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The Mandovi and Zuari Estuaries



Editors

Satish R. Shetye, M. Dileep Kumar, and D. Shankar



National Institute of Oceanography, Goa, India



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National Institute of Oceanography
Dona Paula, Goa, India



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Contents

	Dedication	vii
	Acknowledgements	ix
	Maps	xi
	Prologue	1
Chapter 1	The environment that conditions the Mandovi and Zuari estuaries <i>S. R. Shetye, D. Shankar, S. Neetu, K. Suprit, G. S. Michael, and P. Chandramohan</i>	3
Chapter 2	Tides and sea-level variability <i>S. R. Shetye, I. Suresh, and D. Sundar</i>	29
Chapter 3	Numerical models <i>A. S. Unnikrishnan and N. T. Manoj</i>	39
Chapter 4	Mixing and intrusion of salt <i>S. R. Shetye, G. S. Michael, and C. Pradnya Vishwas</i>	49
Chapter 5	Variability of nitrate and phosphate <i>S. Sardesai and D. Sundar</i>	59

Chapter 6	Phytoplankton diversity, biomass, and production <i>S. G. Prabhu Matondkar, Helga do R. Gomes, Sushma G. Parab, Suraksha Pednekar, and Joaquim I. Goes</i>	67
Chapter 7	Zooplankton <i>R. Jyothibabu and N. V. Madhu</i>	83
Chapter 8	Benthic macrofauna <i>Z. A. Ansari, S. Sivadas, and B. S. Ingole</i>	91
Chapter 9	Distribution of iron and manganese <i>Analia M. Mesquita and Sujata Kaisary</i>	99
Chapter 10	Distribution of tributyltin (TBT) in the Mandovi estuary <i>Narayan B. Bhosle</i>	105
Chapter 11	Sewage-pollution indicator bacteria <i>N. Ramaiah, V. Rodrigues, E. Alvares, C. Rodrigues, R. Baksh, S. Jayan, and C. Mohandass</i>	115
Chapter 12	The <i>khaznam</i> of Goa <i>S. N. de Sousa</i>	121
	Epilogue	137
	References	139

This book is dedicated to our colleague

Dr. Mahesh D. Zingde

on his 60th birthday

in appreciation of his service

*to the study of the Indian estuarine and coastal regions
and his endeavours towards controlling its pollution
and ensuring its sustenance.*

