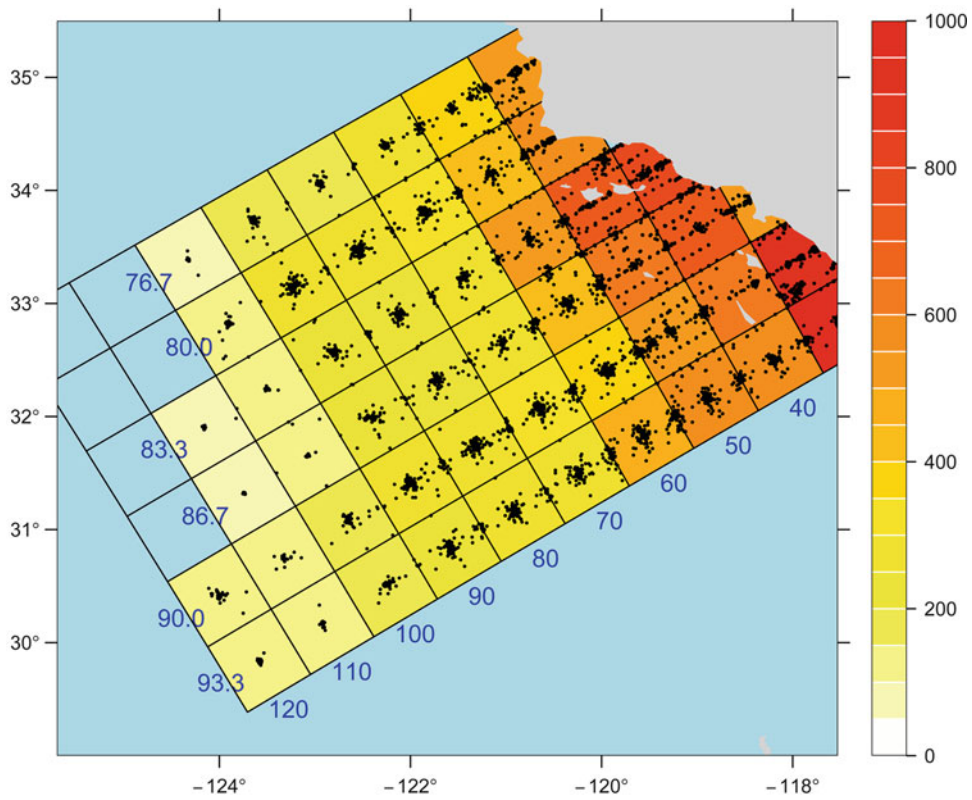

Regional Fisheries Oceanography of the California Current System



Grid pattern of 3.3-line by 10 station cells in the core CalCOFI sampling area (CalCOFI lines 76.7–93.3). *Color key* indicates the actual number of sorted oblique tow samples collected within each cell for the period 1951–2010. *Black dots* indicate the actual sample locations (Courtesy of Ed Weber, NOAA Fisheries SWFSC)

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Regional Fisheries Oceanography of the California Current System

The CalCOFI program

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This book is dedicated to my wife, Elena Turin, who is "my best friend in the whole world".

Preface

My purpose in this book is to bring together in one place a summary of the voluminous information relevant to fisheries oceanography that has been published during the more than 60 year span of the California Cooperative Oceanic Fisheries Investigations (CalCOFI). Though providing a large bibliography, my intent was to extract themes relevant to current research rather than to prepare a compendious review of the literature. The scope of this book is regional to the California Current System stretching from British Columbia, Canada, to Baja California Sur, Mexico, and the time frame extends from the late 1940s to the present.

This book is aimed at graduate students and researchers in oceanography with a special interest in the California Current System. As such I have not made any effort to provide background for a more general audience, which is not to say that the material is inaccessible to non-specialists. The book can potentially provide a reference text for a graduate-level university course on the regional fisheries oceanography of the California Current System. It is not a general fisheries oceanography textbook, and so does not outline the underlying paradigms for this field that one would expect in a broader textbook. The book should provide a useful review and reference point for scientists with an interest in fisheries oceanography of the California Current System. Surprisingly the current literature provides no comprehensive, integrated review of the regional fisheries oceanography of the California Current System. The closest references to such a review are already dated by at least 20 years, although still very useful as reviews from their time [152, 208, 284, 410]. This book updates some of the material in the earlier contributions, but also has a different focus. While most of the earlier works [152, 208, 284] compiled a series of papers by authors who were experts in their field, I attempted to produce a book with a more consistent flavor and style, hopefully without losing too much of the depth that experts bring to their contributions.

