WORLD SEAS

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EDITED BY CHARLES SHEPPARD

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EUROPE, THE AMERICAS AND WEST AFRICA

World Seas: An Environmental Evaluation

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World Seas: An Environmental Evaluation

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Edited by

Charles Sheppard
Emeritus Professor, School of Life Sciences
University of Warwick, United Kingdom

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Contributors

Numbers in parenthesis indicate the pages on which the authors' contributions begin.

Peter Aastrup (45), Aarhus University, Roskilde, Denmark

Mohamed M. Abdel-Daim (261), Suez Canal University, Ismailia, Egypt

Jaime A. Aburto (673), Universidad Católica del Norte; Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Alicia Acuña (703), Oceanografía & Ecología Marina, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República (UdelaR), Montevideo, Uruguay

Moisés A. Aguilera (673), Universidad Católica del Norte; Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Coquimbo, Chile

Jahson Alemu (567), The University of the West Indies, St Augustine, Trinidad and Tobago

Lotfi Aleya (261), Université de Bourgogne Franche-Comté, Besançon Cedex, France

Álvarez-Filip, L. (637), Universidad Nacional Autónoma de México, Pto. Morelos, Quintana Roo, Mexico

Sergey V. Alyomov (209), The A.O. Kovalevsky Institute of Marine Biological Researches (IMBR), Sevastopol, Russia

Rachid Amara (855), Univ. Littoral Cote d'Opale, Univ. Lille, CNRS UMR 8187 LOG F62930, Wimereux, France

David Amouroux (113), CNRS/University of Pau and Pays de l'Adour, Institut des Sciences Analytiques et de Physico-Chimie pour l'Environnement et les Matériaux, Pau, France

Pierre Anschutz (113), EPOC, Université de Bordeaux, Bordeaux, France

Andrés H. Arias (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Christos Arvanitidis (227), Hellenic Centre for Marine Research, Institute of Marine Biology, Biotechnology and Aquaculture, Heraklion, Crete, Greece

Jerald S. Ault (427), University of Miami, Miami, FL, United States

Bolaji Benard Babatunde (835), University of Port Harcourt, Port Harcourt, Rivers State, Nigeria

Vicente Barros (783), Ciudad Universitaria, Buenos Aires, Argentina

María Cielo Bazterrica (759), Universidad Nacional de Mar del Plata (UNMdP); Instituto de Investigaciones Marinas y Costeras (IIMyC–UNMdP/CONICET), Mar del Plata, Argentina

Béchir Béjaoui (261), Institut National des Sciences et Technologies de la Mer, Salammbô, Tunisie

Trine Bekkby (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Jacek Bełdowski (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Rodolfo C. Bennett (725, 743), Bluefields Indian & Caribbean University, Bluefields, Nicaragua

Agnieszka Beszczyńska-Möller (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Donna Marie Bilkovic (379), Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, United States

Ferdinando Boero (283), Università del Salento, CoNISMa, Lecce; Istituto di Scienze Marine (ISMAR) CNR, Genova, Italy

David Boertmann (45), Aarhus University, Roskilde, Denmark

Angel Borja (113), AZTI, Pasaia, Spain

Alejandro Bortolus (783), Instituto Patagónico para el Estudio de los Ecosistemas Continentales, Puerto Madryn, Argentina

Sandra E. Botté (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS); Universidad Nacional del Sur (DBByF–UNS), Bahía Blanca, Argentina

Luis Bravo (673), Universidad Católica del Norte; Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Bernardo R. Broitman (673), Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Coquimbo; Center for the Study of Multiple-Drivers on Marine Socio-Ecological Systems (MUSELS), Pontificia Universidad Católica de Chile, Santiago, Chile

Ernesto Brugnoli (703), Oceanografía & Ecología Marina, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República (UdelaR), Montevideo, Uruguay

Brenda Burd (333, 363), Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada

JoAnn M. Burkholder (405), North Carolina State University, Raleigh, NC, United States

Lawrence B. Cahoon (405), University of North Carolina Wilmington, Wilmington, NC, United States

Sara Calabrese (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Yiping Cao (465), Southern California Coastal Water Research Project, Costa Mesa, CA, United States

Patricia G. Cardoso (189), CIIMAR—Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Matosinhos, Portugal

Norving J.T. Cardoza (743), FUNDAR, Managua, Nicaragua

Xavier Chiappa-Carrara (655), National School of Higher Studies, Merida Unit, National Autonomous University of Mexico, Merida, Mexico

Brindusa Cristina Chiotoroiu (209), Constanta Maritime University, Constanta, Romania

Tom Christensen (45), Aarhus University, Roskilde, Denmark

Jorge O. Codignotto (783), Servicio Geológico y Minero Argentino, SEGEMAR, Buenos Aires, Argentina

Sarah Cook (363), Coastal and Ocean Resources, Victoria, BC, Canada

Roberto Danovaro (283), Università Politecnica delle Marche, Ancona; Stazione Zoologica Anton Dohrn di Napoli, Napoli, Italy

Jean-Claude Dauvin (153), Normandie University, Caen, France

Antonio M. de Frias Martins (501), University of the Azores, Azores, Portugal

Silvia G. De Marco (759), Universidad FASTA; Universidad Nacional de Mar del Plata (UNMdP); Instituto de Investigaciones Marinas y Costeras (IIMyC–UNMdP/CONICET), Mar del Plata, Argentina

Juan Domingo Delgado (483), Universidad Pablo de Olavide, Sevilla, Spain

Stacy L. Deppeler (1), Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS, Australia

Amel Dhib (261), Institut National des Sciences et Technologies de la Mer, La Goulette, Tunisie

Mamadou Diop (855), Laboratoire de Toxicologie et d'Hydrologie (LTH) UCAD, Dakar, Sénégal

Cheikh Diop (855), Laboratoire de Toxicologie et d'Hydrologie (LTH) UCAD, Dakar, Sénégal

Marina Dolbeth (189), CIIMAR—Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Matosinhos, Portugal

Muhammet Duman (307), Dokuz Eylul University, Izmir, Turkey

Monia El Bour (261), Institut National des Sciences et Technologies de la Mer, Salammbô, Tunisie

Rym Ennouri (261), Institut Supérieur de Pêche et d'Aquaculture de Bizerte, Bizerte, Tunisie

Cecilia Enríquez (637, 655), Multidisciplinary Teaching and Research Unit—Sisal, National Autonomous University of Mexico, Sisal, Mexico

Hüsnü Eronat (307), Dokuz Eylul University, Izmir, Turkey

Bettina Fach (209), Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey

Melisa D. Fernández Severini (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Mouna Fertouna-Bellekhal (261), Institut Supérieur de Pêche et d'Aquaculture de Bizerte, Bizerte, Tunisie

Sandra Fiori (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS); Universidad Nacional del Sur (DBByF–UNS), Bahía Blanca, Argentina

James W. Fourqurean (427), Florida International University, Miami, FL, United States; University of Western Australia, Perth, Western Australia, Australia

Helene Frigstad (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Janne Fritt-Rasmussen (45), Aarhus University, Roskilde, Denmark

François Galgani (261), FREMER/Laboratoire Environnement Ressources PAC/Corse Imm Agostini, Bastia, France

Rafael A. García (673), Universidad de Concepción, Concepción; Instituto de Ecología y Biodiversidad (IEB), Santiago, Chile

Garza-Pérez, R. (637), Multidisciplinary Teaching and Research Unit—Sisal, National Autonomous University of Mexico, Sisal, Mexico

María Andrea Gavio (759), Universidad Nacional de Mar del Plata (UNMdP); Instituto de Investigaciones Marinas y Costeras (IIMyC–UNMdP/CONICET), Mar del Plata, Argentina

Carlos F. Gaymer (673), Universidad Católica del Norte; Centro de Estudios Avanzados en Zonas Áridas (CEAZA); Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Stefan Gelcich (673), Center of Applied Ecology and Sustainability (CAPES); Center for the Study of Multiple-Drivers on Marine Socio-Ecological Systems (MUSELS), Pontificia Universidad Católica de Chile, Santiago, Chile

Marcela S. Gerpe (759), Instituto de Investigaciones Marinas y Costeras (IIMyC–UNMdP/CONICET), Mar del Plata, Argentina

Ferdinand Dumbari Giadom (835), University of Port Harcourt, Port Harcourt, Rivers State, Nigeria

Erica Giarratano (783), Centro para el Estudio de Sistemas Marinos (CESIMAR-CONICET), Puerto Madryn, Argentina

Mónica Noemí Gil (783), Centro para el Estudio de Sistemas Marinos (CESIMAR-CONICET); Universidad Nacional de la Patagonia San Juan Bosco, Puerto Madryn, Argentina

Judith Gobin (567), The University of the West Indies, St Augustine, Trinidad and Tobago

Moncho Gómez-Gesteira (113), Universidade de Vigo, Vigo, Spain

Gongora María Eva Góngora (783), Instituto de Investigación de Hidrobiología, Universidad Nacional de la Patagonia San Juan Bosco, Trelew, Argentina

Shannon Gore (549), Coastal Management Consulting BVI; Association of Reef Keepers, Road Town, British Virgin Islands

Norman Green (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Amy E. Grogan (405), University of North Carolina Wilmington, Wilmington, NC, United States

Valeria A. Guinder (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Juan Manuel Gutiérrez (703), Oceanografía & Ecología Marina, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República (UdelaR), Montevideo, Uruguay

Anders G. Hagen (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Christopher Harman (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Ioannis Hatzianestis (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Kirk J. Havens (379), Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, United States

Rasmus Hedeholm (45), Greenland Institute of Natural Resources, Nuuk, Greenland

Mohamed-Amine Helali (261), Université de Tunis El Manar, Tunis, Tunisie

Carl H. Hershner (379), Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, United States

Kieth Holmes (333), Hakai Institute, Victoria, BC, Canada

Jennifer Jackson (333), Hakai Institute, Victoria, BC, Canada

Stephen C. Jameson (725, 743), Coral Seas, The Plains, VA, United States

Kostas Kapiris (227), Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Agios Kosmas, Attiki, Greece

