Estuaries of the World

Eric Wolanski
Editor

Estuaries of Australia in 2050 and Beyond

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Estuaries of the World

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ISSN 2214-1553 ISSN 2214-1561 (electronic)
ISBN 978-94-007-7018-8 ISBN 978-94-007-7019-5 (eBook)
DOI 10.1007/978-94-007-7019-5
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2013946905

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

I dedicate this book to my grandson Oliver, born and being brought up on the shores of Australian estuaries; I hope that some will remain healthy for him to entrust to his children.

Eric Wolanski

Foreword

Why This Book Series? Why This Book?

Over the last decade, there have been numerous advances in both understanding and managing estuaries, with an increasing focus on multidisciplinary studies, through numerous case studies and projects at local and national levels. In addition, regional and global programmes have been developed; some are being implemented and some are in evolution. However, despite the rapidly increasing knowledge about estuarine ecosystems, crucial questions on the causes of variability and the effects of global change versus local anthropogenic pressures are still poorly understood. At the same time, courses at university increasingly focus on environmental science and management but with comparatively very little emphasis on estuaries. There are excellent textbooks in this field, mostly process-based and about synthesising science, but by and large they do not reflect the great variety of estuaries around the world; so the practical application of this knowledge to one estuary or one coast with several estuaries is very complex and not straightforward. As a result, most of the time, students studying a particular estuary or coast use ill-assorted websites, sometimes of doubtful quality. The situation is comparable to that of decision-makers and managers. They are submerged by all sorts of publications, very few concentrating on one estuary or on specific problems.

Because the perception of politicians and managers of coasts is slowly shifting from a mainly short-term economic approach towards a long-term socio-ecological perspective, Springer Publishers recognised the need to make existing scientific information much more manageable to non-specialists, without compromising the quality of the information. The series *Estuaries of the World* was established in such a context, giving the scientific community the opportunity to assemble and put in order (sometimes disorganised) existing knowledge. Overall, the series will encompass all scientific aspects of estuaries through a multidisciplinary approach.

This book (the first in the collection) deals with a selection of estuaries which are characteristic of a whole continent: Australia. The country is so large that it spreads from the tropics (10th parallel) to the temperate zone in Tasmania. Estuaries themselves differ by an order of magnitude in terms of size; yet, they all have common properties and processes. In Australia, as anywhere else in the world, the coastal zone and its estuaries, large or small, are amongst the most endangered areas. Pollution, eutrophication, urbanisation, land reclamation, dams, irrigation, over-fishing and exploitation continuously threaten the future of some estuaries, which bear the full pressure of these developments. However, unaffected systems still exist in Australia and, if not strictly pristine, enjoy an exceptional ecological quality. In between these two categories, unfortunately some high-quality environments are currently being degraded because of loose management. The major challenge that humans face today is protecting estuaries, which benefit from a good ecological status, by managing their use. Preventing other systems to further degrade and restoring them require immediate action so that future generations can also enjoy the fantastic visual, cultural and edible products that

they provide. Such an approach assumes that all users of the environment share views and are able to communicate wisely on the basis of robust science. Current changes in climate (e.g. temperature rise, sea-level rise, increased risks of floods and droughts and ocean acidification) may increase the risk of abrupt and non-linear changes in many estuarine ecosystems, which would affect their composition, function, biodiversity and productivity. In order to provide a solid scientific background to future debates, this book does not just attempt compiling case studies but puts into light best practice both in scientific research and coastal management.

Institute of Estuarine and Coastal Studies, Jean-Paul Ducrotoy
The University of Hull, Hull, UK
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Dr. Eric Wolanski is a coastal oceanographer and ecohydrologist. Eric has 360 publications; he is a fellow of the Australian Academy of Technological Sciences and Engineering, the Institution of Engineers Australia (ret.) and l'Académie Royale des Sciences d'Outre-Mer. He was awarded an Australian Centenary Medal for services in estuarine and coastal oceanography, a Doctorate Honoris Causa from the Catholic University of Louvain, a Queensland Information Technology and Telecommunication award for excellence and the Estuarine and Coastal Sciences Association (ECSA) Lifetime Achievement Award. Eric is a member of the IGBP-IHDP Scientific Steering Committee of Land-Ocean Interactions in the Coastal Zone (LOICZ) and a member of the Scientific Planning Committee of Japan's Environmental Management of Enclosed Coastal Seas (EMECS). He is chief editor of *Estuarine, Coastal and Shelf Science*, *Wetlands Ecology and Management*, and the *Treatise on Estuarine and Coastal Science*.

Prologue

The majority of the Australian population lives near estuaries and the coast. Many Australian estuaries were historically degraded and others are at risk of degrading as the population and the economy are increasing rapidly. Is Australia's development ecologically sustainable for estuaries and coasts? This book addresses this question by detailed studies of a number of iconic Australian estuaries and bays. This book demonstrates, through the writings of eminent Australian scientists, how these estuaries function by merging the physical oceanography, the ecosystem processes and the socio-economic science. The chapters describe most types of Australian estuaries from pristine in the tropics to those impacted by irrigation, urbanisation and industrialisation. The key message is that the basic science has been done, and this makes it possible to understand how these brackish water ecosystems function. This enables the scientists to forecast with some confidence what these estuaries will look like by 2050 based on political and socio-economic decisions that are now made.

This book offers science-based solutions to achieve ecologically sustainable development. It is a wake-up call that every Australian estuary faces present and future socio-economic and environmental problems with various scales. This book shows that we have much to learn by understanding the lessons from the past and from each other as they apply to the wide variety of Australian estuaries in order to ensure that future developments do not occur at the cost of the environment. To help achieve this outcome, this book demonstrates how to use science to balance the socio-economic imperatives with the ecological needs of the estuaries so that they can deliver the full range of ecosystem services – such as a high quality of life – that the population expects.

I commend this book for its comprehensive coverage of the variety of estuaries in Australia and for using the best science available. I hope that it will create constructive discussions and awareness of the opportunities and risks for Australian estuaries and the human population living on its shores and the need for integrating our efforts to deal with these development issues.

This book is especially important because both major political parties have virtually adopted a policy of a "little Australia", probably as a means of avoiding environmental and developmental difficulties and the investment that would be needed for both.

There are some people in Australia who believe that this country is already fully populated. Nobody in any other country in the world, having regard to the world's population pressures, would hold a similar view.

In other words, Australia's current policies are not sustainable.

At the end of the Second World War, Australian political leaders of all persuasions knew that Australia was indefensible with its resources and population. They set about expanding both in a vigorous and farsighted manner which has done much to benefit Australia and to diversify our society.

We need to embrace the future with a similar commitment. We need to aim for a much larger population, not only to justify our holding a large and wealthy continent in the eyes of the world but also to give us greater weight to advance Australian values, to make a greater contribution to security and to peace throughout the Western Pacific.

In short, an Australia of 40 or 50 million would find it much easier to be independent of major powers. We have too often followed major powers into their wars of no direct interest to Australia. That policy which has dogged Australia since Federation needs now, quite desperately, to be ended.

This book is valuable because the research gives us intimate knowledge of how to handle the consequent population pressures, how to protect and enhance the environment and what investments will be necessary to do so. It can therefore be most helpful as a guide for the future of Australia.