The broader aim of this book is to provide an up-to-date reference on the fisheries oceanography in the California Current System. While “up-to-date” pertains to the publication date, this book should continue to provide a solid foundation of knowledge that can be updated with more recent material over time. The California Current System is one of the best studied ocean regions of the world, and the level of oceanographic information available is perhaps only surpassed by the northeast and northwest Atlantic. The volume of studies in these regions is partly a result of the number, concentration, and historical legacy of oceanographic, fisheries and marine biology institutes, university departments and consulting firms. It is also the result of the long-running oceanographic and fisheries survey programs conducted under the banners of International Council for the Exploration of the Sea (ICES), Sir Allistair Hardy Foundation for Ocean Science (SAHFOS), and CalCOFI. CalCOFI, now in its 63rd year since regular surveys began in 1950, is the second longest running fisheries oceanography survey program in the world, after SAHFOS, started in 1931. Understanding of the California Current System is well-established, and so even as new studies are undertaken at an ever increasing pace, the foundation for this book is unlikely to change radically.

To understand the California Current System and the drivers for environmental variability affecting its pelagic fisheries, one must understand the physical oceanography, at very least on the descriptive level. For this reason, in Chap. 2 I spend a considerable amount of time on the descriptive physical oceanography of the region, with additional focus in Chap. 4 on

processes that impact the production and productivity of the system and variability of its fisheries. A review of this nature is inadequate to cover all the relevant detail, so I provide a substantial body of literature in the bibliography that the reader can delve into. Many of these papers originated from work with little connection to the CalCOFI program, but they provide essential background to understanding the results of the CalCOFI program as well as the structure and functioning of the California Current System.

In a region as well studied as the California Current System, it is also important to understand the historical context, and researchers should have a firm grounding in the historical literature. CalCOFI has a wealth of now retired or emeritus researchers (e.g., Joe Reid, John McGowan, Paul Smith, John Hunter, Ron Lynn, Bob Owens, Geoff Moser, Dave Ambrose, Gail Theilacker, Arnold Mantyla, Elizabeth Venrick, Richard Eppley, Richard Schwartzlose, Nancy Lo) who are still with us, and others who have passed on: Reuben Lasker, Ahlie Ahlstrom, Mike Mullin, Ed Brinton, Warren Wooster and John Isaacs among them. Their work and collaborations often provided the foundation for more recent studies. I review many early studies because I believe one should understand what has already been done, and its relationship to the questions that are currently being addressed. This work, and that which followed, forms the core of the legacy of CalCOFI. Reference to the work of these researchers is scattered throughout the book. In Chap. 3, I write about the classic CalCOFI sampling methods that provided the basis for the historical work, and summarize the contribution of the CalCOFI Atlases that were an important contribution of the CalCOFI program.

One chapter reviews what I term “themes” in the regional fisheries oceanography. These are ideas or concepts that have received considerable attention by researchers and have guided trends in the interpretation of research results. In Chap. 4, I organize these themes on the basis of temporal scales and discuss the decadal, inter-annual, seasonal and weather scales. I discuss regime shifts, the basin hypothesis of range contraction and expansion, cycles in fish assemblages, and geographical shifts of assemblages with secular trends in climate. I then focus on effects of El Niño/La Niña, recruitment dynamics and environment, the flow hypothesis, and studies relevant to essential fish habitat. When focusing on seasonal scales, I discuss upwelling and production and the related topics of the timing of the spring transition and the optimal environmental window concept. I then discuss mesoscale features, connectivity and larval dispersal. Last, I discuss weather scale variability encompassing daily to weekly time frames, and ideas about mixing, stability and recruitment, mortality and patchiness.

In Chap. 5, I turn from the surveys to the experimental work that was an important part of CalCOFI at the Southwest Fisheries Science Center in the 1970s and 1980s, but has since taken a less prominent role. These experimental studies were focused on the two principal factors affecting the survival of the early life history stages of small pelagic fish, notably starvation and predation. I review the work on bioenergetics, growth, cannibalism and predation relevant to CalCOFI, but make no attempt to cover the wider topics, like fish reproduction, which have been addressed elsewhere.