Øyvind Kaste (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Monika Kędra (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Inès Khedhri (261), Institut National des Sciences et Technologies de la Mer, Salammbô, Tunisie

Ruy K.P. Kikuchi (813), Federal University of Bahia, Salvador, Brazil

Ferah Kocak (307), Dokuz Eylul University, Izmir, Turkey

Filiz Kucuksezgin (307), Dokuz Eylul University, Izmir, Turkey

Karol Kuliński (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Noelia La Colla (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Zelinda M.A.N. Leão (813), Federal University of Bahia, Salvador, Brazil

Diego Lirman (427), University of Miami, Miami, FL, United States

Alan Logan (591, 617), University of New Brunswick, Saint John, NB, Canada

Boris A. López (673), Universidad Católica del Norte, Coquimbo; Universidad de Los Lagos, Osorno, Chile

María Celeste López Abbate (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Jerome J. Lorenz (427), Audubon Florida, Tavernier, FL, United States

Gustavo Lovrich (783), Centro Austral de Investigaciones Científicas (CADIC-CONICET), Ushuaia, Argentina

Michael A. Mallin (405), University of North Carolina Wilmington, Wilmington, NC, United States

Panagiota Maragou (227), WWF-Greece, Athens, Greece

Jorge E. Marcovecchio (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca; Universidad FASTA, Mar del Plata; Universidad Tecnológica Nacional, Bahía Blanca; Academia Nacional de Ciencias Exactas, Físicas y Naturales (ANCEFN), Ciudad Autónoma de Buenos Aires, Argentina

Ismael Marino-Tapia (637, 655), Department of Marine Resources, Center for Research and Advanced Studies of the IPN, Merida Unit, Merida, Mexico

Maria Virgínia Alves Martins (261), Universidade do Estado do Rio de Janeiro—UERJ, Rio de Janeiro, Brazil

Karen McLaughlin (465), Southern California Coastal Water Research Project, Costa Mesa, CA, United States

Flemming Merkel (45), Aarhus University, Roskilde, Denmark; Greenland Institute of Natural Resources, Nuuk, Greenland

Molly M. Mitchell (379), Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, United States

Azad Mohammed (567), The University of the West Indies, St Augustine, Trinidad and Tobago

Terry Mohammed (567), The University of the West Indies, St Augustine, Trinidad and Tobago

Vivian Montecino (673), Universidad de Chile, Santiago, Chile

Alejandro J. Monti (783), Instituto de Investigaciones Geográficas de la Patagonia (IGEOPAT), Universidad Nacional de la Patagonia San Juan Bosco, Puerto Madryn, Argentina

Shelly Moore (465), Southern California Coastal Water Research Project, Costa Mesa, CA, United States

Adele K. Morrison (1), Research School of Earth Sciences, and ARC Centre of Excellence for Climate System Science, Australian National University, Acton, ACT, Australia

Brian Morton (501), The University of Hong Kong, Hong Kong, China

Anders Mosbech (45), Aarhus University, Roskilde, Denmark

Pablo Muniz (703), Oceanografía & Ecología Marina, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República (UdelaR), Montevideo, Uruguay

Andrew Myers (549), Montserrat Reef Project, St. Peters, MSR

Maite Narvarte (759), Universidad Nacional del Comahue, San Antonio Oeste, Argentina

Ana L. Oliva (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Marília D.M. Oliveira (813), Federal University of Bahia, Salvador, Brazil

Tatyana S. Osadchaya (209), The A.O. Kovalevsky Institute of Marine Biological Researches (IMBR), Sevastopol, Russia

Achref Othmani (261), Université de Tunis El Manar, Tunis, Tunisie

Baghdad Ouddane (855), Equipe Physico-Chimie de l'Environnement, LASIR UMR CNRS 8516, Université de Lille, Villeneuve d'Ascq Cedex, France

Walid Oueslati (261), Université de Tunis El Manar, Tunis, Tunisie

Eivind Oug (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Panayotis Panayotidis (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Vassilis P. Papadopoulos (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Vanesa Papiol (655), Multidisciplinary Teaching and Research Unit—Sisal, National Autonomous University of Mexico, Sisal, Mexico

Marcela Pascual (783), CRIAR, Criadero de Especies Marinas, Centro de Investigación Aplicada y Transferencia Tecnológica en Recursos Marinos Almirante Storni (CIMAS), Río Negro, Argentina

Aníbal Pauchard (673), Universidad de Concepción, Concepción; Instituto de Ecología y Biodiversidad (IEB), Santiago, Chile

Alexandra Pavlidou (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Giorgos Paximadis (227), WWF-Greece, Athens, Greece

Idil Pazi (307), Dokuz Eylul University, Izmir, Turkey

Janusz Pempkowiak (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Victor Quintino (189), Department of Biology and CESAM—Centre for Marine and Environmental Studies, University of Aveiro, Aveiro, Portugal

Nancy N. Rabalais (445), Louisiana State University, Baton Rouge; Louisiana Universities Marine Consortium, Chauvin, LA, United States

Marcel Ramos (673), Universidad Católica del Norte; Centro de Estudios Avanzados en Zonas Áridas (CEAZA); Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Miroslav Rangelov (209), Institute of Organic Chemistry with Center of Phytochemistry, Bulgarian Academy of Sciences (IOCCP-BAS), Sofia, Bulgaria

Tania Raymond (1), Antarctic Conservation and Management Program, Australian Antarctic Division, Kingston, TAS, Australia

Paulo Relvas (189), CCMAR—Center of Marine Sciences, University of Algarve, Faro, Portugal

Cristóbal Reyes-Hernández (655), University of the Sea, UMAR, Puerto Angel, Mexico

Rodrigo Riera (483), CIMA S.L., Tenerife, Spain; Universidad Católica de la Santísima Concepción, Concepción, Chile

Frank Rigét (45), Aarhus University, Roskilde, Denmark; Greenland Institute of Natural Resources, Nuuk, Greenland

Rioja-Nieto, R. (637), Multidisciplinary Teaching and Research Unit—Sisal, National Autonomous University of Mexico, Sisal, Mexico

Andrés L. Rivas (783), Centro para el Estudio de Sistemas Marinos (CESIMAR-CONICET); Universidad Nacional de la Patagonia San Juan Bosco, Puerto Madryn, Argentina

Diego H. Rodríguez (759), Instituto de Investigaciones Marinas y Costeras (IIMyC–UNMdP/CONICET), Mar del Plata, Argentina

José A. Rutllant (673), Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Coquimbo; Universidad de Chile, Santiago, Chile

Claudio A. Sáez (673), University of Playa Ancha, Viña del Mar, Chile

Dimitris Sakellariou (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Baris Salihoglu (209), Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey

Maria Salomidi (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Denise M. Sanger (405), Marine Resources Research Institute, SC Department of Natural Resources, Charleston, SC, United States

Rui Santos (189), CCMAR—Center of Marine Sciences, University of Algarve, Faro, Portugal

Ricardo Delfino Schenke (783), Fundación Patagonia Natural (FPN), Puerto Madryn, Argentina

Kenneth Schiff (465), Southern California Coastal Water Research Project, Costa Mesa, CA, United States

Kathleen Sullivan Sealey (591, 617), University of Miami, Coral Gables, FL, United States

Alexandra Silva (189), IPMA—Portuguese Institute for Sea and Atmosphere, Lisboa, Portugal

Nomiki Simboura (227), Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Attiki, Greece

Struan R. Smith (531), Natural History Museum, Bermuda Aquarium Museum and Zoo, Bermuda

Erik Smith (405), University of South Carolina, Baruch Marine Field Laboratory, Georgetown, SC, United States

Ronaldo Sousa (189), Department of Biology, CBMA—Centre of Molecular and Environmental Biology, University of Minho, Braga, Portugal

Carla V. Spetter (759), Instituto Argentino de Oceanografía (IADO–CONICET/UNS), Bahía Blanca, Argentina

Jonathan S. Stark (1), Antarctic Conservation and Management Program, Australian Antarctic Division, Kingston, TAS, Australia

Kara Stevens (725, 743), Washington, DC, United States

Beata Szymczycha (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Alicia Tagliorette (783), Fundación Patagonia Natural (FPN); Instituto de Investigaciones Geográficas de la Patagonia (IGEOPAT), Universidad Nacional de la Patagonia San Juan Bosco, Puerto Madryn; Universidad Nacional de la Patagonia Austral (UNPA), Río Gallegos, Argentina

Martin Thiel (673), Universidad Católica del Norte; Centro de Estudios Avanzados en Zonas Áridas (CEAZA); Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Richard Thomson (333, 363), Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada

Nadezhda Todorova (209), Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences (IBER-BAS), Sofia, Bulgaria

Tolga Gonul (307), Dokuz Eylul University, Izmir, Turkey

Lamia Trabelsi (261), Institut National des Sciences et Technologies de la Mer, Monastir, Tunisie

Hilde Trannum (69), The Norwegian Institute for Water Research (NIVA), Oslo, Norway

Souad Turki (261), Institut National des Sciences et Technologies de la Mer, La Goulette, Tunisie

R. Eugene Turner (445), Louisiana State University, Baton Rouge, LA, United States

Fernando Ugarte (45), Greenland Institute of Natural Resources, Nuuk, Greenland

María C. Uyarra (113), AZTI, Pasaia, Spain

Luis Valdés (113), Instituto Español de Oceanografía, Santander, Spain

Nelson Valdivia (673), Universidad Austral de Chile; Centro FONDAP de Investigación en Dinámica de Ecosistemas Marinos de Altas Latitudes (IDEAL), Valdivia, Chile

Vasil Vasilev (209), Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences (IBER-BAS), Sofia, Bulgaria

Natalia Venturini (703), Oceanografía & Ecología Marina, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República (UdelaR), Montevideo, Uruguay

Tammy Warren (531), Department of Environment and Natural Resources, Bermuda Government, Bermuda