The Right Honourable Malcolm Fraser, AC CH
Former Prime Minister of Australia, 1975–1983

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Estuaries of Australia in 2050 and Beyond – A Synthesis

Eric Wolanski and Jean-Paul Ducrotoy

Abstract

This book "*Estuaries of Australia in 2050 and Beyond*" in the series "*Estuaries of the World*" addresses the question: Is Australia's growing human population and economy environmentally sustainable for its estuaries and coasts by 2050? To answer this question, this chapter summarises detailed studies of a number of iconic Australian estuaries and bays. They can be divided in three types based on the human impact, namely (1) estuaries that bore the full pressure of the historical developments, (2) estuaries being degraded, and (3) estuaries that are still relatively pristine. For type (1) the case studies focus on Sydney Estuary, the Coorong/Murray-Darling Estuary, Port Philip Bay, and the Tamar Estuary. For type (2) the case studies focus on the Gold Coast Broadwater, the Hawkesbury Estuary, the Burdekin flood plains, Moreton Bay, the Ord River estuary, Brisbane peri-urban estuaries, South Australia gulfs, Hervey Bay, and Darwin Harbour. For type (3) the case studies focus on the Mary River estuary and floodplains in the Northern Territory and Deluge Inlet in Queensland. In addition, summaries are also provided of the state of the environment and the management strategy for a number of other estuaries and coastal waters. Overall, this chapter synthesises multidisciplinary scientific knowledge in time and space across Australia to suggest what Australian estuaries may look like in 2050 based on socio-economic decisions that are made now, and the changes that are needed to ensure sustainability.

Keywords

Rainfall • Evaporation • Population • Ecosystem services • Estuaries • Quality of life • Development • Environmental impact • Sustainability • Australia

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E. Wolanski (ed.), *Estuaries of Australia in 2050 and Beyond*, Estuaries of the World,
DOI 10.1007/978-94-007-7019-5_1,

Introduction

Is Australia's growing human population and economy environmentally sustainable for its estuaries and coasts? To answer this question, this book reports detailed studies of a number of iconic Australian estuaries and bays. This chapter is a synthesis that integrates this knowledge in time and space across Australia to suggest what the Australian estuaries may look like in 2050 and beyond based on socio-economic decisions that are made now, and the changes that are needed to ensure sustainability.

For this synthesis, it is necessary to remember that Australia is a vast continent with a wide variety of natural settings that shaped the estuaries before the human impact. The human impact is an additional recent impact. As a result no two estuaries are alike. It is necessary to take a step back and understand the importance for the estuaries of the geography and the recent history.

The Geography and the Recent History of Australian Estuaries

Australia is a continent with a land surface area of 7.7×10^6 km^2. It has a long history of human inhabitation lasting several tens of thousands of years and a very short modern history that started with British settlement in 1788 (Flannery 1994). The human population at that time was very small, estimated at about 0.35×10^6. It is likely that most rivers and estuaries were then healthy ecosystems. That is not to say that they were in a virgin state, because the human population, even if small compared to present values, had substantially modified the vegetation cover over the watersheds through the use of man-made bushfires.

The large watersheds of Australia are shown in Fig. 1, the largest watershed being that of the Murray-Darling River, which comprises about 14 % of the total area of Australia. In addition there are numerous small watersheds, many of them are mangrove-fringed in the tropics and sub-tropics, and their number has not been determined.

The human population of Australia in modern history has increased rapidly, and is still increasing rapidly by one person every 1 min 21 s (Fig. 2). By 2100, the population curve is expected to resemble a S-curve characterised by a rapid, non-linear growth followed by a flattening out to levels between 30 and 100×10^6 that depend on the rates of immigration (Fig. 2). The population is now nearing 23×10^6.

While this population S-curve somewhat resembles that in North America following mass immigration (Daniels 1990), the spread of the population differs greatly between the North American and the Australian continents. While there are numerous large inland cities in North America, such is not the case in Australia. The main reason for this difference is the rainfall distribution that in North America enables human settlement over much of the continent while in Australia rainfall is largely restricted to a narrow coastal strip (Fig. 3a). The country is divided between a tropical North and a temperate South (Fig. 3b). As a result much of the human population is concentrated along the temperate coast where rainfall allows it (Fig. 3c), but not along the tropical coast where rainfall is abundant but historically people have been reluctant to settle. There are several reasons for that reluctance, including: firstly the harsh tropical climate, secondly the remoteness of the area, thirdly the devastating monsoonal floods, fourthly in Australia's tropics evaporation commonly exceeds rainfall (Fig. 3d) and as result many tropical rivers are dry in the dry season. All these facts combine to make Australia have scarcely more than two persons per km^2 of total land area. However the population density is large along the temperate coast where reliable rainfall occurs. Australia is one of the world's most urbanised countries as 89 % of its population live in urban areas mainly near estuaries and coasts.

It is apparent from Fig. 1 that the political map of Australia was drawn with no regard to the hydrology. This leads to economic, administrative and political constraints that result in the Australian State governments cooperating little with each other and with the Australian government in water resources management. It is still as if the land, the river, the estuary and the sea were not part of the same system. Large-scale, intensive irrigation farming has been developed in the most suitable catchments in the temperate south. Agriculture requires water, but the availability of water in Australia varies markedly from year to year, with rainfall characterised by a succession of 'good years' (i.e. years with well above average rainfall) and 'poor years' (i.e. years with well below average rainfall; Fig. 4). 'Poor years' commonly occur in succession of several years. Using short term rainfall data from 'good years', water resources managers have commonly over-estimated the availability of water during 'poor years' and thus commonly they have over-allocated water that can be used for irrigation with insufficient water available in 'poor years' for both irrigation and the environment. During 'poor years' the usual management policy in Australia has been to satisfy the needs for irrigation first and neglect the environmental needs of the rivers and estuaries.

The resulting impact of such water usage policies on the estuary is most evident in the Murray-Darling River (Fig. 1). The river catchment extends to several States and in practice there is no catchment water authority; the water resources managers in the various riparian States upstream of South Australia commonly have over-allocated irrigation water licences in their own States and ignored the cumulative impacts on the river from similar allocation in the other riparian States. During 2005–06, which were 'poor years', water extractions were over 9,000 GL from 6,530 GL of