For this book, I have drawn extensively on figures and data from the literature on the oceanography of the California Current System, including some of my own work. This includes a variety of sources, including published papers in peer-reviewed journals, reports, as well as “gray literature,” particularly in the fisheries and stock assessment fields. Relevant literature on this topic is so vast that I will undoubtedly have missed some key publications. I have imposed on colleagues to read sections of the book and alert me to glaring omissions, but some important material will inevitably be overlooked, for which I apologize. In many cases I have drawn extensively on the careful literature reviews included in published papers. When doing so, I cited both the authors of the original papers and those of the review. I have paraphrased and synthesized the material in these reviews and tried to be mindful of the dangers of plagiarism. I have also gone over the majority of the original papers to check that I am not compounding any potential errors by citing literature that I have not read myself. Where I did not check the original reference, I cited the original as attributed to. The nature of the material is also both

multidisciplinary and technical so there are dangers of misinterpretation or misrepresentation of the original material in my syntheses. I have tried to minimize these errors by drawing on colleagues who are experts in the sub-fields of oceanography or fisheries to read sections of the book and to offer criticism and comments. It would have been impossible to write this book without drawing on the reviews in previously published work and I extend my thanks to those authors for their careful syntheses of the literature which I have been able to use.

Readers familiar with the literature of the California Current System will note some biases and omissions in my material, as this book is slanted toward fisheries-related studies of southern and central Californian waters. This is the natural outcome of the evolution of the CalCOFI program from a program ranging from the Oregon border to southern Baja California, Mexico, to the current focus on southern and central Californian waters. I have also focused on the peer-reviewed literature and there is a wealth of other material in the gray literature (i.e. not peer-reviewed, not commonly cited, that may not be readily available), most of which were omitted from the bibliography in the book. Another notable gap is that I have neglected salmon. This is partly because the regional focus is on the southwest rather than the northwest US, but it is also partly due to the fact that there is already an abundance of literature on salmon. Attempting to cover even part of it would dilute the focus on CalCOFI. Some readers will notice that I have not covered alternation of small pelagic fish species. This topic is really a subset of the broader topic of low frequency variability that I address in the section on small pelagic fish and the PDO. While alternations of sardine and anchovy occurred in the California Current System, the paleoclimate record shows that sardine-anchovy alternations are not detectable over long time scales. I have not reviewed the literature on climate and pelagic fish in different eastern boundary currents because this is covered well in the book by Checkley et al. (2009) [103]. I have not covered the seabird and marine mammal work that are an important component of CalCOFI. I have also neglected some of the phytoplankton (e.g., many studies by Elizabeth Venrick) and zooplankton work related to CalCOFI (e.g., many of the copepod studies by Michael Mullin), instead choosing to include those studies that are relevant to production processes underpinning fisheries. The justification for these omissions is that these studies are not really fisheries oceanography. The bird and mammal studies are fundamental to ecosystem studies, and to the development of indices for the “state” or “health” of the California Current ecosystem. Their omission in this book is a matter of limiting the scope of this edition rather than any comment on their importance in the suite of CalCOFI measurements and time series. I have not covered much of the literature from the Mexican IMECOCAL program, some of which is in Spanish, nor have I covered the results from the NSF LTER program. The LTER program is focused more on biological than fisheries oceanography. I also had to draw a fine line between summarizing scientific results and material best categorized as history of the CalCOFI program. In reviewing the literature I have been inevitably drawn into the historical aspects of how the data came to be collected, the scientific lineages of some of the scientists and technicians involved, and the formation and dissolution of various groups. There is a tremendous amount of material in the Scripps Institution of Oceanography archives on these historical aspects of the CalCOFI program, but these topics are beyond the scope of this book, and await the attention of a historian. In recognition of the importance of history, Chap. 8 presents personal perspectives by people who have been deeply involved with CalCOFI over the years. These contributions to this book are idiosyncratic, and add color to the more technical material.

Southwest Fisheries Science Center, La Jolla, CA
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Sam McClatchie

Acknowledgments

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I appreciate the support of my colleagues Tony Koslow, Bill Watson, Paul Smith, and Ric Brodeur who agreed to act as independent experts accessible to the publisher. Tony Koslow, SungHyun Nam, and Annie Townsend reviewed parts of the book prior to submission, and provided valuable feedback and comments. I especially appreciated the painstaking editorial and scientific reviews of the entire manuscript provided by Paul Fiedler, Bill Watson, and Andrew Thompson.