Susse Wegeberg (45), Aarhus University, Roskilde, Denmark

Stephanie White (567), The University of the West Indies, St Augustine, Trinidad and Tobago

Kathleen Wood (617), SWA Environmental, Providenciales, Turks and Caicos Islands, British West Indies

Stuart P. Wynne (549), Fisheries and Marine Resources, Government of Anguilla, The Valley, Anguilla

Cintia Yamashita (261), Universidade do Estado do Rio de Janeiro—UERJ, Rio de Janeiro, Brazil

Noureddine Zaaboub (261), Institut National des Sciences et Technologies de la Mer, Salammbô, Tunisie

Nenibarini Zabbey (835), University of Port Harcourt, Port Harcourt, Rivers State, Nigeria

Agata Zaborska (85), Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Sergia Zalba (759), Universidad Nacional de Mar del Plata (UNMdP), Mar del Plata; Universidad Nacional del Sur (DBByF–UNS), Bahía Blanca, Argentina

Boutheina Ziadi (261), Institut National des Sciences et Technologies de la Mer, La Goulette, Tunisie

Chapter 19

Southern California Bight

Kenneth Schiff, Karen McLaughlin, Shelly Moore, Yiping Cao
Southern California Coastal Water Research Project, Costa Mesa, CA, United States

19.1 PHYSICAL AND ECOLOGICAL SETTING

The Southern California Bight (SCB) coastal environment is a unique ecological resource (Fig. 19.1). Extending >600 km from Point Conception (United States) to Punta Colonet (Mexico), the SCB is a dynamic subtemperate region where the cold, southward-flowing California Current mixes with the warm, northward-flowing California Countercurrent (Hickey, 1993). Large variations of interannual average ocean temperature occur during El Niño and La Niña, ranging >10°C in surface waters of the SCB.

The SCB borderland has relatively complicated geography (Dailey, Anderson, Reish, & Gorseline, 1993). Located at the margin of the North American and Pacific plates, this active tectonic region has a narrow continental shelf averaging 5 km width. At the continental shelf break in roughly 200 m depth, continental slopes plunge to 1000 m depth forming deep-water basins, only to rise again in a chain of nine offshore islands (Fig. 19.2).

The SCB's heterogenous physical settings and dynamic ocean currents provide habitat for a large diversity of flora and fauna (Dailey et al., 1993). Cumulative across all habitats, >350 fish and 5000 invertebrate species are endemic to the SCB, including over one dozen threatened or endangered marine mammals and seabirds. Biomes are generally spread across latitude which varies with ocean temperature—warmer species to the south and colder species to the north—and depth. Population recruitment and senescence are often coincident with El Niño when warm water species dominate and La Niña when cold water species dominate. Approximately 85% of the species in the SCB are at the extreme northern or southern end of their range.

The SCB has several ecologically critical habitats. One characteristic ecosystem in the SCB is subtidal rocky reefs dominated by the giant kelp *Macrocystis* (Fig. 19.3). These "kelp forests" are estimated to be among the most productive on earth, rivaling coral reefs (Claisse et al., 2014; Pondella II et al., 2015). The SCB has 331 coastal wetlands (Fig. 19.4), but only 23 are >100 HA and most are very small and fractured (<1 HA). The majority (57%) of the SCB coastal wetland area has been lost to coastal development since the turn of the 19th century (Stein et al., 2014). The remaining coastal wetlands are critical habitat providing fish nurseries and overwintering stops for birds along the Pacific Flyway (Dailey et al., 1993).

19.2 HUMAN INFLUENCE

Perhaps because of its unique physical setting and ecological resources, the SCB is also a unique economic resource. Renowned for its beaches, the SCB hosts ~175 million beach visits annually, more than Florida, Hawaii, and New Jersey combined (Schiff, Morton, & Weisberg, 2003). The five coastal counties in the SCB generate an estimated $22 billion annually in gross revenue and support over 800,000 jobs from ocean-related tourism and leisure activities (Kildow & Colgan, 2005).

The intersection of biodiversity and economics means that the SCB is a coastal ecosystem vulnerable to the impacts of anthropogenic influences. More than 20 million people live within an hour's drive of the SCB coast. It is home to the nation's two largest commercial ports (Los Angeles and Long Beach) and third largest naval facility (San Diego), as well as the world's largest manmade small-craft harbor (Marina del Rey). There are 17 wastewater treatment plants that discharge a cumulative 4×10^9 L day^{-1} of treated effluent to the SCB (Lyon & Stein, 2009). While precipitation is relatively infrequent in the SCB, averaging 12 storms that total 30 cm year^{-1} (Ackerman & Schiff, 2003), precipitation is frequently intense, with stormwater flows routinely increasing orders of magnitude in less than an hour (Schiff & Tiefenthaler, 2011). In total, there are 17 major watersheds that discharge largely untreated surface runoff from urban and agricultural land uses to the SCB.

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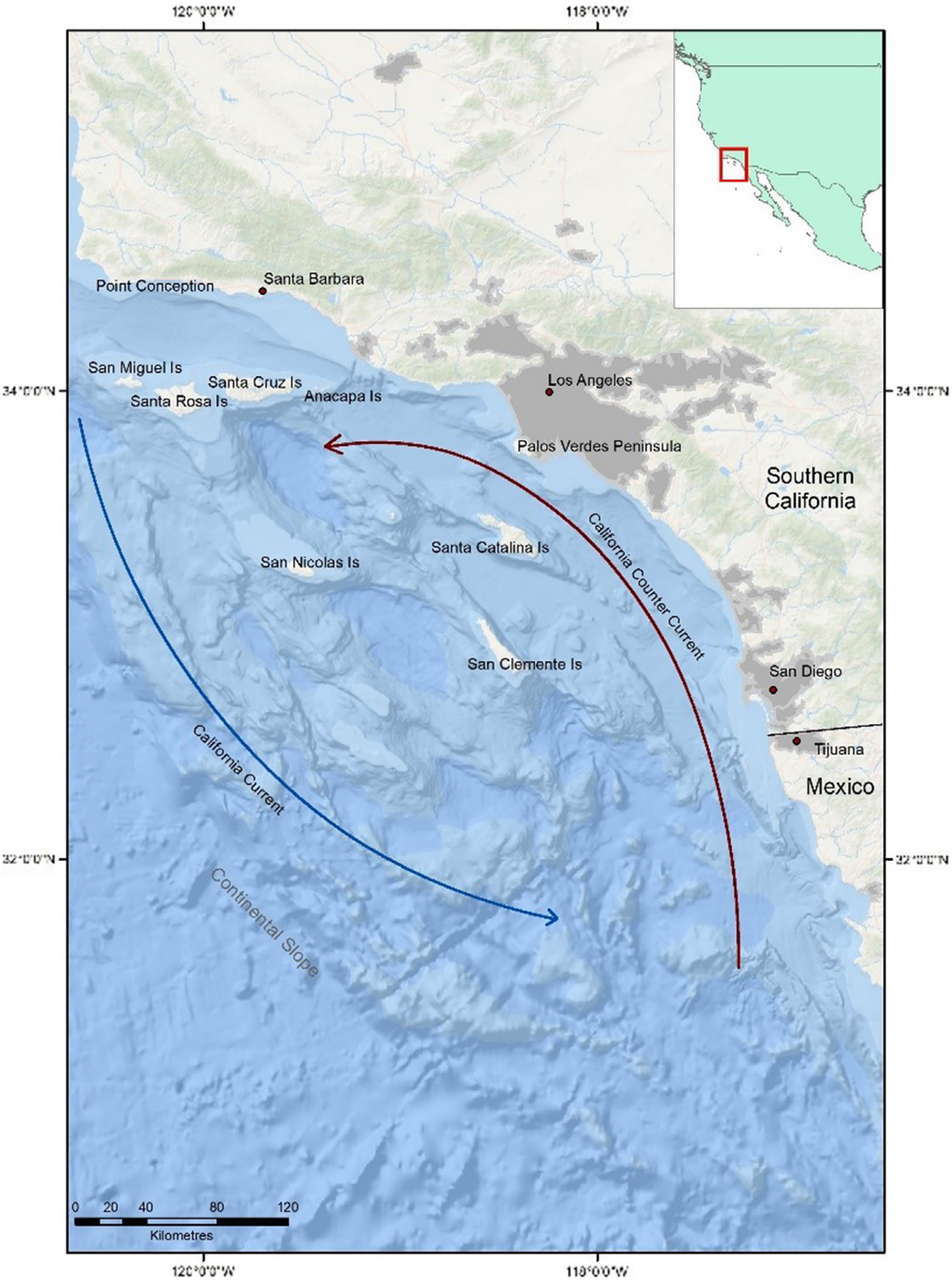

FIG. 19.1 Map of the Southern California Bight.

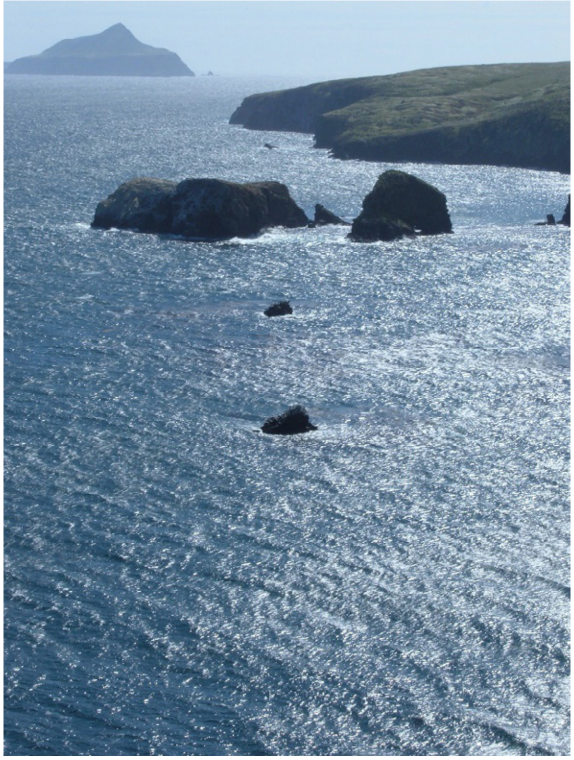

FIG. 19.2 The offshore chain of islands.