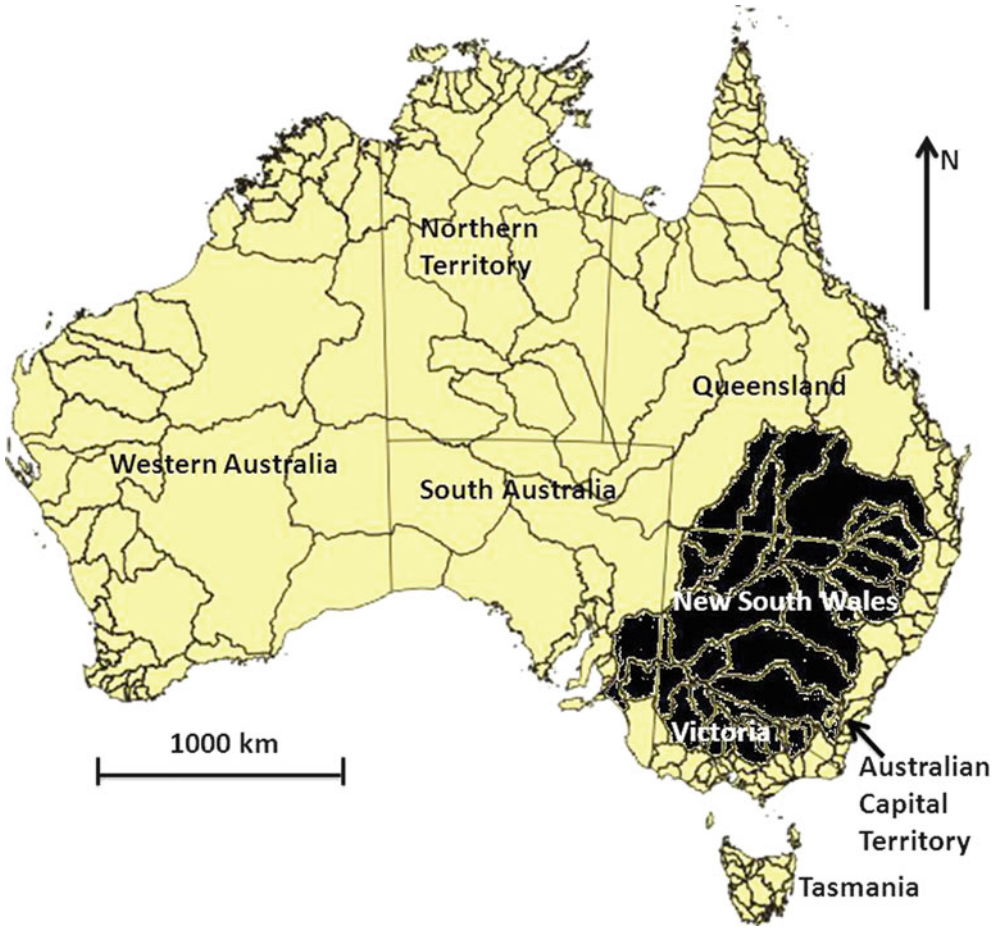

Fig. 1 The political map and the watershed map of Australia. The *darkened area* is the watershed of the Murray-Darling river basin

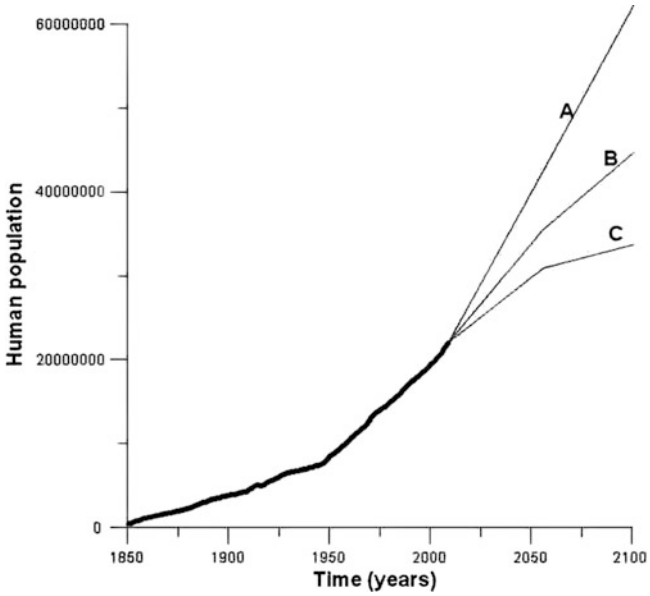

Fig. 2 Time series-plot of the human population in Australia (*thick line*) since 1850 until present, and in the future as scenarios *A*, *B* and *C* that depend on likely rates of immigration (The data were provided by the Australian Bureau of Statistics)

inflow, the balance being due to using of water stored in impoundments in previous 'good years' (Murray–Darling Basin Ministerial Council 2007). As a result during such 'poor years' zero or negligible river flows reached the sea for months at a time. This is totally a man-made environmental crisis and the results for the estuary are devastating, and this is described in chapter "The Murray/Coorong Estuary Meeting of the Waters?" by Jochen Kaempf about the Coorong/Murray Estuary in this book.

Rivers are impacted by changes to river flows and pollution by nutrients, pesticides and herbicides from large-scale irrigation farming that was encouraged by State governments policy of expanding the water supply while environmental management was a secondary consideration (Hussey and Dovers 2006; Petheram et al. 2008). As a result, although European settlement in Australia is only slightly over 200 years old, its environmental impact on Australian rivers is dramatic. From an Australia-wide survey of the river environment index, approximately 85 % of the rivers' length is affected by catchment disturbance (NLWRA 2000). Of the regulated and unregulated rivers for which data are available, over 80 % are modified to some extent

