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Foreword I

It is with great pleasure that I introduce Dr. Reza Naderloo's *Atlas of Crabs of the Persian Gulf.* It will prove to be a valuable reference not only for specialists in the taxonomy of Brachyura, but for marine biologists, ecologists, conservationists, and anyone interested in the biodiversity of the marine environment. For a long time, those of us involved in the taxonomy and ecology of Brachyura tended to think of the Persian Gulf as a simple extension of the Indo-West Pacific region. Dr. Naderloo's *Atlas* shows that this is not so. Faunistically and ecologically speaking, the Gulf is a lot more than an appendix of the big ocean. The marine life of the Gulf has evolved to adapt to a unique environment subject to particular physical, chemical, and biological factors. It is unfortunately also critically affected by the impact of us humans. This *Atlas* will therefore validate the appreciation and protection of the rich and valuable marine biodiversity of the Persian Gulf, not only for the inhabitants of the countries bordering the Gulf, but for the rest of the world as well.

Rancho Palos Verdes, CA, USA — Peter Castro
June 2017

Foreword II

A good atlas of the fauna of an interesting region is always an asset to scientists studying biodiversity – be it for systematics, ecology or conservation. It allows any new researcher entering a field to grasp the diversity of an area and quickly introduces him or her to the taxa present. Even for experienced scientists, a good atlas is a useful tool to help him plan for interesting research questions for the future. The present atlas of the Persian Gulf brachyuran fauna by Reza Naderloo is exactly that. The brachyuran crab fauna of this major body of sea is defined by the unique physiochemical properties and biogeographical history, and while the area shares faunistic elements with the Arabian Sea and western Indian Ocean, it also has many species known only from its waters. The present atlas is the result of many years of painstaking work, put together by someone with a deep knowledge of the region and a great passion for his animals. It is scientifically valuable in its up-to-date taxonomy, concise literature, excellent figures and detailed maps, documenting a total of 37 families, 150 genera and almost 256 species. But it is a list that will certainly grow in the years ahead. I was amused to read that the author actually captured a passing remark I made to him some time back about one of the pioneers of carcinological research in the Persian Gulf, the well-known Danish scientist Knud Stephensen. I had commented that while Stephensen's 1946 tome was still a major reference for the region, his work was but a "superficial scratch to this group, with many more discoveries to be expected". In the years since 1946, some 50 species have been added to the area, many of which are not just new records but new species as well. As Stephensen's work set the stage for subsequent generations of researchers on Indian Ocean carcinology, I am certain Naderloo's will as well!