FIG. 19.3 The giant kelp *Macrocystis* is a keystone species of the shallow rocky sublittoral zone.

FIG. 19.4 One of the remaining salt marches along the southern California coast.

19.3 ASSESSING HUMAN IMPACTS IN THE SCB

When the status of the SCB was documented in the Seas at the Millennium (Schiff, Bay, Allen, & Zeng, 2000), impaired sediment quality from legacy contamination was a primary issue. State and federal agencies struggled with not just how to clean up contaminated sites, but also how to assess which sites needed clean-up and how clean SCB sediment should be. One outcome at the millennium was the adoption of sediment quality objectives (SQOs) by the State of California, a first-of-its-kind regulation anywhere in the United States (SWRCB, 2009). These precedent-setting regulations utilized a weight-of-evidence approach combining sediment chemistry, sediment toxicity, and benthic infauna to assess direct contaminant effects on sediment dwelling organisms (Bay & Weisberg, 2008).

The goal of this chapter is to update the status of the SCB, documenting where management actions have succeeded and uncovering new challenges facing SCB managers. To that end, the chapter is broken into four sections:

- Sediment quality
- Beach water quality
- Plastic trash and debris
- Ocean acidification (OA)

Each one of these issues are captured in the SCB Regional Marine Monitoring Program (Bight Program), which takes a collaborative, integrated approach to addressing holistic questions about the SCB. The Bight Program was born from the frustration of environmental managers' inability to answer simple, holistic questions about the SCB coastal environment (NRC, 1990). Initiated in 1994, the Bight Program has grown both in size and scope with each successive survey, which has been conducted about every 5 years (1998, 2003, 2008, 2013) (Schiff, Trowbridge, Sherwood, Tango, & Batiuk, 2016). By utilizing the Bight Program, the results described herein incorporate hundreds of sites and the collective conclusions of dozens of regulatory and regulated management agencies, nongovernmental organizations, and academic researchers.

19.4 SEDIMENT QUALITY

The SCB has a long history of sediment contamination (Schiff et al., 2000). A focal point has been on four large wastewater outfalls that discharge to the ocean. Cumulatively, these outfalls discharge advanced primary and secondary treated effluent through engineered diffusers at depths of 60–100 m to maximize dilution and keep the buoyant plumes submerged below the thermocline. Even with a rapidly growing population that has nearly doubled in the last 50 years, effluent volumes have decreased by 10%, and pollutant loading for most parameters has decreased by >95% (Lyon & Stein, 2009). The dramatic reductions in large wastewater flows and pollutant loads are generally attributed to reclamation, source control, and improved treatment. The four large wastewater outfalls in the SCB are supplemented by 13 small wastewater outfalls. The small outfalls, which discharge in much shallower water closer to shore, cumulatively comprise <10% of the flow and <5% of the pollutant loading of the large outfalls (Lyon & Stein, 2009).

While pollutant loading from wastewater effluent has been dramatically reduced, SCB stormwater has not experienced comparable declines in pollutant loading (Ackerman & Schiff, 2003). The Mediterranean-like SCB climate is arid, experiencing a long dry season from March to October that enables contaminant buildup in the region's densely populated coastal urban areas. The SCB climate is punctuated by a handful of short but intense storm events during the winter season. To prevent flooding during these storm events, engineers have constructed a labyrinth of concrete culverts and lined-stream channels that prevents flooding by efficiently and rapidly transporting urban runoff to the coastal ocean. Because of the large increase in storm flows, there are no combined stormwater-sanitary sewer systems in the region. Thus, urban runoff receives no treatment prior to discharge into the SCB.

In this section, we present integrated findings from the Bight Program's sediment quality monitoring element. For more than two decades, the Bight Program has addressed questions about the extent and magnitude of sediment quality impacts in the SCB. The extent and magnitude of sediment quality impacts is contextualized by comparing different habitats of interest, and by comparing changes in extent and magnitude dating back to 1998, just prior to the millennium.

19.4.1 Approach

A total of 385 sites were sampled for the Bight Program, encompassing approximately 15,911 km^2. Sites were selected via a stratified, random sampling design to remove bias and ensure statistical representativeness (Stevens Jr, 1997). Sediment was sampled using a modified Van Veen grab from 12 different habitats that fall into two broad categories: embayment and offshore habitats. Embayments encompass habitats including estuaries (mouths of coastal streams and rivers), marinas (small boat harbors), ports (commercial, industrial, and naval activity), and other open bay habitats (i.e., open navigation channels like the Los Angeles Outer Harbor and San Diego Bay). Offshore habitats include the mainland continental shelf (5–200 m depth), the northern Channel Islands (30–120 m depth), the continental slope and basins (200–1000 m depth), and submarine canyons (10–1000 m depth). All sediment samples were analyzed for 198 chemical contaminants and benthic infaunal community composition. A subset of sites was analyzed for sediment toxicity (B'13 Benthic Committee, 2013; B'13 CIA Committee, 2013a, 2013b; B'13 Field and Logistics Committee, 2013).

To provide a more comprehensive understanding of sediment quality in the SCB, sediment chemistry, sediment toxicity, and benthic community structure were integrated into a single sediment condition score and placed into one of five categories:

- **Unimpacted**. Confident that sediment contamination is not causing significant adverse impacts to aquatic life living in the sediment.
- **Likely unimpacted**. Sediment contamination is not expected to cause adverse impacts to aquatic life, but some disagreement among the three different lines of evidence reduces certainty in classifying the site as unimpacted.
- **Possibly impacted**. Sediment contamination may be causing adverse impacts to aquatic life, but these impacts are either small or uncertain because of disagreement among the three different lines of evidence.
- **Likely impacted**. Evidence for a contaminant-related impact to aquatic life is persuasive, even if there is some disagreement among the three different lines of evidence.
- **Clearly impacted**. Sediment contamination is causing clear and severe adverse impacts to aquatic life.

This scoring system follows a framework adopted by the State of California to assess sediment quality in enclosed bays and estuaries (SWRCB, 2009); the State considers the first two categories (unimpacted and likely unimpacted) as healthy or representative of conditions undisturbed by pollutants in sediment. While the State's regulatory framework only applies to embayments, the Bight program adapted the same approach for assessing sediment quality on the mainland continental shelf and offshore islands (B'13 CIA Committee, 2016).

19.4.2 Extent and Magnitude of Impacted Sediment Quality in the SCB

Overall, sediment quality in the SCB is good. A combined 93.8% of the seafloor area is clearly or likely unimpacted, and no site is in the most impacted category of clearly impacted (Fig. 19.5). The remaining 6.2% of area with impacted sediment quality is not dispersed evenly throughout the SCB. Impacted sediment quality disproportionately occurs in embayments, where 18% of area is impacted, compared to 5% in offshore habitats (Fig. 19.5). Nearly, half of the area in marinas (48%) and about one-third (35%) of the estuaries have impacted sediment quality, compared to less than one-seventh of the area in ports (13%) and bays (11%).

In general, sediment quality in the SCB reflects proximity to pollutant sources. For example, copper and other biocides are frequently used in vessel bottom paints to retard the growth of fouling organisms (Schiff, Diehl, & Valkirs, 2004). This likely result in marinas having the highest sediment copper concentrations of any habitat in the Bight (Dodder, Schiff, Latker, & Tang, 2016). Similarly, estuaries are a sink for untreated wet and dry weather discharges from urban runoff from contributing watersheds. As a result, some of the region's greatest zinc, polynuclear aromatic hydrocarbon (PAH), and current-use pesticide concentrations are observed in estuaries (Dodder et al., 2016). Zinc, PAH, and current-use pesticides originate from land-based activities (i.e., automobiles or home applications) and are washed off during storm events (Schiff & Sutula, 2004; Stein, Tiefenthaler, & Schiff, 2006; Tiefenthaler, Stein, & Schiff, 2008).

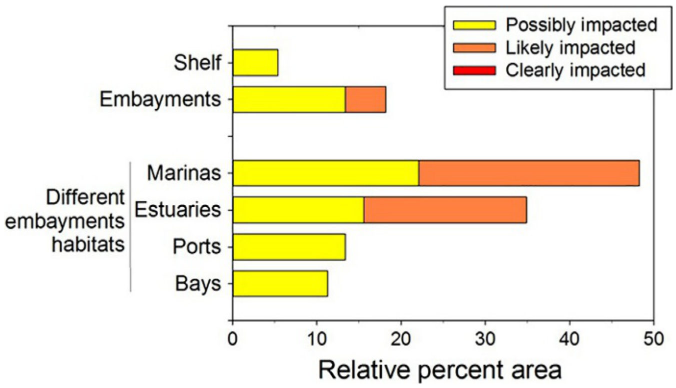

FIG. 19.5 Extent of contaminant impacted sediments by habitat defined by multiple lines of evidence (sediment chemistry, sediment toxicity, benthic community structure).

19.4.3 Trends in Extent and Magnitude of SCB Sediment Quality

Although embayments have the greatest relative extent of sediment contamination, this extent has been steadily decreasing since the turn of the century (Fig. 19.6). Between 1998 and 2013, the extent of contaminated sediments decreased from 55% to 18% of embayment area. Not only has the extent of sediment quality impact decreased over time, but the magnitude of impact has also decreased. In 1998, roughly 5% of the embayment area was classified as Clearly Impacted. In 2013, no site was classified as Clearly Impacted. Similarly, in 1998, 15% of the embayment area was classified as Likely Impacted; the extent of this impact has monotonically decreased, to 5% in 2013.