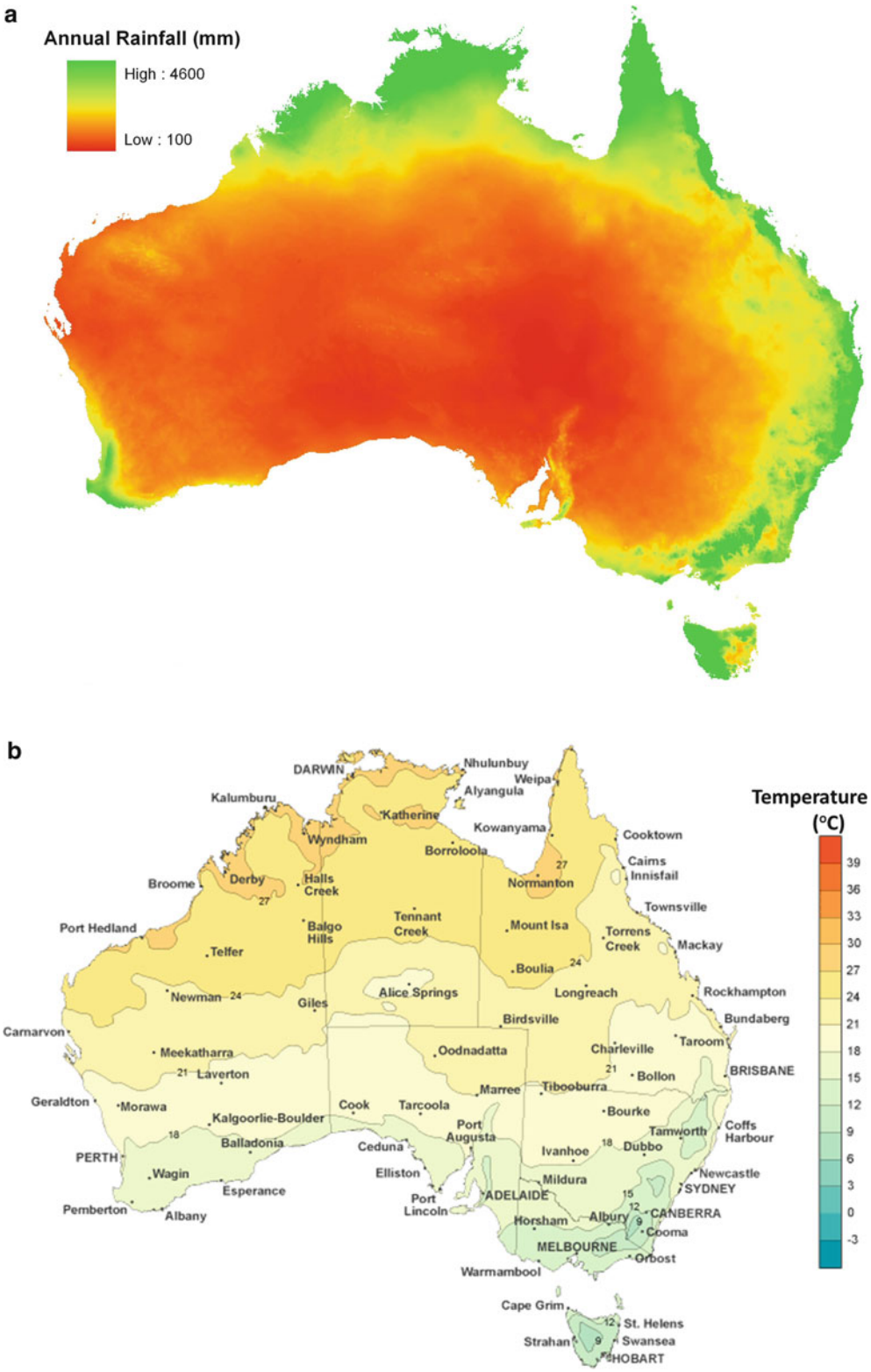

Fig. 3 Distribution map of (**a**) mean annual rainfall (mm/year), (**b**) mean temperature (°C), (**c**) human population density and location of capital cities, (**d**) mean annual evaporation (mm/year) ((**a**) is modified from the National Land and Water resources Audit, (**b**) and (**d**) are modified from the Bureau of Meteorology, and (**c**) is modified from Regional Population Growth, Australia)

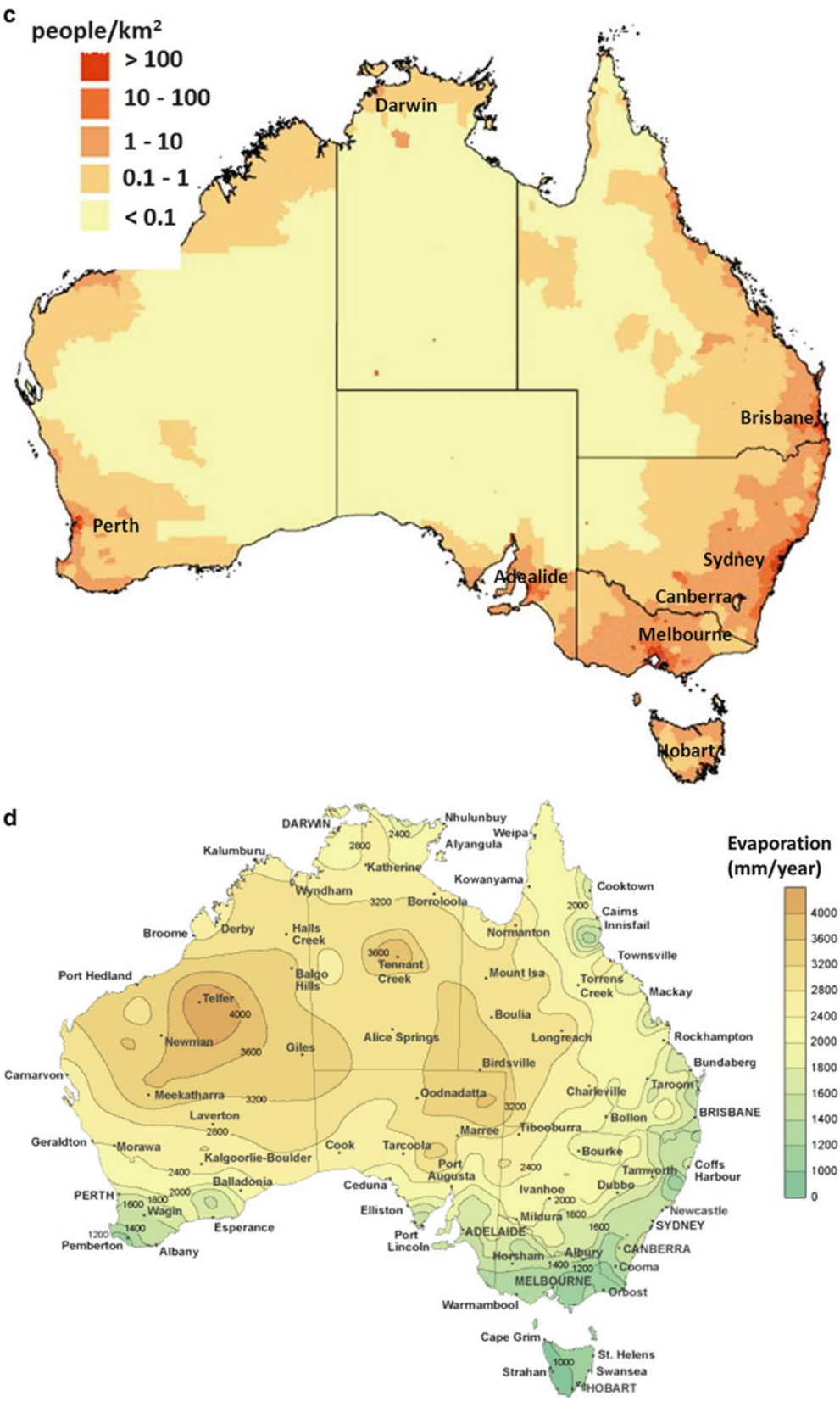

Fig. 3 (continued)

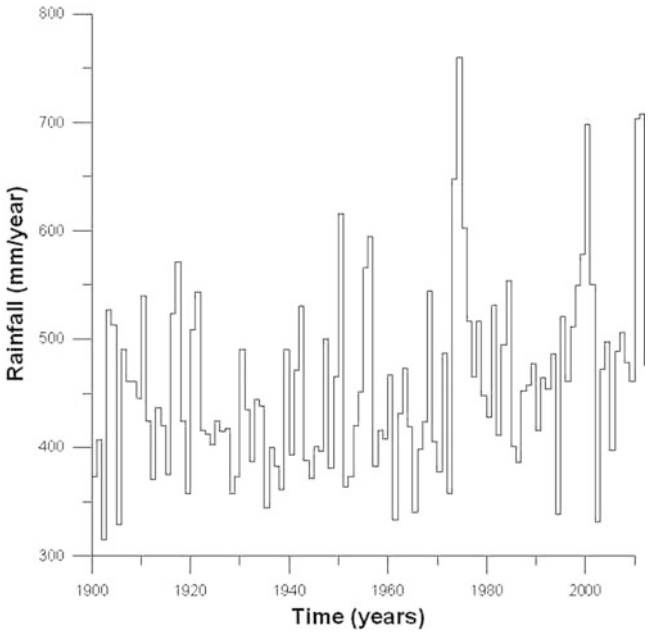

Fig. 4 Time-series plot of Australia-wide annual rainfall from 1900 to present (The data were provided by the Commonwealth Bureau of Meteorology)

and nearly 30 % are substantially modified. Changes to riverine habitats are severe in the Murray-Darling Basin, South Australia, and parts of the Western Australian wheat belt. Nutrient (mainly phosphorus) and suspended sediment loads are greater than natural levels for over 90 % of the length of Australian rivers and are severely modified in almost 10 % of total river length (NLWRA 2000).