National University of Singapore, Singapore | Peter Ng
June 2017,

Preface

The importance of biodiversity and its conservation have been subject of serious debate since "the Rio Earth Summit" in 1992. For years, scientists, environmental activists, and even politicians have addressed different aspects of biodiversity, have highlighted the services provided by biodiversity, and are concerned about its loss. Therefore, biodiversity conservation looked to be an immediate action which had to be taken into account. Wilson (1988) once cited a celestial statement in conserving the biodiversity "… that fauna and flora of country will be thought part of the natural heritage as important as its art, language, and …." But here, the main concern is the amount of barrels of crude oil extracted daily in the Persian Gulf. We follow the oil price fluctuations by surfing different media every day, but have no interest to hear even a single word about the diversity change and its consequences on the environment and our lives. We do not know that the second largest population of an interesting marine mammal *Dugong dugong* lives in the seagrass meadows of the southeastern Gulf. Regional politicians discuss about their own share from a common oil field for hours, but do not pay their share to conserve the biodiversity of the environment. The Persian Gulf is surrounded by eight rich oil--producing countries including Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE. Oil and gas-based industries of such ever-developing countries in the Gulf are the main threat for such a fragile environment. Marine pollutions originate mainly from these industries, particularly when taking in account that 60% of the exported oil and its derivatives are shipped using tankers through the Strait of Hormuz. Scientists working in the Gulf will find tar balls and trace metals distributed everywhere in the different coastal habitats. In particular, the coastal environments of the Gulf are severely subjected to such anthropologic effects, mainly resulting from coastal developments. Habitat destruction by using dredging and filling in shallow coastal regions for economical and recreational purposes and overfishing, when accompanied with mismanagement, are possibly two more important stresses. Supposedly, desalination plants are silent but severely affect pollution source in the Gulf. The desalination plants are mostly based along the Kuwait, Saudi Arabia, and UAE coasts and discharge hot and hypersaline water into the coastal environment (Lattemann and Höpner 2008). Reportedly, other countries around the Gulf are planning to establish desalination plants along their coasts, without examining the capacity of the small-scaled marine basin with limited freshwater input. For these, we should add stresses coming from sewage discharges, recently increasing air dust, and alluvial sediments. I have witnessed all such environmental corruptions whenever I went for sampling in the last 13 years. Furthermore, the effects of these stresses will undoubtedly be doubled under the direct effect of the recently alarming global warming, and they will be multiplied by silently entering alien and invasive species. A regional conceptual framework is necessarily needed in order to document and regularly monitor the marine biodiversity in the region. However, the success of such regional framework is unlikely as the function of ROPME (Regional Organization for the Protection of the Marine Environment) in the last four decades since its foundation in 1979 is a good evidence for this fact. The main impediment for local scientists to perform regional collaboration in documenting and conserving biodiversity is the political turbulence between the countries bordering the Persian Gulf.

There is no doubt that for any biologist, in particular for those quantifying and evaluating the biodiversity, "species" is the main concern and a basic entity. The species must be identified, named, and classified using the most updated classification hierarchy. Taxonomists take this fundamental but cumbersome responsibility. Unfortunately, few comprehensive taxonomic researches have been conducted on the different marine taxa in the region so far, mostly because of the paucity of a regional taxonomist. Expertise in the taxonomy of the different marine groups is being developed among a new generation of regional scientists. Most of them have studied abroad and returned to the region to pursue their field of expertise. I am among the scientists of the generation and started to study the brachyuran crabs since 2002 when I started my masters in animal biosystematics at the University of Tehran. Since then, I have been collecting material and notes during my several field trips over the past 13 years. I did substantial works during my PhD at the Senckenberg Museum of Frankfurt where I performed extensive taxonomic studies on the material I had collected myself and the materials collected from the region, in particular those of Stephensen (1946), Titgen (1982), and Apel (2001).

An atlas like this is a basic and an important step in understanding and reconstructing the biodiversity of life in this geographical region. The book provides baseline information on the brachyuran fauna of the Persian Gulf and the Gulf of Oman and, at the same time, reflects the huge gap of required fundamental knowledge in other groups of marine animals. Within crustaceans, for example, there is a lack of such a data for caridean shrimps, amphipods, isopods, cumaceans, mysids, ostracodes, tanaids, and many others. I hope that young scientists will fill the gaps in the near future.

Tehran, Iran Reza Naderloo

Acknowledgment

I am most grateful to Alireza Sari (University of Tehran, Iran), who is the fundamental carcinologist in Iran with wide information of Iranian crustaceans. Alireza Sari encouraged me and first got me interested in the brachyuran crabs of the Persian Gulf when I was a master student under his supervision at the University of Tehran between 2002 and 2005. I am especially thankful and extremely honored working under the supervision of the late Michael Türkay (Senckenberg Museum, Frankfurt am Main, Germany) during my PhD in Frankfurt am Main. Michael Türkay helped me in the course of preparation of this atlas in any possible occasions by providing working space, material, and funding during the last 8 years. My special thanks is due to Michael Apel (Museum Mensch und Natur, Munich, Germany), who did the comprehensive ecological and taxonomic works on the brachyuran crabs in the region, particularly, along the Arabian coasts during the years 1991–2001, and compiled a huge amount of information on this group. Michael Apel has always helped me from my first visit to Senckenberg Museum in 2005 up to now and further encouraged me to continue the study of the brachyuran crabs of the region. He allowed me to use the data from his unpublished PhD thesis in this atlas which is greatly appreciated.