The 15-year trend of reduced sediment quality impacts in Southern California embayments reflects improvements within all three lines of evidence, which has provided additional confidence in the observed trends (B’13 CIA Committee, 2017). The moderate and high disturbance of infaunal biological communities decreased from 14% of embayment area in 1998 to 7% in 2013. Likewise, moderate and high sediment toxicity decreased from 30% of embayment area in 1998 to 4% in 2013. Meanwhile, the chemistry line of evidence showed the largest relative decrease of impacted embayment sediment quality, with the moderate and high exposure from sediment chemistry decreasing from 61% of embayment area in 1998 to 28% in 2013. Further details can be found in Bight Program’s three final assessment reports for each line of evidence (Bay et al., 2015; Dodder et al., 2016; Gillett, Lovell, & Schiff, 2017).

19.4.4 Challenges for the Future

Environmental managers have been addressing sediment quality of the SCB for decades. Research into sediment quality effects dates to the 1970s, and this investment continues to pay dividends. The Bight Program finds signatures from both point sources including wastewater and stormwater, and nonpoint sources such as boats and atmospheric deposition (Schiff et al., 2000). Sediment quality near some point sources has been improving steadily over the same time period in which SCB management actions have occurred (Stein & Cadien, 2009).

Other sediment quality problems are not as easy to solve. Constituents of emerging concern (CECs) are a good example (Maruya et al., 2015). While the Bight Program measures sediment samples for nearly 200 chemicals, most of these are legacy constituents such as trace metals, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dichlorodiphenyltrichloroethane (plus degradation products, DDTs). Tens of thousands of CECs exist that are rarely measured and the Bight Program is just beginning to address this need. For example, polybrominated diphenyl ethers (PBDEs, a fire retardant) and pyrethroid pesticides are now in common use and these CECs were widely detected during the Bight Program (Dodder et al., 2012; Lao et al., 2012). However, the use of PBDEs was discontinued in 2008 and the result of this source control was observed during the Bight 2013 Program (B’13 CIA Committee, 2016). Average sediment PBDE concentrations dropped by an order of magnitude between 2008 and 2013. In contrast, pyrethroids are still in common use and average sediment pyrethroid concentrations have changed little in this 5-year time span.

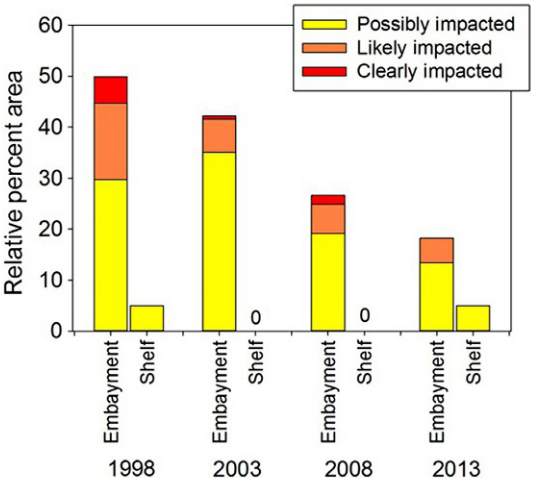

FIG. 19.6 Relative extent of sediment impact in continental shelf or embayment area between 1998 and 2013 based on by multiple lines of evidence (sediment chemistry, sediment toxicity, benthic community structure).

19.5 BEACH WATER QUALITY

Beaches are a critical element of the Southern California lifestyle. Surfing, body surfing, swimming, sailing, and scuba diving draw hundreds of millions of beachgoers each year. To ensure that SCB beaches are "swimmable," environmental managers monitor over 570 sites and 87,000 analyses each year (Schiff et al., 2003). This routine monitoring targets fecal indicator bacteria (FIB), including total and fecal coliforms and enterococci. Although none of these FIB are pathogenic and will cause illness, FIB are numerous in sewage and are much easier to measure than the pathogens themselves. Because routine monitoring in the SCB is focused on public health protection, the study design is focused on potential hot spots to uncover a problem early should it occur. In the SCB, these hot spots typically occur near flowing storm drains.

Managers face two significant challenges by relying on FIB for hotspot monitoring. First, FIB are not specific to humans or sewage; FIB can come from any warm-blooded animal (i.e., dogs, cats, birds, etc.) and can regrow in the environment (Desmarais, Solo-Gabriele, & Palmer, 2002; Ferguson et al., 2016); nonhuman FIB sources do not carry the same pathogen load as human sewage (Soller et al., 2014). Thus, in the absence of human fecal sources, FIB may not translate to the same human health risk as FIB from human sewage. Second, the focus on monitoring hotspots makes it difficult to compile regional FIB data for regional assessments; the entire region would look like a hotspot.

In this section, we present the Bight Program's efforts to identify spatial and temporal patterns in SCB beach water quality. The Bight Program focuses on capturing a holistic view of beach water quality, and then uses regional assessments to determine pervasiveness of human sources. Human sources are quantified using molecular technology that targets the HF183 genetic sequence of 16S ribosomal DNA from *Bacteroidales*, a DNA fragment known to be specifically human associated (Boehm et al., 2013).

19.5.1 Approach

The Bight Program uses a stratified random sampling design to address water quality along SCB beaches, and focuses on multiple habitats, including all open coastal beaches and beaches directly in front of flowing storm drains (Noble et al., 1999). During summer 1998, 307 sites were sampled between Point Conception (United States) and Punta Colonet (Mexico). Samples were collected weekly for 5 weeks. This design was repeated during winter 1999 for 240 sites. During winter 2000, a one-time sampling event was conducted following a storm event that brought at least one in of rainfall to every area of the SCB coastline. Samples were analyzed for total coliform, fecal coliforms (or *Escherichia coli*) and enterococci using standard methods, and results were compared to their single-sample water quality objectives (Noble et al., 1999). These three integrated analyses allow for a comparison of beach water quality during summer dry weather, winter dry weather, and wet weather.

In 2013, a targeted sampling design was used to evaluate the contribution of human sources to 22 storm drains that discharge to SCB beaches (Cao et al., 2017). Fifty weekly samples were targeted during summer dry weather conditions between 2013 and 2015. A similar design was used specifically to collect samples during wet weather. Storm drains were selected based on frequent historical enterococci exceedances at nearby swimming beaches for which the storm drains serve as important source water. Samples were analyzed for enterococci by EPA Method 1600 (US EPA, 2002) or Enterolert and the HF183 human fecal marker (Cao et al., 2017).

19.5.2 Extent and Magnitude of FIB Water Quality Exceedances at SCB Beaches

Beach water quality across the SCB is generally good in dry weather, unless the site is near a flowing storm drain (Fig. 19.7). Only 3% of the shoreline mile-days at SCB beaches exceed water quality standards for FIB, and these exceedances are triggered almost exclusively by enterococci. However, the exceedance rate jumps to 38% for sites directly in front of flowing storm drains during summer dry weather. Similar results are observed during winter dry weather.

FIB exceedances differ markedly following a storm event, with 65% of the SCB shoreline exceeding water quality standards for enterococci in wet weather (Fig. 19.7). Beaches directly in front of drains experience an even higher exceedance rate of 85%. In sum, enterococci levels at most SCB beaches look like the end of a storm drain following storm events.

19.5.3 Rate of Human Fecal Influence

The HF183 marker is ubiquitous in monitored freshwater outlets (Fig. 19.8). Although the frequency of human fecal contamination (as indicated by the presence of the HF183 marker) differs among sites and between dry and wet weather conditions, the HF183 marker is consistently detected during both dry and wet weather (at all but two sites in dry weather, and at all sites during wet weather).

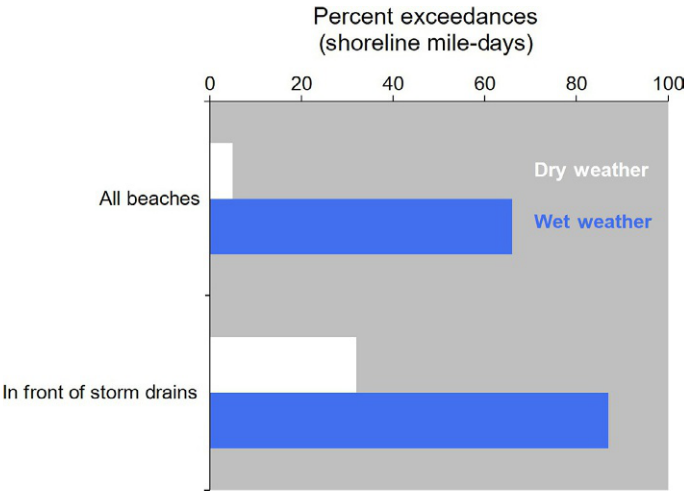

FIG. 19.7 Extent of water quality standard exceedances at all SCB beaches and those located directly in front of storm drains. Extent is compared during dry weather and wet weather.

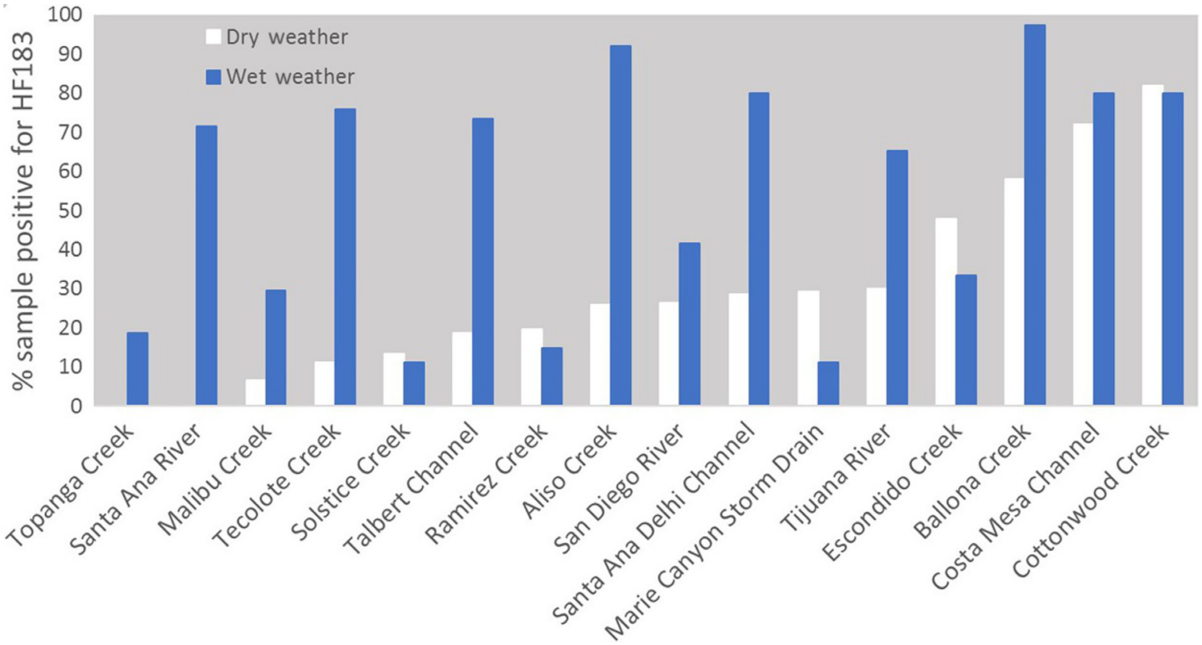

FIG. 19.8 Frequency of HF183 detection by site in wet versus dry weather conditions. Frequency of HF183 detection is defined as % samples that are positive for HF183, and a sample is deemed positive for HF183 if the HF183 marker was amplified in any of the three qPCR replicates. Sites are sorted from left to right by frequency of detection under dry weather conditions.