These farm-derived nutrients, sediment and also pesticides and herbicides reach the estuaries and coastal waters, which they degrade. In most cases the environmental degradation is local, e.g. a particular estuary or coast is degraded and this affects mainly the local community. In some cases this degradation is significant for Australia; such is the case for the Great Barrier Reef of Australia. Seagrasses in key areas such as Cairns are now at their smallest ever recorded distribution (Rasheed et al. 2013). Coral calcification rates have declined by 15 % since 1990 (De'ath et al. 2009), and coral cover has declined by nearly 50 % over the last 27 years (Dea'th et al. 2012). Farm-derived nutrients, sediment, pesticides and herbicides are responsible for this degradation of the Great Barrier Reef, the management of which does not include managing land-use in the adjoining catchments (Brodie and Waterhouse 2012). This is probably the most spectacular case of failed coastal management in Australia from ignoring to manage the entire ecosystem including the watershed as one system (Wolanski 2007; Mee 2012). This degradation will be further exacerbated by planned, massive coal export ports and industrial developments in or adjacent to the Great Barrier Reef Marine Park, an issue about which in 2012 the UNESCO World Heritage Committee expressed particular concern and (at the time of writing this synthesis) is evaluating if the Great Barrier Reef should be officially listed as a World Heritage *in danger*.

Can the Swan River Estuary Health Be Restored?

The microtidal Swan (also called Swan-Canning) Estuary flows through the city of Perth. The estuary is highly eutrophicated (Peters and Donohue 1999; Hamilton et al. 2001; Brearley 2005) because of slow flushing (Stephens and Imberger 1996; Etemad and Imberger 2005) and runoff from rural and urban catchments (John 2013). The State government recognises the iconic value of the estuary and created the Swan River Trust, which provides funding for a number of mitigation measures that include supporting community groups undertake on ground restoration projects, pilot projects to reduce sedimentation from building sites, improve local government processes to reduce the impact of light industry on the rivers, facilitate community involvements and the review of new development proposals, and facilitate the creation of urban wetlands that help filter urban stormwater (Swan River Trust 2012). It is also advocating progressively phasing out highly water-soluble phosphate fertilisers and improving fertiliser practices in rural and urban catchments. Despite these restoration efforts, the frequency of algal bloom occurrences has remained relatively stationary and the annual average Index of Sustainable Functionality (an index of the sustainable health of the estuary) did not improve from 1995 to 2009 (Kristiana et al. 2012). Thus the mitigation measures to counter eutrophication at best have countered the increased pressures on the health of the estuary from new land development and climate change, but they did not improve the health of the estuary.

Case Studies: The State of Knowledge

Only a limited number of Australian estuaries have been studied in great detail – indeed there are not enough estuarine scientists in Australia to study all the estuaries, neither is there enough research funding. Nevertheless this book brings together the majority of the detailed studies of

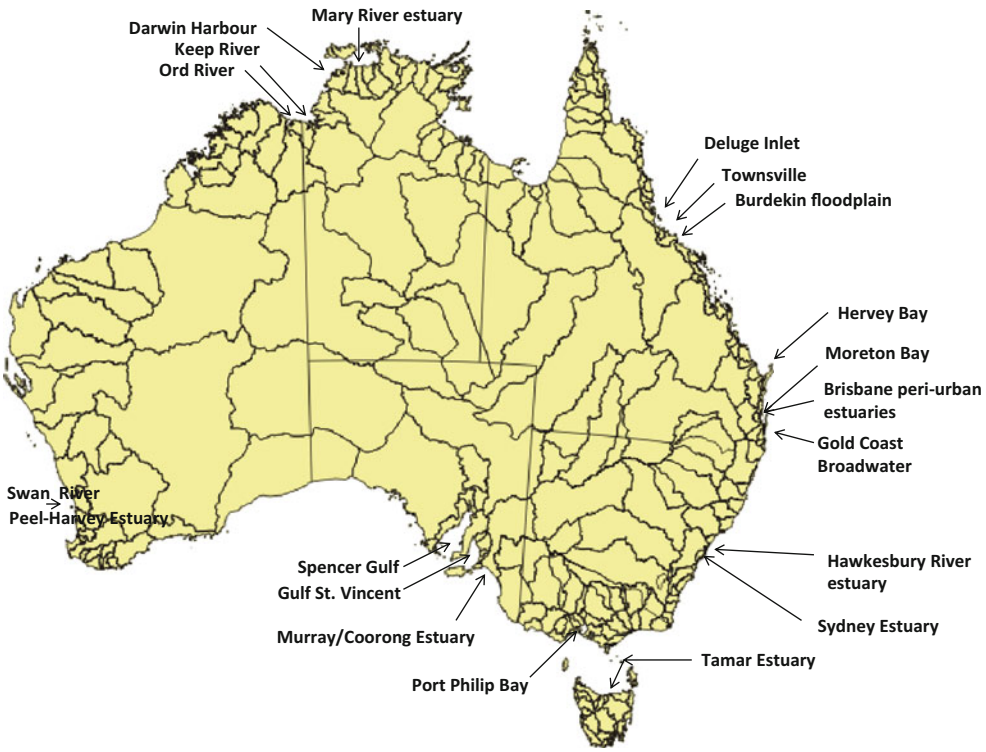

Fig. 5 A location map of the estuaries and coastal waters featured in this book. The Swan, Keep, and Peel-Harvey estuaries, and the estuary and coastal waters of Townsville are discussed in this synthesis; the other sites are described in a chapter each in this book

Australian estuaries and coastal waters. The study sites are shown in Fig. 5.

The case studies of Australian estuaries in this book can be divided in three types based on the human impact, namely (1) estuaries that bore the full pressure of the historical developments, (2) estuaries being degraded, and (3) estuaries that are still relatively pristine. For type (1) the case studies focus on Sydney Estuary, the Coorong/Murray-Darling Estuary, Port Philip Bay, and the Tamar Estuary. For type (2) the case studies focus on the Gold Coast Broadwater, the Hawkesbury Estuary, the Burdekin flood plains, Moreton Bay, the Ord River estuary, Brisbane peri-urban estuaries, South Australia gulfs, Hervey Bay, and Darwin Harbour. For type (3) the case studies focus on the Mary River estuary and floodplains in the Northern Territory and Deluge Inlet.

The response of these estuaries to the human impact is described below, it depends strongly on the geomorphology and hydrology, and thus on the geographic location of each estuary.

A Socio-economic Classification of Australian Estuaries

These case studies demonstrate, through the writing of eminent Australian estuarine scientists, how these estuaries function and this knowledge requires merging the physical, chemical and biological oceanography, the ecosystem processes, and the human impact. The studies describe most types of Australian estuaries from pristine estuaries to estuaries heavily impacted by urbanisation, harbour operations, industrialisation, and intensive irrigation and water management schemes in the river catchments. The basic science has been done in some estuaries particularly those in the capital cities, and is being done in other estuaries. This makes it possible to understand, at least as a first order approximation, how these brackish water ecosystems function. This enables the scientists to forecast with some confidence and some uncertainty what these estuaries may look like by 2050 based on political and socio-economic decisions that are made now, just like the decisions made a few decades ago dictate what these estuaries look like now. This book shows that we have much to learn by understanding the lessons from the past and from each estuary. It is hoped that these lessons can then be applied to all Australian estuaries in order to ensure an environmentally sustainable Australia where the estuaries will keep delivering the full range of ecosystem services that the population expects in order to maintain a high quality of life.

The Baggage of History

Historically Australian estuaries were seen as little more than navigation channels and convenient waste dumping

sites, a viewpoint similar to that held during the development of ports and harbours in the Asia Pacific region (Wolanski 2006). The impact on Australian estuarine environments from developments along their shores and from land-use in the river catchment was seen as inconsequential. That was the old practice of development at all costs.