I am grateful to many colleagues in NOAA and at Scripps that I have had the privilege of working with since I joined the CalCOFI program in 2007. They include Ed Weber, Karen Nieto, Bill Watson, Andrew Thompson, Noelle Bowlin, Russ Vetter, Paul Fiedler, Roger Hewitt, Nancy Lo, Kevin Hill, Dave Griffith, Dan Rudnick, Art Miller, Hajoong Song, Bruce Cornuelle, Matt Matson, Uwe Send, Ralf Goericke, Tony Koslow, Dave Checkley, Mark Ohman, John McGowan, Annie Townsend, Ron Dotson, Paul Smith, David Demer, Randy Cutter, Juan Zwolinski, Suzy Kohin, Heidi Dewar, Frank Schwing, Roy Mendelssohn, and Steven Bograd. I also thank the sea-going teams that run the CalCOFI surveys, the Scripps Institution of Oceanography Pelagic Invertebrate Collection and the SWFSC Ichthyoplankton laboratory that curate the CalCOFI net and CUFES samples, the Scripps CalCOFI analytical laboratory, the data processing and management staff that handle the data flow from ship to the users of the CalCOFI data, and the fisheries management scientists who clarified my understanding of management issues. Debra Losey never failed to find articles for me on very short notice, which I appreciated. Blaize Mekinna professionally redrafted many figures to improve their appearance.

I am grateful to each of the authors of the vignettes included in Chap. 8 for providing entertaining and informative biographical accounts that help to make the material in the book more personal and interesting. These vignettes were written by George Hemingway, John McGowan, Carl Boyd, Roger Hewitt, Dave Griffith, Ron Dotson, James Wilkinson, John Butler, Geoff Moser, Bill Watson, Andrew Thompson, Paul Smith, Tony Koslow, Gail Theilacker, John Hunter, Nancy Lo, Steve Bograd, Ralf Goericke, Bertha Lavaniegas, Dan Rudnick, Amanda Netburn, Noelle Bowlin, and Rebecca Asch.

I am particularly grateful to Geoff Moser, Paul Smith, and Nancy Lo for their interest in this project, for bringing important material to my attention, and for sharing their appreciation of the importance of history with me. I also thank Tony Koslow for his regular encouragement and confidence that I could complete the book. I greatly appreciated the editorial comments provided by Stephanie Schott. Last, but certainly not least, I thank my wife, Elena Turin, for her unfailing support and patience, for listening to me talking at length about oceanography, and for her spirited discussions on topics of management and administration.

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Acronyms

ABC	Allowable Biological Catch
ADCP	Acoustic Doppler Current Profiler
AHC	Agglomerative Hierarchical Clustering
BEST	Bivariate ENSO Time series
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalVET	CalCOFI Vertical Egg Tow
CCE	California Current Ecosystem
CCMP	Cross-Calibrated Multi-Platform
CCS	California Current System
CMSP	Coastal Marine Spatial Planning
COADS	Comprehensive Ocean-Atmosphere Data Set
CPSMT	Coastal Pelagic Species Management Team
CPUE	Catch Per Unit Effort
CPS	Coastal Pelagic Species
CTD	Conductivity Temperature Depth [sensor]
CUFES	Continuous Underway Fish Egg Sampler
DEPM	Daily Egg Production Method
EBM	Ecosystem Based Management
ENSO	El Niño – Southern Oscillation
EOF	Empirical Orthogonal Function
FAO	Food and Agriculture Organization of the United Nations
FMP	Fishery Management Plan
ICES	International Council for the Exploration of the Sea
IEA	Integrated Ecosystem Assessment
LTER	Long-Term Ecological Research
MEI	Multivariate ENSO Index
MIK	Modified Isaacs-Kidd midwater trawl
MOHT	Matsuda-Oozeki-Hu Trawl
MSY	Maximum Sustainable Yield
NAO	North Atlantic Oscillation
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDBC	National Data Buoy Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOI	Northern Oscillation Index
OFL	Over-Fishing Level
ONI	Oceanic Niño Index
PairoVET	Paired Vertical Egg Tow
PAR	Photosynthetically Active Radiation
PDO	Pacific Decadal Oscillation

PDO ⁺	Positive or warm phase of the Pacific Decadal Oscillation
PDO ⁻	Negative or cool phase of the Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council
PNA	Pacific North American pattern
PRPOOS	Plankton Rate Processes in Oligotrophic Ocean Systems net
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SBB	Santa Barbara Basin
SCB	Southern California Bight
SCE	Southern California Eddy
SCCOOS	Southern California Coastal Ocean Observing System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIO	Scripps Institution of Oceanography
SHAT	Soutar-Hemingway Animal Trap
SLP	Sea Level Pressure
SOI	Southern Oscillation Index
SPAR	Surface Photosynthetically Active Radiation
SR	Stock Recruit
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
SSH	Sea Surface Height
SWFSC	Southwest Fisheries Science Center
TAO	Tropical Atmosphere Ocean
TNI	Trans-Niño Index
TOGA	Tropical Ocean–Global Atmosphere
VPA	Virtual Population Analysis
XBT	Expendable bathythermograph