Three results of interest emerge from this regional survey of human fecal influences. First, HF183 on average is detected at twice the rate in wet weather compared to dry weather, with HF183 quantifiable at 44% of drains in wet weather versus 22% in dry weather. Second, the rank order of detection frequency by drain changes between dry and wet weather, suggesting the sources of human fecal pollution change in most drains depending on weather condition. Third, enterococci concentrations do not correlate with HF183 concentrations in either dry or wet weather, suggesting that there may be sources of enterococci that are not of human origin in drain discharges.

19.5.4 Future Challenges

Bight Program findings indicate that water quality at the vast majority of SCB beaches is safe for water-contact recreation in dry weather; the one exception is sites near a flowing storm drain in dry weather. In contrast, water quality is poor in most SCB locations in wet weather. These findings are consistent with source tracking efforts that show human sources increase in storm drain discharges following storm events. However, nonhuman sources of FIB are also detected in SCB storm drains that may contribute to exceedances of FIB water-quality objectives.

The differences in sources of FIB to wet weather discharges naturally lead some managers to the concept of health risk. There have been a number of epidemiology studies conducted in the SCB during both dry and wet weather (Arnold et al., 2017, 2013; Colford et al., 2012, 2007; Yau et al., 2014). In each case during dry weather, where human sources of fecal pollution existed, there was an increased risk of gastrointestinal illness and this risk frequently was related to enterococci concentrations in beach waters (Colford et al., 2012). In wet weather, there was also an increased risk of gastrointestinal illness, and this risk was also related to enterococci concentrations (Arnold et al., 2017). A large difference between dry and wet weather at SCB beaches, however, was the larger fraction of nonhuman enterococci sources in wet weather discharges. This, in turn, changes the relationship between enterococci and gastrointestinal illness. Beach managers are now deciding what is an acceptable level of risk. Beach usage in wet weather, while still numbering 10^5 annually following wet weather, is a fraction of what beach usage is in dry weather. However, costs for cleaning up wet weather discharges are orders of magnitude greater than dry weather.

19.6 TRASH AND DEBRIS

Trash has emerged as a pervasive global concern in marine environments, impacting aesthetics and ecosystem integrity in not only populated coastal areas, but also the most remote parts of the ocean (Moore, Gregorio, Carreon, Leecaster, & Weisberg, 2001; NRC, 2009). Trash has become problematic across many discrete habitats, including estuaries, bays, shorelines, and open ocean waters, and has impacted the surface, the water column, and benthos. Sources of marine debris can be either ocean or land based, and are often attributed to illegal dumping, accidental loss, and natural disasters (EPA, 2008; Sheavly, 2007). Marine debris can affect local economies through loss of revenue from decreased tourism (Leggett, Scherer, Curry, Bailey, & Haab, 2014), and it can harm marine organisms through ingestion and entanglement (Adimey et al., 2014; Anastasopoulou, Mytilineou, Smith, & Papadopoulou, 2013; Anderson & Alford, 2014; Boerger, Lattin, Moore, & Moore, 2010; Bond et al., 2013; Di Beneditto & Arruda Ramos, 2014; Goldstein & Goodwin, 2013; Lusher, McHugh, & Thompson, 2013; Waluda & Staniland, 2013).

Given the potential for marine debris impacts in the SCB, environmental managers have placed emphasis on controlling the amounts of debris in runoff from land-based sources to the marine environment. These include total maximum daily load (TMDL) regulations that set limits of zero for allowable trash discharges (CRWQCBLA, 2007, 2015), policies that call for installation of "full-capture" trash devices in urban areas (SWRCB, 2015), and statewide legislation that bans carry-out plastic bags and microplastic beads in personal care products (NCSL, 2017; NRDC, 2015).

In this section, we present spatial and temporal trends for debris on the SCB seafloor. Since the Bight Program's inception in 1994, trawling has been used to evaluate the extent and magnitude of anthropogenic debris along the coastal margin. Because the Bight Program has been conducting these surveys consistently, it is now possible to examine temporal trends over two decades.

19.6.1 Approach

A total of 164 sites were sampled by trawl using a probabilistic design (similar to the sediment quality element of the Bight Program, above), enabling unbiased estimates of extent (Stevens Jr., 1997). Sites were sampled from open bays, the continental shelf and upper continental slope (1–500 m depth). Trawls were conducted using a semi-balloon otter trawl with a 7.6 m (25 ft) headrope and 1.3 cm (0.5 in.) cod-end mesh (B'13 Field and Logistics Committee, 2013). Trawls were towed along isobaths at a speed-over-ground of 1.0 $\mathrm{m\,s^{-1}}$ (or 1.5–2.0 knots) for 10 min. Trawl debris were sorted and quantified by recording the specific types of material and the number of pieces of each type. Debris larger than 1.3 cm were quantified and placed into categories: plastic, glass bottles, cans, metal debris, lumber, and other (includes fishing gear, tires, cloth, tape, paper, fiberglass, clinkers bricks, and caulk). Bight Program trawl surveys were conducted comparably between 1994 and 2013.

19.6.2 Extent and Magnitude of Anthropogenic Debris in the SCB

An estimated 26% of the SCB contains anthropogenic debris, as measured during the 2013 regional survey of the coastal seafloor (Fig. 19.9). Plastic has the greatest extent (22% of the SCB). The "other" category has the second greatest extent (10% of SCB area), and includes items such as cloth, tape, paper fiberglass, clinkers, and caulk. Lumber and metal debris has the smallest extent (2% of SCB area). While plastic is the most abundant item sampled, overall abundance of trawl-caught debris has generally been low. One item per trawl is the average abundance for the vast majority of trawls in the SCB.

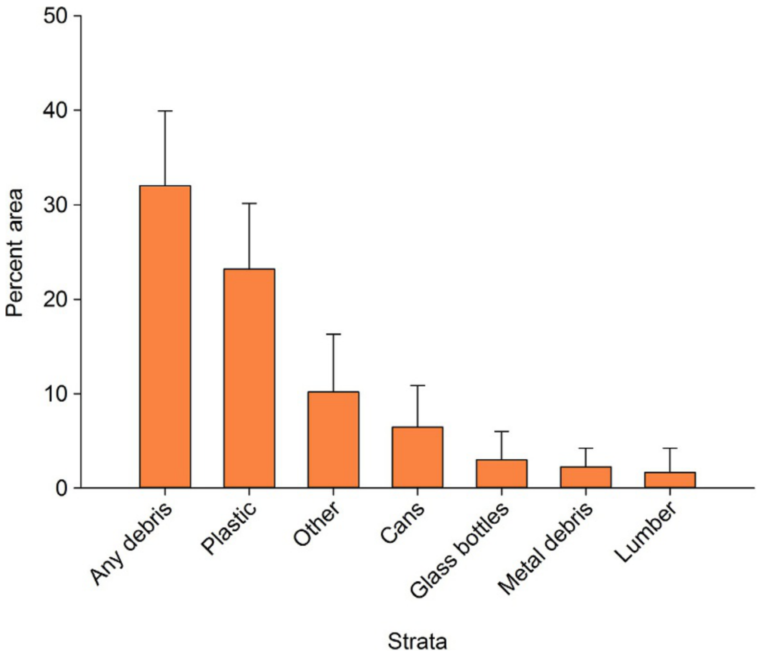

FIG. 19.9 Extent of anthropogenic debris (% of area ± 95% CI) in 2013 in the Southern California Bight by debris type.

19.6.3 Trends in Extent and Magnitude of Anthropogenic Debris of the SCB

The extent of anthropogenic debris in the SCB has increased over the past 20 years (Fig. 19.10). Between 1994 and 2013, there has been a nearly monotonic increase in the percent of area with anthropogenic debris on the SCB continental shelf (14% in 1994 to 23% in 2013). Much of this change is driven by plastic debris, which has increased in extent threefold over the two decades (6% in 1994 to 18% in 2013). Notably, this increase is not associated with changes in sampling frequency, techniques, or measurement, as each of these factors was held consistent during all regional surveys.