Shared Water Resources

Where an estuary depends on the good will of various State governments and the Commonwealth governments, no political compromise has yet been fully agreed by all governments to enable ecological restoration and the system is allowed to further degrade, if not collapse (e.g. see the chapter "The Murray/Coorong Estuary Meeting of the Waters?" by Jochen Kaempf about the Coorong/Murray estuary).

Urbanisation

All State capital cities are harbours built along estuaries or sheltered bays. These are important cities (see Fig. 3c) with large industrial and urban centres, whose respective footprints on the estuaries have now merged. However Australia has become a developed modern, savvy society and in its State capital cities the population is now demanding a high quality of life that includes enjoying the benefits of a healthy estuarine ecosystem. Responding to this public demand, governments do actually attempt to restore some of the ecological functions of degraded urban estuaries (e.g. Port Philip Bay, Sydney Estuary, and Gulf St. Vincent) and they implement policies to try to prevent further degradation of estuaries from creeping urbanisation (e.g. the Gold Coast Broadbeach Estuary, Hervey Bay, and Brisbane small peri-urban estuaries).

In the State capital cities, with the possible exception of Darwin, large efforts are made to restore, or at least preserve, some sort of viable ecosystem in the estuaries and coastal waters. The results of such efforts are exemplified in the case of Perth, described in the box above.

In some capital cities with a population demanding healthy waterways, the State government push for developments can conflict with the population demanding healthy estuaries. A compromise is then sought. For instance in Brisbane – see the chapters "Turbulent Mixing and Sediment Processes in Peri-Urban Estuaries in South-East Queensland (Australia)" and "Moreton Bay and Its Estuaries: A Subtropical System Under Pressure From Rapid Population Growth" by Hubert Chanson and colleagues and Badin Gibbes and colleagues in this book – the government policy seems to attempt to preserve the health of coastal waters and small peri-urban estuaries. However no remediation measures are implemented for the heavily degraded Brisbane River estuary where the Port of Brisbane is located and whose dredged mud is still allowed to be dumped in high-value, urbanised, coastal waters.

Chemical pollution from industrialisation can be remediated by technology. However water pollution by stormwater runoff from urbanised areas is an extremely difficult problem to solve (Beach 2002). The Gold Coast Local Government and those surrounding Port Philip Bay may be the pioneer Local Governments in Australia actually addressing that problem by requiring new developments to treat wet weather runoff (e.g. see the chapters "Gold Coast Broadwater: Southern Moreton Bay, Southeast Queensland (Australia)" and "Port Phillip Bay" by Ryan Dunn et al. and Joe Sampson et al. in this book) to oblige new urban developments to treat urban stormwater at the source, while discussions have started to retrofit stormwater runoff treatment at the Gold Coast Broadwater and in Sydney (see the chapters "Gold Coast Broadwater: Southern Moreton Bay, Southeast Queensland (Australia)" and "Sydney Estuary, Australia: Geology, Anthropogenic Development And Hydrodynamic Processes /Attributes" by Ryan Dunn et al. and Lee and Birch in this book). Several other Local Governments in Australia have developed, or are developing, strategies to improve stormwater quality, such as harvesting and use options for the local park irrigation or urban wetlands. So far however there are no policies to retrofit existing urban areas with such features. Such features will be expensive but are necessary to maintain the quality of life of the urbanised population; for instance it is estimated that retrofitting such features along the 15 km long Saltwater Creek on the Gold Coast to achieve the desired water quality load reductions would cost about A$ 65 million. An additional funding challenge of such features will be the high ongoing maintenance costs of urban wetlands and gross pollutant traps (N. Waltham, personal communication 2013).

Limits to Restoration

Complete restoration to the original pre-European conditions of the urban estuary is however generally impossible on ecological grounds (Duarte et al. 2009) and there is thus a limit to what can be realistically achieved. For Australian urban estuaries, preventing further degradation is a substantial achievement by itself. The urban population seems satisfied that the ecosystem is relatively healthy even if it does not resemble the pre-European system (e.g. see the chapter "Past, Present and Futures of the Tamar Estuary, Tasmania" in this book by Joanna Ellison and Matthew Sheehan about the Tamar River estuary).

Social Inequity

In Darwin Harbour the government can safely encourage rapid port developments and industrialisation on the east side of the harbour with minimal remediation measures. This is because about half of the harbour's watershed and mangroves are protected by Aboriginal traditional owners on the west side of the harbour and this, together with swift tidal flushing, keeps Darwin Harbour ecologically healthy (Wolanski 2006). This may lead to social inequity as the Aborigines may not benefit from the ecosystem services (such as the rich fishing grounds in the harbour) that they provide to Darwin. This healthy state of Darwin Harbour could also change if there is ever an accident leading to a major pollution event, because the pollutants may remain trapped in the mangrove wetlands for decades or even centuries, as is shown in the chapter "Hydrodynamics and Sediment Transport in a Macro-tidal Estuary: Darwin Harbour, Australia" by Fernando Andutta and colleagues in this book.

Suburbs and Regional Towns

State governments respond to public demands for healthy waterways. Such pressure is lacking in some suburbs of capital cities and in regional towns. Regional towns generally have single industries that drive the local economy and/or have a lower socio-economic status than capital cities. The population is generally unwilling to hurt their economy to improve the health of rivers and estuaries and it sees environmental health as a lower priority. Consequently, with no votes to gain in an election, State governments are unwilling to commit money to prevent the degradation of estuaries. This is the case of the Hawkesbury Estuary described by Peter Collis in this book. The present sewage treatment plants are already unable to prevent the on-going eutrophication of the Hawkesbury Estuary. Even with the upgrades of all the sewage treatment plans there will still be an increase of about 20–50 % of the discharge of nutrients to the estuary when the population doubles by 2050; some of this nutrient loading will come from stormwater runoff, a problem which the Local Governments in the Hawkesbury River catchment have chosen to ignore. All this will further increase the eutrophication of the estuary by 2050. No solution is proposed by the State government for the Hawkesbury, it is to be increasingly eutrophicated.

A similar situation of a lack of effective action to prevent further eutrophication also exists in the microtidal Peel-Harvey Estuary (also known as the Peel Inlet-Harvey Estuary) located south of Perth. A new channel was constructed to improve flushing, but land use remediation measures were not implemented. As a result, eutrophication still persists as evidenced by the sharp decline of the density of crustaceans and molluscs and the occurrence of algal blooms and occasional fish kills (Brearley 2005; Davis and Kloop 2006; Wildsmith et al. 2009).

A similar situation also occurs with the industrialisation of Spencer Gulf, even though science suggests that this poses the biggest threat to the gulfs' ecosystem health, as is shown by Jochen Kaempf in his chapter "The Murray/Coorong Estuary, Meeting of the Waters?" in this book.