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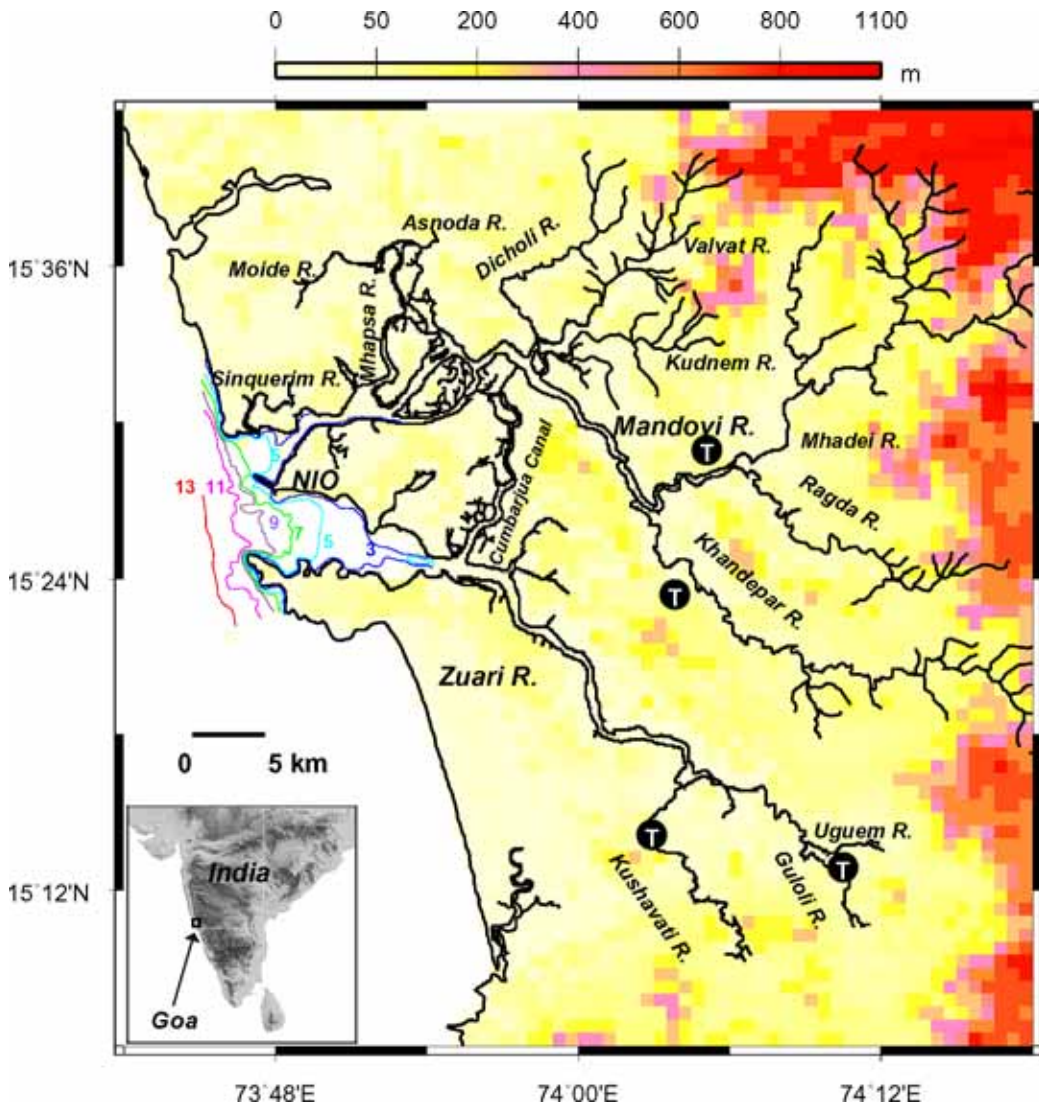
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