This publication was really impossible without contributions of many other individuals. These are Peter Ng and Christopher Mendoza (National University of Singapore), Paul Clark (Natural History Museum, London), Peter Castro (California State Polytechnic University, USA), Peter Dworschak (Natural History Museum, Vienna), Danièle Guinot and Laure Corbari (Muséum national d'Histoire naturelle, Paris, MNHN), Mortiz Sonnewald (Senckenberg Museum, Frankfurt am Main, Germany), and Venkataraman Krishnamoorthy and Kandasamy Valarmathi (Zoological Survey of India, Kolkata, India). James Bishop (Kuwait Institute for Scientific Research) and Alireza Keikhosravi (Shahid Hakim University of Sabzevar, Iran) helped me in editing the introduction and improved the text.

I have been helped by a number of my students in different issues. These are Sepideh Barzgar, Rashed Abdollahi, Mehrnaz Afkhami, Abolfazl Arab, Arash Reeisbahrami, Saeed Ebrahimnejad, Samaneh Pazoki, Elahe Parvizi, and Zahra Rajaie who are greatly acknowledged. The photographs presented in this book have been mostly taken by Sven Träkner (Senckenberg Museum, Frankfurt am Main, Germany) and Rashed Abdollahi (Zoology Museum, University of Tehran) and some by Harry Taylor (Natural History Museum, London) and Soheil Shahbazi. All photographs are very much appreciated [all help by all photographers].

Contents

Introduction

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Abbreviations

CL	Carapace length
CB	Carapace breadth
G1	Male first pleopod
G2	Male second pleopod
MNHN	Muséum National d'Histoire Naturelle, Paris, France
NHM	Natural History Museum, London
NHMW	Naturhistorisches Museum Wien, Vienna, Austria
RMNH	Naturalis, formerly Nationaal Natuurhistorisch Museum, Leiden, Netherlands
SMF	Research Institute and Natural Museum Senckenberg, Frankfurt am Main, Germany
SNMNH	Saudi National Museum of Natural History, Riyadh, Saudi Arabia
ZMG	Zoological Museum of Gottingen, Germany
ZMUC	Zoological Museum, University of Copenhagen, Denmark
ZRC	Zoological Reference Collection, Raffles Museum of Biodiversity Research, National University of Singapore
ZUTC	Zoology Museum, University of Tehran, Iran

The Persian Gulf

The Persian Gulf is a semi-enclosed sea which is located in a subtropical, hyper-arid region of the northwestern Indian Ocean. The Persian Gulf is a shallow sedimentary basin stretching from southeast to northwest, about 1000 km long and between 200 to 300 km wide, and covers an area of about 251,000 km^2. The basin is characterized with generally eastward dipping seafloor, with its deepest regions along the Iranian coast. A maximum depth of 100 m is recorded in the Strait of Hormuz, and the average depth of the basin is 35 m (Barth and Khan 2008). The low-salinity oceanic water enters to the Persian Gulf through the Strait of Hormuz, flowing along the Iranian coast in a counterclockwise direction, remarkably increasing in salinity along the Arabian side and discharging into the Gulf of Oman (Sale et al. 2010). Harsh environmental conditions result mostly from high evaporation and low fresh water input (Fig. 1.1).

The present structure of the Persian Gulf primarily formed due to tectonic movements in the Tertiary period. It was basically established in the Miocene (25–5 Mya), when the orogenic process resulted in the