Irrigation in the Tropics

In the tropics, the government push for developments is the least constrained by environmental considerations, and this is facilitated by these areas being the furthest away from capital cities and by the local economy being dominated by one single driver, such as an irrigation project. The two major tropical irrigation projects in Australia are in the Ord river and Burdekin river floodplains and they are discussed in this book in the chapters "The Ord River Estuary: A Regulated Wet-Dry Tropical River System" and "Water Resource Development and High Value Coastal Wetlands on the Lower Burdekin Floodplain, Australia" by Barbara Robson et al. and Aaron Davis et al. Both projects are young but already suffer from increased salinization problems that may impact their long-term sustainability. Nevertheless both schemes are expanding. In the case of the Burdekin, the tail waters from irrigated areas are affecting with nutrients, pesticides and herbicides, the whole length of the stream and, further they flow into, and pollute, a RAMSAR wetlands site. Remediation measures are discussed but at present they are not implemented (see the chapter "Water Resource Development and High Value Coastal Wetlands on the Lower Burdekin Floodplain, Australia" by Aaron Davis and colleagues in this book). In the case of the Ord, detailed studies have been undertaken of the fate of the nutrients in the tailwaters from irrigated areas, as described in the chapter "The Ord River Estuary: A Regulated Wet-Dry Tropical River System" by Barbara Robson and colleagues in this book. These studies were used to forecast as small the likely impact of the on-going increase by 236 % of the irrigated areas. This sounds reassuring and is indeed backed by science, until one realises that most of the tailwaters from these new irrigated areas will flow not to the Ord River in Western Australia but to the Keep River in the Northern Territory, which is not governed by Western Australian legislation. The Northern Territory government chose to ignore the finding from two independent studies, by Wolanski (unpublished data) and by its own hydrologist, that the Keep River estuary is susceptible to eutrophication from nutrient-enriched tailwaters from irrigation because

at neap tides it forms poorly-flushed pools of water separated by rock bars (D. Williams, personal communication 2011). Instead it simply required the developer to undertake a comprehensive water quality monitoring programme for the Keep River but it stipulated no water quality criteria to be met (Northern Territory Government 2012). Further The Northern Territory Environmental Assessment Act does not cater for appeals. All this gives the green light to development at all costs.

Conflicts of Interest

The Queensland government has a conflict of interest because it owns several ports (and thus it wants to maximise economic returns) and at the same time it has a duty of care to the population and the environment. The port of Townsville is government owned. The port seawalls have created a stagnant zone in coastal waters where mud accumulates (Lambrechts et al. 2010) and the mass resuspension of this mud during occasional storms and its later mass deposition on seagrass beds may be responsible for the severe recent decline in seagrass and resulting mass mortality sea turtles in coastal waters off Townsville (Elmore 2011). The Queensland government proposes no remediation measures for the port operations. Further, the port is used to export mining ore, including Lead (Pb). This generates pollution and Pb-enriched marine sediment is evident downwind of the Port (Doherty et al. 2000a, b). No remediation measures are proposed for the port operations. Finally, airborne black dust deposits in the suburbs downwind of the Port of Townsville (Fig. 6a). Some members of the local community feel threatened by this dust both from a quality of life perspective and from a health/toxicology perspective, particularly with regards to Pb. With the Queensland government dismissing these concerns outright with no studies, concerned people collected black dust around their houses on clean plates kept outside the houses or scooping the dust from window sills and outside tables and benches or from floors. The samples do not seem to have been contaminated by lead paint or pipes. These dust samples were analysed for Pb at certified laboratories in Australia. Figure 6b shows the spatial distribution of the particulate Pb concentration in Townsville during the tradewind season of 2008. The suggested pollution plume was consistent with the pattern expected from a Pb source in the port area. Figure 6c shows the time-series plot during from 2005 to 2009 of particulate Pb in the black dust collected at a house in Townsville downwind of the port; this figure suggests that there is a Pb pollution threat and that the 'safe' limit may have been exceeded all the time during 5 years.

In reply to a letter by concerned citizens, in August 2011 the Queensland Minister for the Environment stated that Pb pollution was safe because Pb does not build up in the human blood after a few months of exposure. This statement however is contradicted by medical evidence (EPA 1998; Balch and Balch 2000; Grandjean 2010) that there is probably no safe exposure to Pb and further that:

> Lead remains in the blood stream for weeks, then is absorbed in the bones, where it can collect for a lifetime. Lead that is not excreted through the digestive system accumulates and is absorbed directly from the blood into other tissues. When lead leaves the blood stream, it is stored in the bones where it continues to build up over a lifetime. Lead from the bones may then reenter the blood stream at any time as a result of severe biologic stress, such as renal failure, pregnancy, menopause, or prolonged immobilization or illness.

The Queensland government has refused to comment ever since. Also no remediation measures are taken in the port since the Pb-rich black dust continues to settle (S. van Grinsven, personal communication 2012).

The Queensland government also has a conflict of interest in the coal export port of Gladstone because it owns both the port and the railway transporting coal to the port from mines inland. The wagons are uncovered and thus Queensland Rail loses 4.8 million tons of coal dust a year to the wind (MacDonald 2010). The port stores the coal in open areas and the conveyor belts to the ships are uncovered, thus the wind blows away coal dust that deposits over the city of Gladstone (K. Burns, personal communication 2012). The Queensland Government (2010) reported mean air pollution levels within acceptable levels for an industrial area but, by not showing coal dust deposition data, it simply brushed over spikes in the air quality data, the excess of self-reported symptoms of asthma in both adults and children, and the 100 % increase in the incidence of the cancer Chronic Lymphoid Leukaemia (Queensland Government 2007). No remediation measures are apparently implemented in the rush to develop the coal export industry.

With such industry-friendly State governments with conflicts of interest, there is no independent agency examining the links between environmental pollutants and human health, suggesting Australia tropical States have ignored the overseas lessons of the need to battle pollution for the sake of public health and quality of life (Davis 2002).

Water pollution issues are treated with the same cavalier attitude in Australia tropics in the policy of development at all costs. For instance Ross Creek, the estuary of Townsville, is the most polluted by heavy metals and hydrocarbons of all the North Queensland estuaries that were sampled (Inglis and Kross 2000). This pollution was known for two decades and is particularly high near the mouth of the estuary downstream of the port (Doherty et al. 2000a, b; da Silva et al. 2004). Yet no remediation measures are seemingly implemented.