19.6.4 Future Challenges

The Bight Program's regional surveys of marine debris show that the majority of trash on the near-coastal seafloor appears to be land based, not ocean based. This conclusion is also supported by a 2013 Bight Program survey of micro-plastics in

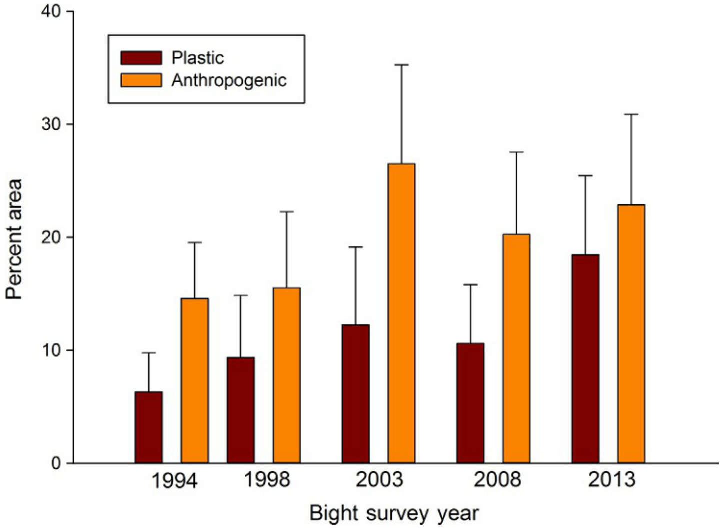

FIG. 19.10 Comparison of trends in extent of anthropogenic debris and specifically plastic debris on the continental shelf of the SCB between 1994 and 2013.

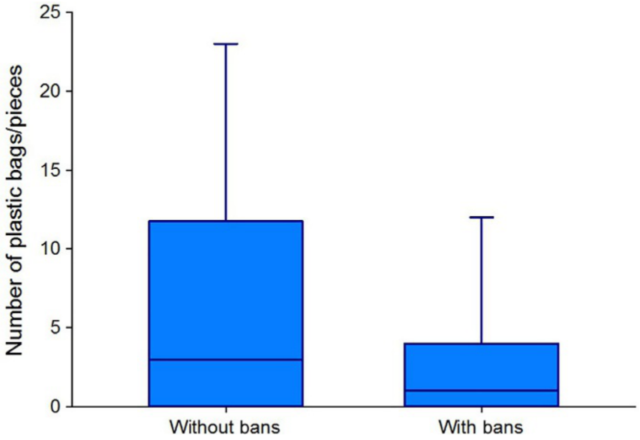

FIG. 19.11 Number of plastic bags/pieces in rivers and streams in Southern California during 2011–13 study. Box plot represents median, 75th, and 90th percentiles.

SCB seafloor sediments (Moore, Sutula, Von Bitner, Lattin, & Schiff, 2016). In the micro-plastics survey, micro-plastics embedded in seafloor sediment show clear spatial trends closest to land-based discharges, such as estuaries and embayments near urban rivers and streams. Furthermore, regional surveys of trash in streams draining to the SCB are unambiguous; nearly 100% of the roughly 5000 km urban stream-miles in the SCB contain trash (Moore et al., 2016). During one 72-h SCB storm event alone, ~30 metric tons of plastic are estimated to have been discharged from the Los Angeles and San Gabriel Rivers (Moore, Lattin, & Zellers, 2011).

Because most of the trash found in the SCB is land based, the most effective solutions for remediating marine debris are likely to be land based. Despite relatively recent policy and legislative mandates to control trash entering streams and the coastal ocean, it is not yet clear if these actions have been effective. Initial evidence from the Bight Program suggests that municipal bans on carry-out plastic bags have reduced the abundance of plastic bags in nearby streams about three-fold, compared to municipalities without the bans (Fig. 19.11).

19.7 OCEAN ACIDIFICATION

Global increases in atmospheric carbon dioxide (CO_2) have led to increases in oceanic dissolved CO_2 concentration, as well as concomitant decreases in pH and the depth of aragonite saturation state (Ω_{arag}), a condition known as ocean acidification (OA) (Robbins, Hansen, Kleypas, & Meylan, 2010; Zeebe, 2012). These changes have been particularly substantial along the US West Coast (Feely et al., 2012, 2016; Feely, Sabine, Hernandez-Ayon, Ianson, & Hales, 2008; Leinweber & Gruber, 2013; McLaughlin et al., 2018; Turi, Lachkar, Gruber, & Münnich, 2016), where coastal upwelling frequently transports subsurface waters with high levels of CO_2 and with low pH to surface waters nearshore (Fassbender, Sabine, Feely, Langdon, & Mordy, 2011; Harris, DeGrandpre, & Hales, 2013). Ship-based surveys along the West Coast routinely encounter OA hotspots, where large regions of the continental shelf are undersaturated with respect to aragonite ($\Omega_{arag} < 1$) in shallow nearshore waters (Feely et al., 2008, 2016). OA hotspots present a potential impairment to the ability of many marine organisms to form calcareous shells (Barton et al., 2015; Bednaršek et al., 2017; Fabry, Seibel, Feely, & Orr, 2008; Hofmann et al., 2010). Indeed, there is a growing body of evidence that OA may be affecting distributions of calcifying species and the health of nearshore marine ecosystems (Barton et al., 2015; Kroeker, Kordas, Crim, & Singh, 2010; Sato, Levin, & Schiff, 2017).

Measurements of aragonite saturation state have been conducted predominantly on cruises in deeper oceanic waters. However, in nearshore waters like the SCB continental shelf, there are multiple factors that have the potential to exacerbate acidification conditions (Duarte et al., 2013; Harris et al., 2013; Hendriks et al., 2015), including anthropogenic nutrient contributions from land that can result in eutrophication, which, in turn, can trigger production of CO_2 during bacterial decomposition of the excess algal mass. However, comprehensive surveys of the SCB continental shelf are lacking, and the need for management action to control eutrophication is unknown.

In this section, we present the Bight Program's assessment of OA extent and magnitude on the SCB continental shelf. The primary study questions focus on evaluating the status of the carbonate system in the SCB continental shelf, which involves comparing Ω_{arag} in the water column at various locations, depths, and seasons. This assessment provides preliminary information to SCB environmental managers on the potential threat posed by OA in the SCB, and on the utility of exploring immediate future action as a reasonable next step.

19.7.1 Approach

Discrete water samples for spectrophotometric pH measurements and alkalinity were collected at 72 stations on 22 transects across the SCB continental shelf quarterly for 2 years beginning in May 2014. Sample stations ranged from 30 to 200 m depth. Samples were collected near the surface and at 2 m above bottom; a subset of 24 stations were limited to a maximum depth of 100 m. Water samples were collected using Niskin bottles and transferred into 500 mL Pyrex bottles overfilled by a minimum of 250 mL. Alkalinity and pH samples were collected in the same bottle, which was poisoned with ~120 μL of saturated mercuric chloride solution, sealed with a greased glass stopper secured with a rubber band, and stored at room temperature until analysis. Field duplicates were collected for 10% of the samples. pH was quantified using the Carter, Radich, Doyle, and Dickson (2013) spectrophotometric pH technique, estimating pH at 25°C on the total hydrogen ion scale using purified m-cresol purple indicator dye and calibration equations developed by Liu, Patsavas, and Byrne (2011). CO_2 reference materials were run for quality control. Total alkalinity was determined by open-cell potentiometric titration (Dickson, Afghan, & Anderson, 2003). Ω_{arag} and dissolved inorganic carbon (DIC) were calculated from pH and total alkalinity using the CO2calc Version 1.2.8 (Robbins et al., 2010). Program preferences were set to use carbonate system solubility products from Lueker, Dickson, and Keeling (2000), $KHSO_4$ dissociation constants from Dickson, Wesolowski, Palmer, and Mesmer (1990), and total boron from Lee et al. (2010).

Although there is growing scientific consensus around Ω_{arag} as a key indicator of OA (Boehm et al., 2016; Chan et al., 2016), there is not yet a comprehensive Ω_{arag} assessment framework. In the absence of such assessment tools, spatial and temporal patterns in Ω_{arag} were evaluated relative to three biological thresholds that are based on laboratory studies of species known to be sensitive to acidification:

- $\Omega_{arag} = 1.0$, below which aragonite is undersaturated (commonly referred to as corrosive waters)
- $\Omega_{arag} = 1.4$, below which calcareous shells of pteropods exhibit dissolution (Weisberg et al., 2016)
- $\Omega_{arag} = 1.7$, above which oyster larvae grow well in hatcheries (Barton et al., 2015)

19.7.2 Extent and Magnitude of OA in the SCB

Based on the 2-year Bight Program synoptic survey, a substantial portion of the SCB continental shelf waters exhibits Ω_{arag} at levels critical for biological organisms (Fig. 19.12). For three quarters of the year, >80% of the upper water column at depths below 80 m contains water with Ω_{arag} low enough to trigger shell dissolution for sensitive calcifiers like pteropods. Reduced Ω_{arag} also occurs in depths of 0–80 m, but with much less extent, magnitude and frequency.

Aragonite saturation state values for the SCB continental shelf range from 2.99 (Santa Monica Bay, surface waters, spring 2015) to 0.54 (northern SCB shelf, 19 m depth, spring 2015), with a mean of 2.00. The SCB continental shelf Ω_{arag} average is similar to the average for US Pacific Northwest coastal waters (2.2 ± 0.5, Harris et al., 2013), and lower than reported for the North Pacific Ocean (3.3 ± 0.7, Feely, Doney, & Cooley, 2009). SCB continental shelf Ω_{arag} is lower at depth, averaging 2.48 in waters above 100 m and 1.12 in waters below 100 m. However, the relationship between Ω_{arag} and depth is not as strong as the relationship between Ω_{arag} and water density. All SCB continental shelf waters with density $>26\,\mathrm{kg\,m^{-3}}$ were undersaturated with respect to aragonite, similar to observations in the northern California Current System (Feely et al., 2016).

SCB continental shelf Ω_{arag} is strongly correlated with dissolved oxygen ($r^2 = .816$, $P < .001$) and DIC ($r^2 = .938$, $P < .001$); both of these parameters are indicative of deep ocean water with organic respiration that has not yet degassed to the atmosphere (Fig. 19.13). Corrosive waters ($\Omega_{arag} < 1$) in the SCB consistently exhibit dissolved oxygen concentrations $<4\,\mathrm{mg\,L^{-1}}$ (62.5 μM) (Fig. 19.13), indicating that organisms sensitive to changes in acidification may also be subjected to the additional stressor of hypoxia.