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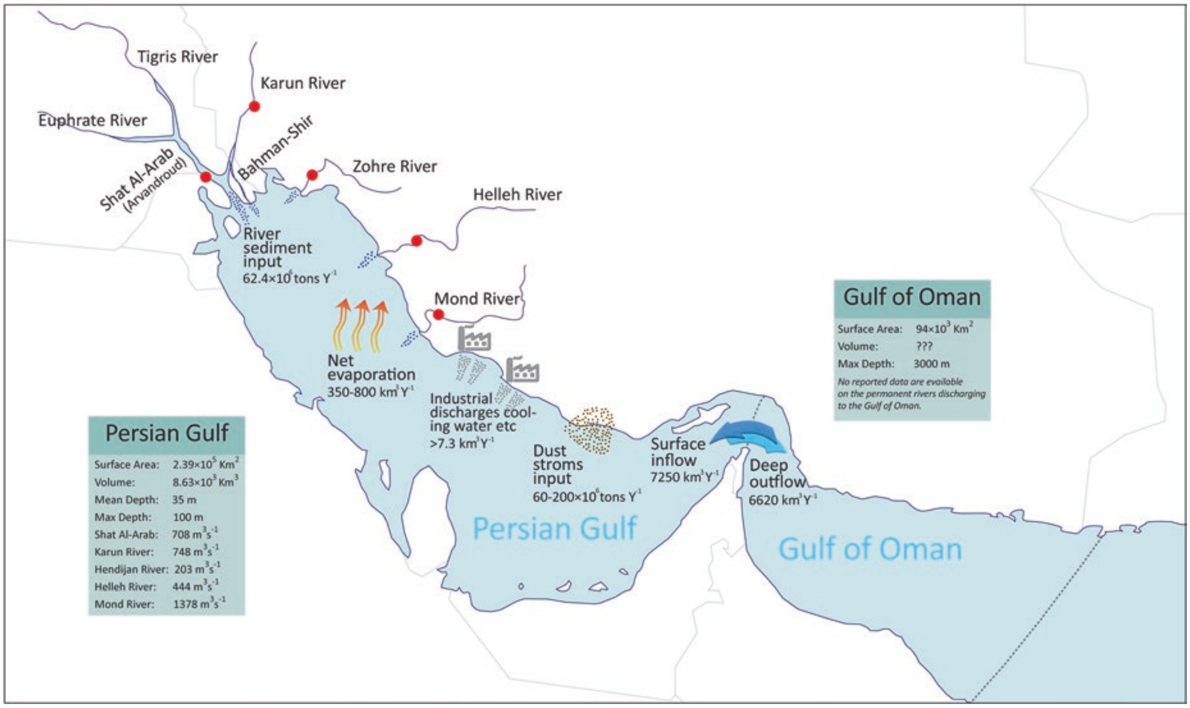

Fig. 1.1 Map of the Persian Gulf and the Gulf of Oman showing their boundaries. Estimates of the water exchange, dust and sediment input were drived from Sheppard et al. (2010). Estimates of the discharge amount of the major rivers flowing into the Persian Gulf are shown in the Persian Gulf box (Data from Reynolds 1993). *Red circles* indicate the recording stations for the estimates

formation of the Taurus, the Zagros Mountains and the Oman mountains (Barth and Khan 2008). Considerable sea level fluctuations occurred during the period of 110 ka BP and 17 ka BP, when the sea level was between 120 and 150 m below its present level, leading to the complete evaporation of the Persian Gulf (e.g. Sheppard et al. 1992; Barth and Khan 2008). The global temperature increased during the Holocene resulting in the sea level transgression that started about 15 ka BP and continued till 6 ka BP. At that time, the Persian Gulf sea level was about 2.5–3.5 m higher than today's level (for detailed see Barth and Khan 2008).

There are four main rivers discharging into the Persian Gulf along the northeastern coast, namely, Shat Al-Arab, Hendijan, Helleh, and Mond. Shat Al-Arab River (known as Arvandroud River in Iran) is formed by combination of Euphrates, Tigris and Karun rivers, and flows down along the border of Iran and Iraq. The Shat Al-Arab River is the largest river with length of 195 km and average width of 500 m and average discharge of 1456 m^3/s (Reynolds 1993). It constructs a large estuarine system with considerable productive marshlands and leads to formation of a large river plume of 30–40 km in the northern Persian Gulf (Al-Yamani 2008). Unfortunately, in recent decades intensive damming in quickly developing countries like Turkey, Syria, Iraq and Iran has reduced the amount of water discharge through this river to the Gulf. This subsequently severely affected the estuary ecosystem, hydrological system and sedimentation in the northern Gulf. Other three rivers, namely Hendijan (203 m^3/s), Helleh (444 m^3/s) and Mond (1387 m^3/s) which feed the Gulf mainly originate from Zagros Mountains in Iran (Fig. 1.1).