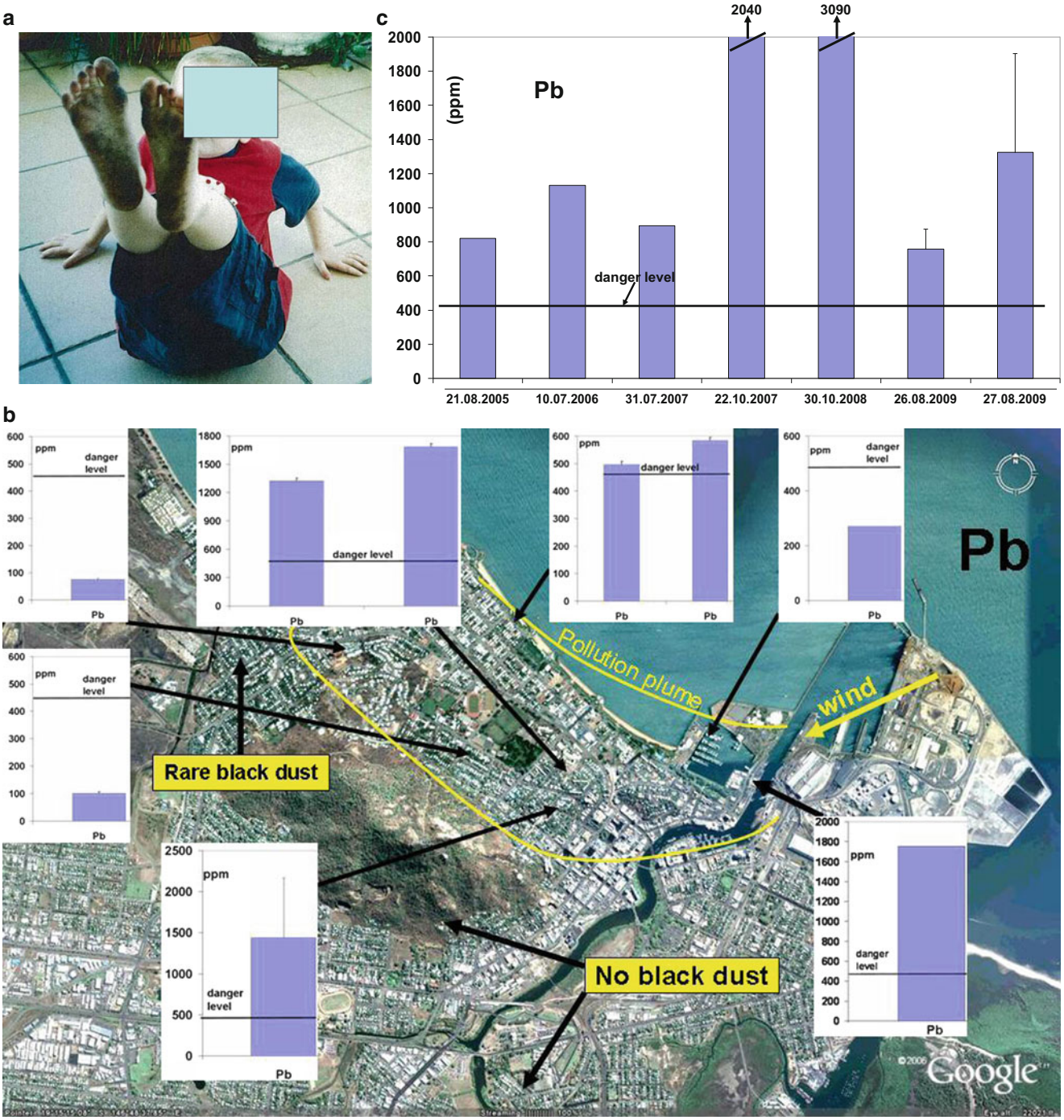

Fig. 6 (**a**) *Black dust* deposited on a patio and sticking on a child foot. This is the result of only one night of deposition at a house near the beach downwind of the port of Townsville in 2008. (**b**) The spatial distribution of the particulate Pb concentration in the black dust deposits in Townsville during the tradewind season of 2008. Also drawn is the local wind direction and the suggested, approximate limit of the pollution plume based on these data. (**c**) A time-series plot of particulate Pb concentration in the *black dust* collected at a house in Townsville downwind of the port from 2005 to 2009. To these data are added the State of Washington EPA legal 'danger level' for polluted soils (Data from Wolanski 2011)

The same philosophy of development at any cost for estuarine water quality is evidenced by the Queensland government allowing in 2013 the discharge of highly chemically polluted mine wastewater in rivers (Queensland Government 2013), in spite of the scientific knowledge that most of these chemical pollutants will be trapped in the estuaries (Wolanski 2007).

Pristine Estuaries

Australia still has several slightly affected and even pristine rivers and estuaries in far north Western Australia and Queensland, western Tasmania, and the Northern Territory –such pristine estuaries are a rarity in the world outside Australia. These estuaries are by themselves an Australian gift to the world of what pristine rivers and estuaries look like. Two chapters in this book address such systems; these are the chapter "Deluge Inlet, a Pristine Small Tropical Estuary in North-Eastern Australia" by Marcus Sheaves and colleagues about Deluge Inlet in Queensland and the chapter Recent, Rapid Evolution of the Lower Mary River Estuary and Flood Plains" by David Williams about the Mary River estuary in the Northern Territory. These pristine estuaries are precious and should not be used and abused.

The Future of Australia's Estuaries

There are calls for a large increase in migration to Australia in order to rapidly increase the human population so as to create a 'big Australia', as explained in the prologue to this book by Mr. Malcolm Fraser, former Prime Minister of Australia.

At the same time, to develop their economy the States and Territories with water and vast tracts of potentially arable land – i.e. mostly in the tropical regions of Queensland, Western Australia and the Northern Territory where the human population is presently small (Fig. 3c) – are pushing for large-scale irrigation projects to be made possible by the proposed construction of up to 100 dams, so that Australia can become the food bowl of Asia if not the world.

As a result most estuaries throughout Australia are now threatened by new projects of urbanisation, irrigation, mining, or industrialisation. Australian States generally recognise that threat. Developments in Australia are now subject to meeting environmental criteria set by legislation and this requires environmental impact studies, although as shown in case studies in this book State governments can and do routinely bypass this process when they want.

Encouragingly however more recently the concept of sustainable development is starting to be discussed in Australia.

Additional changes may also come from climate changes that may impact the water yield of river catchments as a result of changes of the temperature, evaporation and rainfall. Climate change sceptics thrive in the atmosphere of industry-friendly development-focused State governments and their outcome of seeding doubt (Michaels 2005) has been used by several State and Local Governments to dismiss planning for climate change when considering some development projects. Nevertheless climate change is seemingly happening (BOM 2012; CSIRO 2012). For instance rainfall in the southwest corner of Western Australia, that includes the State capital city Perth, has significantly decreased during recent decades (Li et al. 2005).

Engineering and technology by themselves do not provide a solution to sustainable development of Australian estuaries. When assessing the environmental impact of developments, Australian engineering consultants commonly state that the impact will be minimal – without quantifying this statement – and rarely do they value the ecosystem services provided by the estuaries and the quality of life to the people. Common statements by State governments and the engineering community of 'world's best practices' when discussing environmental sustainability of estuaries are nonsense and are not backed by facts as the case studies in this book illustrate.

Thus the answer to the question "Is Australia's growing human population and economy environmentally sustainable for its estuaries and coasts by 2050?" may be, based on the socio-economic decisions made now, (1) ***possibly yes*** in large cities as long as the population is pro-active in demanding a high quality of life, which implies healthy waterways, and (2) ***probably not*** in rural and remote areas and especially so in the tropics.

Hopefully this pessimistic prediction may turn out to be incorrect. Australia is privileged to have a number of eminent estuarine scientists. Hopefully future enlightened governments will emerge that will made socio-economic decisions compatible with a sustainable Australia and will call on these scientists to help provide a safe future for Australian estuaries in 2050 and beyond. This will require adopting an ecosystem-ecohydrology-based management approach at the watershed scale, to avoid repeating all over Australia the mistakes done over the last 200 years. In partnership with engineering and technology, as opposed to mutual exclusion at present, science has key role to play to help develop this approach to ensure a sustainable Australia.

One of us (EW) is a father and grandfather of young Australians and views Australian estuaries as a bank account that we hold in trust for future generations. If Australia does not learn from past mistakes that degraded our estuaries, Australia fails a critical test as a society and we will leave our children and grandchildren a serious debt to pay.

References

Balch PA, Balch JF (2000) Prescription for nutritional healing, 3rd edn. Avery, New York, 784 pp

Beach D (2002) Coastal sprawl: the effects of urban design on aquatic ecosystems in the U.S. Pew Ocean Commission, Arlington

BOM (Bureau of Meteorology) (2012) http://bom.gov.au