The relationship between dissolved oxygen and Ω_{arag} in the SCB remains consistent regardless of whether samples are collected above or below the thermocline (Fig. 19.13), indicating that upwelling from the deep ocean is a probable cause of low Ω_{arag} and low dissolved oxygen in upper surface waters. This finding is consistent with findings in other coastal areas (Cai, Hu, Huang, Murrell, & Lehrter, 2011; Harris et al., 2013). Upwelling also explains the seasonal pattern of corrosive waters in the SCB (see Fig. 19.12). Upwelling in the SCB occurs most frequently in the spring and least frequently in the fall, which is a pattern that matches the increased frequency of low Ω_{arag} in SCB waters at shallower depths during the spring, followed by reduced frequency during the fall.

19.7.3 Future Challenges

The Bight Survey exposed the challenges facing environmental managers in the SCB. OA is a prominent feature of the region which will need to be included in future decision making. Two important decisions lie ahead. First, environmental

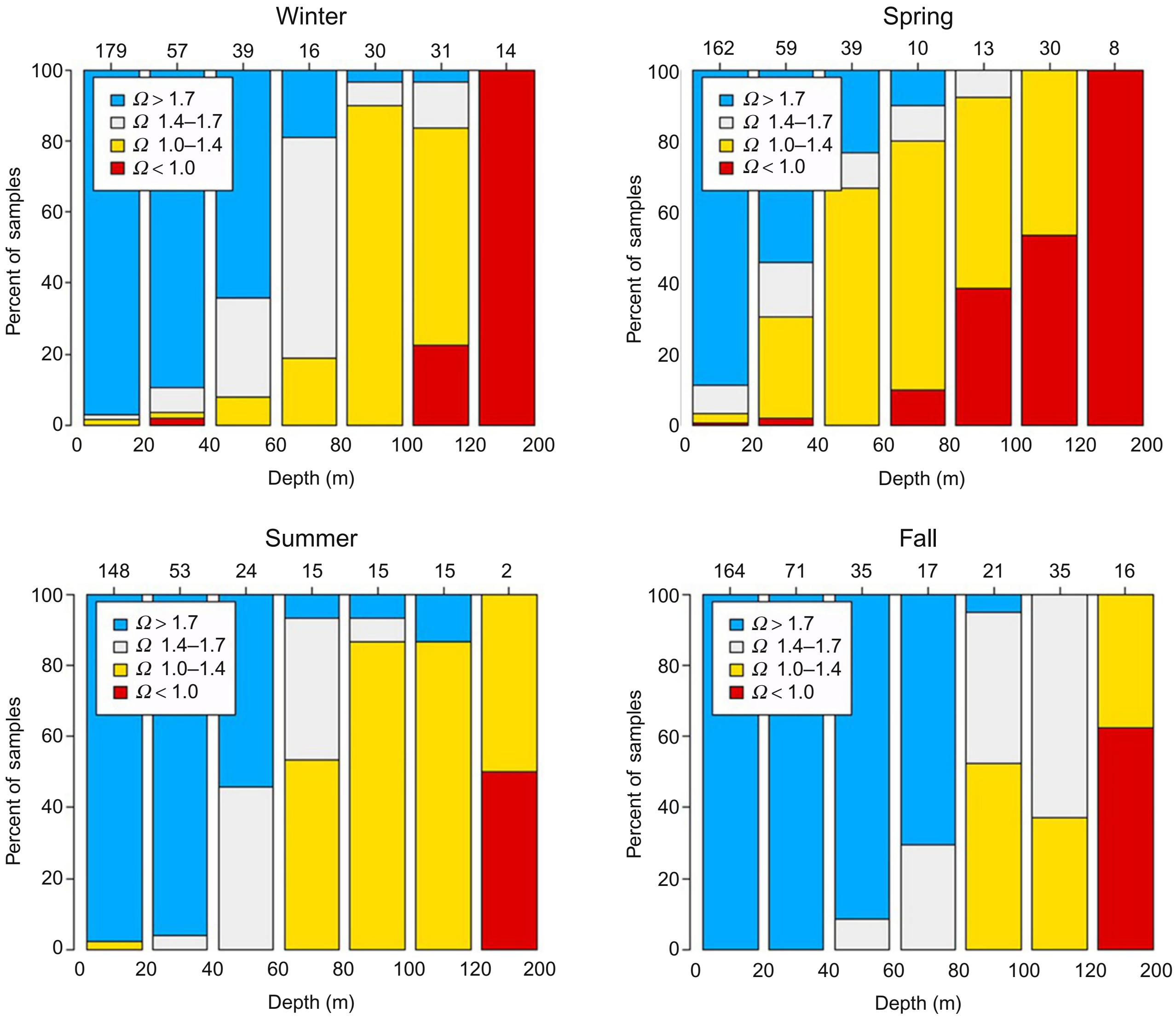

FIG. 19.12 Seasonal variability in percent of samples within Ω_{arag} threshold categories for each depth bin on the SCB continental shelf. Depths are on the bottom axis. Number of samples in each depth bin is on the top axis.

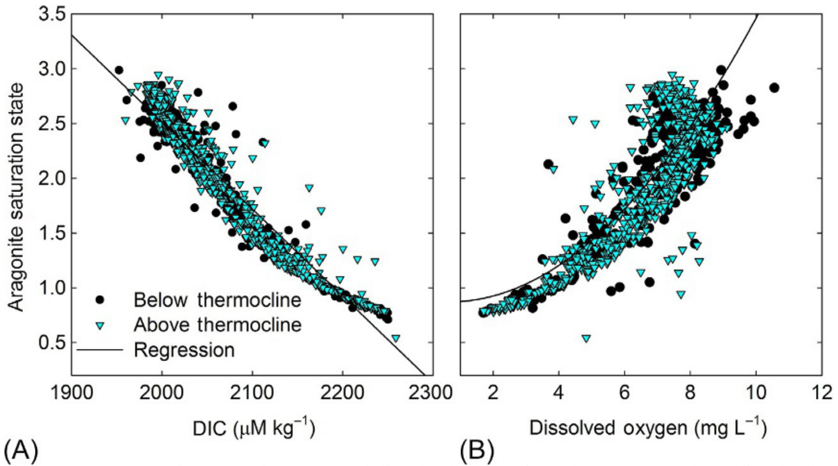

FIG. 19.13 Relationship between: (A) aragonite saturation state and dissolved inorganic carbon (DIC) and (B) dissolved oxygen (DO).

managers need to determine how much OA is too much OA, with the current focus directed at levels where biological effects occur. However, there are a wide range of biological effects that could be considered such as water column or benthic organisms, acute or chronic effects, among others. In this chapter, multiple assumed biological effects thresholds using Ω_{arag} were utilized, taken directly from the literature and ranging between 1.0 and 1.7. However, other measures (or measures in combination) could be used such as pH or alkalinity, among others. Finally, thresholds used herein utilized instantaneous measurements of Ω_{arag}, but other measures of exposure need to be considered including duration, magnitude, and/or frequency.

Second, environmental managers need to assess if any action they might take would ameliorate the effects of OA. Specifically, nutrient inputs have been identified as a potential exacerbator of OA effects (Boehm, Ismail Niveen, Sassoubre, & Andruszkiewicz, 2017; Chan et al., 2016). Anthropogenic nutrient inputs to the SCB can rival natural sources at the local scale (Howard et al., 2014). However, the effect of local nutrient controls on eliminating or minimizing global CO_2 impacts is uncertain. Management strategies for coping with OA, including nutrient reductions measures by wastewater treatment facilities, are likely to cost billions of US dollars, so researchers are now developing coupled physical—biogeochemical models to "virtually" answer the questions about effective nutrient management strategies (Boehm et al., 2015).

19.8 SYNTHESIS

The SCB has exemplified success at addressing large, legacy environmental quality problems. Sediment quality impacts have been at the forefront of environmental management efforts for nearly five decades. The most recent regional assessments indicated that the extent of sediment quality impact is small, accounting for about 6% of the SCB seafloor. Of course, these impacts are not evenly distributed and occur in those habitats closest to human activities such as small urban estuaries and small boat marinas. Yet, even in these habitats close to anthropogenic sources where mixing or dilution are minimized, sediment quality has been steadily improving. While there is work yet to be done, management actions are yielding positive outcomes to challenging issues.

SCB managers have begun addressing other difficult environmental problems, and the outcomes have yet to be fully realized. In this chapter, we describe two; beach water quality and plastic trash pollution. Management actions for ensuring the public health of beach goers has taken a phased approach, starting with what appeared insurmountable in the 1990s—reducing shoreline FIB concentrations during the busy summer swimming season. Yet, after two decades of effort, the vast majority of SCB beaches are "safe to swim." Managers are now addressing the second phase of management actions—reducing shoreline FIB concentrations during the winter wet weather season. The advent of new technology such as human specific markers like HF183, is now providing tools to help chart a path forward towards success during wet weather.

Trash is the second vexing environmental problem managers are currently grappling with. Ambient monitoring of trash illustrated a doubling in extent of plastic pollution on the SCB seafloor over the last 20 years. Partly in response to this increase, managers are implementing regulatory and legislative source reduction mandates such as single-use plastic bag bans. The success of these measures, taken only recently, has yet to be determined. Future monitoring will show if the management actions taken today have stemmed the tide of plastic pollution emanating largely from urbanized watersheds.

The SCB stands on the brink of addressing a truly wicked problem, that of OA. Sediment quality and beach bacteria problems were typically resolved by addressing local sources. Resolving trash problems were perhaps best resolved through regional source control measures, largely because of the persistence of plastic. OA, however, is a global problem. How do managers find solutions for which they have no local or regional control? In this case, SCB managers are determining what local solutions can be taken to slow the onset of global pollution impacts, or at least identify options for enhanced regional resiliency. Currently, SCB managers are trying to characterize the scope and scale of the problem before recommending options and solutions. Undoubtedly, these managers will need the same critical and creative thought processes used to address sediment quality, beach water quality and trash, to successfully address OA.

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