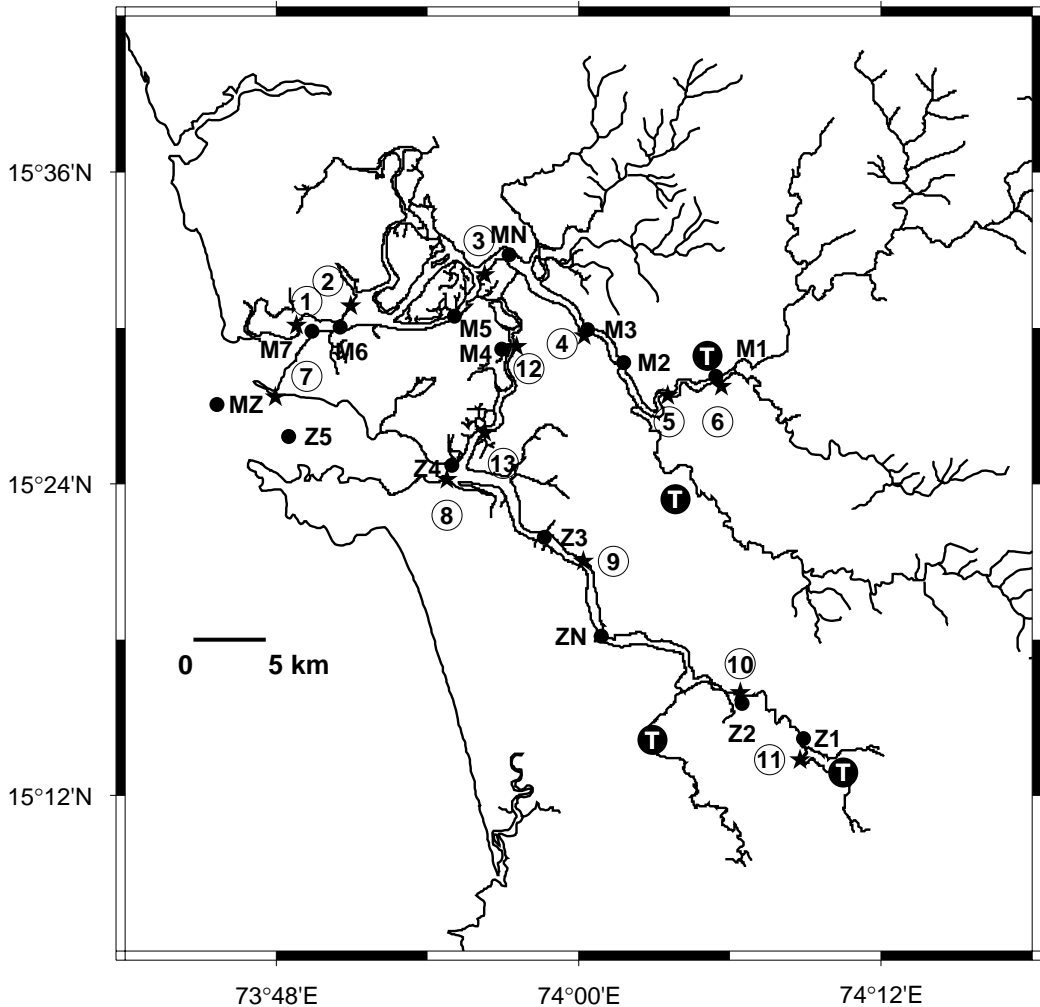
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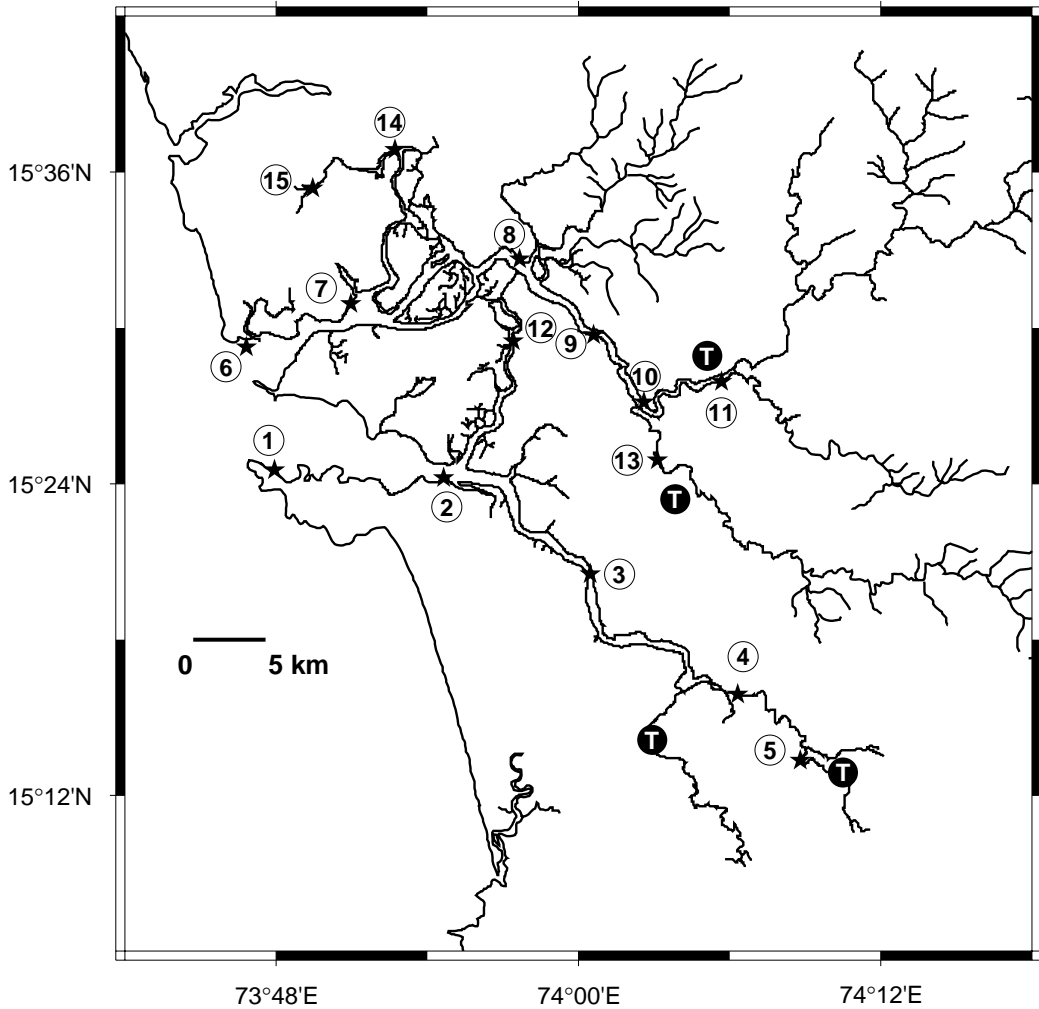
Editors