The substrate of the Persian Gulf Basin is mostly characterized with sedimentary structures (Sheppard et al. 2010; Sale et al. 2010; Naderloo and Türkay 2012). Muddy flat is the dominant substrate along the Iranian and Arabian coast of the Gulf, and usually stretching to deeper zones in most parts. The muddy flats are widely distributed on the northern part of the Gulf where it supports a highly valuable primary production, and provides nursery and spawning ground for shrimps and a grazing ground for migratory birds. In contrast, rocky structures are patchily distributed within the Gulf and generally are more seen along the Iranian coast than the Arabian side (Naderloo and Türkay 2012). Other ecologically important habitats, e. g. mangroves, corals, and sandy beaches, all with their own diversity, can be patchily found within the Gulf. Despite this ecologically diverse environment, the Persian Gulf is generally considered biologically impoverished, partly because of its young age, but mainly because of its harsh environment (Sheppard et al. 2010). Recently, Price and Iszak (Price and Izsak 2005) addressed the importance of the biodiversity in the Persian Gulf by highlighting the high value of taxonomic distinctness and high beta diversity within the Gulf. This makes the environment worthy of conservation attention.

The tidal system in the Persian Gulf, due to its semi-enclosed form, is very complex (Jones 1986a) leading to four different variations of the tidal system as explained by Raffaelli and Hawkins (1996). But, semi-diurnal tides with two unequal tides occur daily with a maximum range of 5 m in the northern part, and a minimum of 2 m in middle part of the Gulf. The most ecologically important fact is that the lowest tides generally occur during the cold months along the Iranian coast (Naderloo and Türkay 2012) and Kuwait coast (Jones 1986a), and the coast experienced low spring tides during the day in cold seasons and during the night in warm seasons. This is essential for intertidal organisms because it protects them from freezing in winter and from desiccation in summer. It is also important for the coastal biologists to perform sampling during the long days of summer. The dominant wind in the Persian Gulf is known as "Shemal", a wind blowing northwesterly throughout the year. Winter Shemal is predominantly stronger, bringing denser air from higher latitudes over to the Persianw Gulf leading to higher temperature fluctuations ranging between 15° and 30 ° C (Reynolds 1993). More detailed information on the different aspects of the Persian Gulf is recently provided by Riegl and Purkis (2012).

The Gulf of Oman

The Gulf of Oman connects the Persian Gulf to the Indian Ocean via narrow Strait of Hormuz. The Gulf of Oman with about 94,000 m^2 surface area is westerly defined by an imaginary line running from Minab on the Iranian coast to Qabr al-Hindi on the Oman coast, and its eastern side is delineated by an imaginary line stretching from Ras Jiwani on the border of Iran and Pakistan to Ras al-Hadd on the Oman coast (Fig. 1.1). In contrast to the shallow Persian Gulf, the Gulf of Oman is quite deep, about 200 m near Strait of Hormuz, getting immediately even deeper up to 2000 m in its middle part and then to maximum depth of 3000 m in eastern part (Reynolds 1993). The Gulf of Oman is markedly different from the Persian Gulf as it is affected by the monsoon systems in the northern Arabian Sea. The monsoons bring southward blowing cool winds in summer and northwardly blowing winds in winter. Therefore, the temperature fluctuation of water is balanced in the Gulf of Oman ranging from 22° to 31 ° C (Reynolds 1993; Piontkovski et al. 2012). Salinity is the second most important physical factor limiting the biodiversity. While it is always more than 37 psu and reaching up to 40 psu in most parts of the Persian Gulf, the maximum summer salinity recorded for the Gulf of Oman is 37 psu (Reynolds 1993). Intertidal regions support wide variety of habitats from sedimentary muddy-sandy in sheltered environments to exposed sandy beaches and active rocky habitats. Comparatively, the Gulf of Oman has more exposed rocky habitats than the coast of the Persian Gulf.

