immune responses.

Impacts of ocean acidification on gametes and fertilization success of invertebrates

Fertilization, in its simplest form, is the fusion of two specialized gametes to form a single viable cell, which is known as the zygote. The release of gametes into the natural seawater column for external fertilization is an ancestral mating strategy commonly employed by various marine invertebrates (Lotterhos & Levitan, 2010). Once discharged, these gametes are in direct contact with the surrounding seawater. In this regard, the gametes and the subsequent fertilization of these marine broadcast spawners may be particularly vulnerable to OA (Table 1.1).

Sperm velocity is theoretically related to the probability of collision of gametes, and studies have shown that sperm with high velocity would be more effective in fertilizing the egg (Kupriyanova & Havenhand, 2005; Levitan, 2000). For example, as compared to faster sperm of the sea urchin *Lytechinus variegatus*, sperm with 0.01 mm/s decrease in velocity

Table 1.1 Effects of ocean acidification on the gametic traits and fertilization success of marine invertebrates.

Taxon	Species	pH/pCO_2	Objectives	Effects	References
Coelenterata	*Acropora digitifera*	pH 8.03–6.55 (400–21,100 ppm)	Sperm	↓Sperm flagellar motility	Morita et al. (2010)
		pH 7.74 (1000 ppm)	Sperm	↓Sperm motility	Nakamura and Morita (2012)
		pH 7.99–7.60 (438–1111 ppm)	Sperm	Unaffected	Iguchi et al. (2015)
	A. palmata	pH 7.7 (998 ppm)	Sperm	↓Fertilization success	Albright et al. (2010)
Mollusca	*Crassostrea gigas*	pH 8.12–7.85	Sperm and egg	Unaffected	Havenhand and Schlegel (2009)
		pH 8.09–7.73 (580–3573 ppm)	Sperm and egg	↓Sperm motility; ↓Fertilization rate	Barros et al. (2013)
	Saccostrea glomerata	600, 750, and 1000 ppm	Sperm and egg	↓Fertilization success	Parker et al. (2009)
	Mytilus galloprovincialis	pH 7.6 (1000 ppm)	Sperm	↓Sperm swimming speed; ↓Percentage of motile sperm	Vihtakari et al. (2013)
	Tegillarca granosa	pH 8.1–7.4 (589–3582 ppm)	Sperm and egg	↓Sperm swimming speed; ↓Fertilization success; ↓Gamete fusion probability;	Shi et al. (2017)
		pH 8.1–7.4	Sperm and egg	↑Polyspermy risk	Han et al. (2021)
Arthropoda	*Acartia tonsa*	pH 8.23–7.15 (385–6000 ppm)	egg	↓Fertilization success	Cripps et al. (2014)
Urochordata	*Ciona robusta*	pH 8.1–7.8	Sperm	↓Sperm motility; ↓Sperm viability.	Gallo et al. (2019)

(*Continued*)

Table 1.1 (Continued)

Taxon	Species	pH/pCO_2	Objectives	Effects	References
Echinodermata	*Hemicentrotus pulcherrimus*	pH 7.35 and 6.83 (2000 and 10,000 ppm)	Sperm and egg	↓Fertilization success	Kurihara and Shirayama (2004)
		pH 8.06–7.55	Sperm and egg	Unaffected	Zhan et al. (2016)
	Heliocidaris erythrogramma	pH 7.7	Sperm	↓Sperm swimming speed; ↓Percent sperm motility; ↓Fertilization success	Havenhand et al. (2008)
	Strongylocentrotus franciscanus	pH 7.81 and 7.55 (800 and 1800 ppm)	Sperm and egg	↓Fertilization success; ↑Polyspermy risk	Reuter et al. (2011)
	S. purpuratus	pH 8.03–7.61	Sperm and egg	Unaffected	Kapsenberg et al. (2017)
	Centrostephanus rodgersii	pH 8.1–7.6 (435–1558 ppm)	Sperm	↓Sperm mitochondrial membrane potential; ↓Sperm swimming speed	Schlegel et al. (2015)
	Acanthaster planci	pH 8.11–7.61 (520–1658 ppm)	Sperm	↓Sperm swimming speed; ↓Sperm motility; ↓Fertilization success	Uthicke et al. (2013)
	Holothuria spp.	pH 8.03–6.55 (400–21,100 ppm)	Sperm	↓Sperm flagellar motility	Morita et al. (2010)
	Glyptocidaris crenularis	pH 7.98–7.48 (453–1674 ppm)	Sperm and egg	↓Fertilization success; ↓percentage of abnormal fertilized eggs	Zhan et al.(2016)
	Lytechinus variegatus	pH 7.8	Sperm and egg	Unaffected	Lenz et al. (2019)