Map A: Map of the Mandovi and Zuari estuaries based on publications from the Survey of India (1967), the Naval Hydrographic Office, India, and the Admiralty, U.K. The depth contours (m) are with respect to mean sea level which is 1.3m above Spring Low Water at Mormugao (see Map C). To avoid clutter, the depth contours are shown only near the mouths of the Mandovi and the Zuari. “T” in a circle shows location up to which tidal influence is felt in the rivers Kushavati, Uguem, Guloli, Khandepar, and Mandovi. Land elevation is shown in colour, the key for which is given above the figure.



Map B: The locations where water level observations were carried out are shown with a star. The name of the location can be determined by the number in a circle adjoining the star: (1) Verem; (2) Britona; (3) Akkada; (4) Valpoi; (5) Usgao; (6) Ganjem; (7) Dona Paula; (8) Cortalim; (9) Borim; (10) Sanvordem; (11) Sanguem; (12) Banastarim; and (13) Madkai. A solid circle with a station number next to it shows a station where biogeochemical variables were measured. These stations are marked as: M₁, M₂, M₃, MN, M₅, M₆, M₇, and MZ in the Mandovi; M₄ in the Cumbarjua Canal (see Map A); Z₁, Z₂, ZN, Z₃, Z₄, and Z₅ in the Zuari; and, MZ near the mouths of the two estuaries. “T” in a circle shows location up to which tidal influence is felt in the rivers Kushavati, Uguem, Guloli, Khandepar, and Mandovi.



Map C: The locations where sea level and salinity were measured during April and August 1993 are shown with a star. The names of locations can be found from the number inside a circle next to the star: (1) Mormugao; (2) Cortalim; (3) Loutulim; (4) Sanvordem; (5) Sanguem; (6) Aguada; (7) Penha de Franca; (8) Sarmanas; (9) Volvoi; (10) Sonarbaag; (11) Ganjem; (12) Banastarim; (13) Khandepar; (14) Sirsai; and (15) Mhapsa. “T” in a circle shows location up to which tidal influence is felt in the rivers Kushavati, Uguem, Guloli, Kandepar, and Mandovi.

Prologue

The International Indian Ocean Expedition (IIOE) of the 1960s was the impetus for oceanographic research in India. Indian veterans of IIOE found a new home to continue their research at the National Institute of Oceanography (NIO), which was founded on 1 January 1966 in newly liberated Goa.

The main campus of NIO is located on a promontory between the mouths of two estuaries, the Mandovi and the Zuari. Researchers at NIO soon began to study the estuaries. In 1977–1978, the Government of Goa funded a study of the two estuaries, often described as lifelines of the state because of their extensive use for fisheries, agriculture, transportation, dumping of waste, etc. The two estuaries have since continued to attract scientific curiosity over the years, thanks in large measure to support from national and local funding agencies. As a consequence, our understanding of the Mandovi and Zuari estuaries has grown, making them almost certainly, the best studied estuaries of India (Qasim 2003).

Being a national institute dedicated to the study of ocean sciences, NIO owes it to the country to disseminate knowledge generated by its scientists for the betterment of society. It also bears the responsibility of creating awareness among our people about the environmental consequences of human activity, and inspiring a new generation of researchers to undertake research in marine systems. To encourage research on other estuaries of India, often home to large human settlements, it was felt that a summary of what is known about the Mandovi and Zuari estuaries would be most helpful. It was also felt that the summary be written in a manner that would appeal to both professionals and amateurs, especially environmental managers and those with special concerns for the environment. This book has been put together to fulfill these and other needs, particularly in the light of the immense environmental pressures our country will face as its economy continues to grow.

The first chapter of the book describes the environment in which the Mandovi and the Zuari exist. Covered in this chapter are the geometry of the terrain over which the estuaries flow, the rainfall and runoff they experience, the winds, etc. Chapters 2, 3, and 4 provide an overview of the basic physics of the two estuaries: nature of tides, efforts made so far to simulate them in numerical models, and characteristics of stratification and mixing. These are followed by chapters that examine the fundamentals of biology and chemistry of the estuaries. A distinct characteristic of the estuaries is the annual cycle that they exhibit. Chapter 5 describes the annual cycle of nutrient concentration, chapter 6 of phytoplankton, chapter 7 of zooplankton, and chapter 8 of benthic macrofauna. A motivation for estuarine research around the world stems from the desire to keep them healthy and free of pollutants and human interference. Chapters 9, 10, and 11 describe three pollutants that are of special relevance to the Mandovi and the Zuari. Chapter 9 describes the observed concentrations of iron and manganese, whose source lies in the extensive iron and manganese mines of Goa. Chapter 10 discusses the distribution of TBT, which is widely used in building of ships and in their maintenance. The channels of the Mandovi and the Zuari have been used extensively in the past for transporting people and goods. Over the last five decades they have been used to transport iron and manganese ore. The estuaries have also been used to discharge sewage, most of it raw. Chapter 11 discusses the distribution of bacteria that are linked to sewage disposal. Chapter 12 discusses characteristics of wetlands found along the banks of the two estuaries. Known locally as *khaznam*, these wetlands have sustained a special form of agriculture and fishery for almost ten thousand years. The chapter describes how *khaznam* work and their relationship with the estuaries. The book concludes with a chapter that discusses future directions for research on the two estuaries.