Tidal system of the Gulf of Oman is semidiurnal as seen in the Persian Gulf with two unequal tides, but it is affected by tidal regime of the Arabian Sea to a greater extent. Unfortunately, geomorphology and biology of the Gulf of Oman has not received much attention compared to that of the Persian Gulf, as the oil exploration in the Persian Gulf accelerated the research in the Gulf by financial supports of the oil companies.

Infraorder Brachyura Linnaeus, 1758

History of Brachyuran Research in the Region

Biodiversity of the Persian Gulf is generally poorly documented. Nevertheless, the brachyuran crabs have received better attention compared to other marine taxonomic groups, and other infraorders of the class Decapoda. The study of this group in the Gulf was started by Heller (1861a) who recorded just one species, *Epixanthus frontalis* from the northern Persian Gulf based on a collection made by T. Kotschy 1843/1844.

Heller's (1861a) work was basically on the infraorders Anomura and Brachyura of the Red Sea and the material was deposited in the Natural History Museum of Vienna. Alcock (1895, 1896, 1898, 1899a, 1899b, 1900, 1901, 1905) has recorded 51 brachyuran species from the Persian Gulf in his works on the crabs collected by scientific vessel "Investigator". Unfortunately, the Persian Gulf sampling localities are not mentioned by Alcock and it is thought that some localities were outside the Gulf, or even "Investigator" had not ever been in inner the Gulf (Apel 2001). Further, Investigator's collection is mostly deposited in the Indian Museum of Calcutta, where, nowadays, it is not easily accessible to scientists, therefore re-examination of the Alcock's material has not been easily possible for long time. The second major contribution to the Persian Gulf decapod crustaceans was made by G. Nobili in his 1906 work entitled "Crustacés décapodes et stomatopodes. In: Mission J. Bonnier et Ch. Perèz - Golfe Persique, 1901". He examined the materials collected by Belgian yacht "Selinka" in the Persian Gulf in 1901 and recorded 50 brachyuran species from the Gulf, the majority of which were from the Arabian side, particularly from the UAE coast. After these works in the early twentieth century, there was no important investigation on the Gulf's crabs for several decades; only few scattered records of these animals from the area followed the earlier studies. MacGilchrist (1905) recorded seven brachyuran species and Klunzinger (1913) and Chopra and Das (1930) each recorded one.

N.V. Bogoyavlensky from "Moscow Society of Natural Science, Ethnography, and Anthropology" made a good sampling from the intertidal coasts of Kuwait, Bahrain and Iran. This collection was deposited in the Zoological Museum of the Moscow University, and unfortunately has not received much attention. Fauvel (1911) studied the polychaetes of this collection and provided basic information of the sampling sites. The brachyuran crabs of the collection was examined by Apel (2001).

The largest collection from the Persian Gulf, so far, was performed by "Danish Scientific Expedition in 1937/38". Iranian government invited Danish fisheries scientists to conduct a preliminary survey in the Gulf in order to improve the Iranian fisheries industry. For this purpose, a 35 ton fishing boat named "Rashgoo", was sold to the Iranian government in 1936 and was sailed to the Persian Gulf by Danish sailors. They made a good collection from the Iranian waters, but mainly from the subtidal zones. The collection is now deposited in Zoological Museum of the Copenhagen University, Denmark. Different taxa of the collection were examined by specific taxonomic experts and provided key literatures which are broadly used nowadays. Brachyuran crabs were examined by K. Stephensen (Fig. 1.2). In his landmark work "Brachyuran Crabs of the Iranian Gulf", he identified 124 species (Stephensen 1946). Thus, he updated the number of brachyuran species known to that time to162. His work is a good reference devoted to Persian Gulf's crabs, but taxonomically speaking, it is thought to be just a "superficial scratch to this group" (Peter Ng, pers comm). Stephensen (1946) described three new species, namely *Dentoxanthus iranicus* Stephensen, 1946, *Typhlocarcinus dentatus* Stephensen, 1946, and *Thalamita iranica* Stephensen, 1946, from the collection.