It is our fond hope that the contents of this book will encourage further studies of the Mandovi and Zuari, and of our country's several other estuaries.

We dedicate this book to our colleague, Dr. Mahesh Zingde, on his 60th birthday. Studies on the estuarine and coastal regions of India have been the hallmark of his professional career. Dr. Zingde's contributions have greatly improved our knowledge of the structure and functioning of the estuaries in the states of Maharashtra and Gujarat. For several years, Dr. Zingde has served as consultant to state and central governments and to the industry. In this capacity, he has been of immense help to the industry and to several diverse institutions, helping them to minimize pollution and to ensure the health of riverine and coastal ecosystems. As he turns sixty, we express our gratitude to Dr. Zingde for his contributions and for his mentorship over the years.

Satish R. Shetye, M. Dileep Kumar, and D. Shankar
(Editors)

June 2007
NIO, Dona Paula, Goa, India.

Epilogue

As noted in the prologue, the primary objective of putting together this book has been to compile the information and knowledge that exists on the Mandovi and Zuari estuaries — two of the most studied estuaries of India. The 12 chapters of this book provide an overview of what we know, and in comparison, of what remains to be discovered. The purpose of this chapter is to reflect on both these issues, and on how we could discover more about other estuaries of India.

The description of the Mandovi and Zuari estuaries provided in this book reveals some distinct characteristics that we summarize here,

- There are advantages in looking at each estuary as consisting of two parts: a bay and a channel. Conditions in the bay are strongly influenced by what happens on the shelf. What happens in the channel is influenced by what goes on in the bay at its downstream end and (in the freshwater source, or river) at its upstream end.
- Both the bay and the channel go through a distinct annual cycle. There are two distinct phases to this cycle,
 - The wet phase (roughly June to mid-October) is the time of flushing the estuaries many times over, thus expelling everything that existed in the water (salt, plankton, etc.); benthic organisms disappear due to the change.
 - The dry phase (mid-October to May) is the time of rejuvenation. Phytoplankton grows; so does zooplankton, and benthic organisms re-colonize the bed. Salt migrates upstream into the channels of the two estuaries.

In essence, two spatial regimes, each with two distinct temporal variations, dominate the behaviour of these estuaries. This book provides a glimpse of the behaviour.

Yes, it is only a glimpse, because we are not yet ready for more. While we do have a fair idea of some of the physical processes — tides, for example —, there are other

aspects we know little about. This book has not discussed tidal currents in the estuaries because we do not have good records to describe them. The channels of the estuaries are too much in use to permit deployment of current meter moorings for sufficiently long periods to allow proper tidal analysis (about a month). The available description of stratification is at best rudimentary, and no effort has yet been made to quantify the upstream migration of salt during the dry phase. We only have a glimpse of how some of the fundamental variables associated with biogeochemical cycling — nitrates, phytoplankton, and zooplankton — behave. Needed are data, more extensive and more systematically collected, to describe the spatial and temporal variability revealed in the chapters of this book. Nevertheless, these glimpses can help design new field and laboratory experiments to describe the evolution of the estuaries with greater confidence than is possible today.

Another challenge today is to describe quantitatively the processes revealed in these chapters using mathematical models. Such efforts have not progressed beyond simulation of tides, and, may be, vertically averaged salinity in the two estuaries. It is time to take the next step, and launch efforts to model biogeochemical cycling, even though we are not particularly happy with the description of the cycling processes that are operating in the estuaries. Perhaps the efforts to model the processes will provide new insights that would help in designing field experiments to describe biogeochemical cycling more comprehensively and efficiently.

In summary, though the material presented in this book documents the advances made since Qasim (2003) in our understanding of the Mandovi and Zuari estuaries, it is evident that much still remains to be done.

We hope this book will inspire studies such as this on the Mandovi and Zuari estuaries. Our fondest hope, however, is that the faculty of a university department, or a college located near an estuary, would, after reading this book, consider the estuary a natural laboratory that can be used to formulate student research projects.

Editors

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