Fig. 1.2 Knud Stephensen (1882–1947), curator in ZMUC of Copehenhagen from 1910 to 1947

In the early 1970s, an Austrian carcinologist, Gerhard Pretzmann from the Natural History Museum of Vienna, who was an expert on the fresh water crabs, made a small collection from the coast of Bandar Abbas along the Iranian side. Pretzmann (1971) reported 12 intertidal crab species, five of which were new records, and two were new to science, namely *Uca iranica* Pretzmann, 1971, and *Macrophthamus* (*Macrophthamus*) *ressli* Pretzmann, 1971. The latter has been later considered as a junior synonym of *Macrophthalmus laevis* A. Milne-Edwards, 1867 (see Naderloo et al. 2011). The next large faunistic study in the Persian Gulf was conducted along the Saudi Arabian coasts by the Saudi Arabian-American Oil Company (ARAMCO) in the 1970s. Basson et al. (1977) published the result of this investigation in a referable book entitled "Biotopes of the Western Arabian Gulf". This was the first ecological study in the Persian Gulf, however, it failed to identify the majority of the specimens up to species level, and many of the specimens were even misidentified, thus it suffered severely from taxonomic problems (Apel 2001). Titgen (1982) from Texas University did his PhD project on the systematic and ecology of Decapoda in Dubai and listed 196 species from the Gulf, most of which were not properly studied and the identification of some species is highly questionable. Nevertheless, he was the first who performed a zoogeographical analysis based on the decapod crustaceans in the Persian Gulf. Jones and Clayton (1983) described two new camptandriid species from muddy shores of Kuwait, namely *Cleistostoma kuwaitense* Jones and Clayton, 1983 [currently known as *Leptochryseus kuwaitensis* (Jones and Clayton 1983)] and *Paracleistostoma arabicum* Jones and Clayton, 1983 [currently known as *Manningis arabicum* (Jones and Clayton 1983)]. Jones (1986a, b) are two further literatures dealing with marine intertidal organisms of Kuwait including brachyuran crabs.

Fig. 1.3 Michael Apel (born in 1964), currently Director of Museum Mensch und Natur, Munich, Germany

A huge oil spill following the Gulf War of 1991 triggered for some important ecological and faunistic surveys in the coastal zone of the Arabian coast, mainly on the muddy shore along Saudi Arabia and Kuwait. Michael Apel (Fig. 1.3), a German carcinologist from Senckenberg Museum of Frankfurt, participated in these projects and devoted over a decade of his life to collecting and examining the Persian Gulf's crabs. He published some important papers scrutinizing the taxonomy and distribution of different intertidal Decapoda, with special emphasis on the brachyuran crabs (e.g. Apel 1994a, b, 1996a; Apel and Spiridonov 1998; Apel and Türkay 1992, 1999). Finally, in his PhD dissertation, Apel (2001) thoroughly reviewed all faunistic and taxonomic works on the Brachyura of the Gulf and undertook intensive sampling along the Saudi Arabian and UAE coasts. He raised the valid species number of the Brachyura occurring in the Gulf to188 species.

Al-Ghais and Cooper (1996) and Cooper (1997) investigated the mangal associated Brachyura of Abu Dhabi (UAE) and Al-Khayat and Jones (1999) compared macrofauna in natural and planted mangroves in Qatar.

In the recent years, Iranian scientists conducted worthy contributions to the marine organisms of the Persian Gulf. In which, brachyuran crabs received well attention by the local scientists, particularly by the author. Two important intertidal groups, superfamily Grapsoidea and family Macrophthlamidae, have been thoroughly revised and several new species have been described (Naderloo 2011; Naderloo et al. 2011). These new species are *Nanosesarma sarii* Naderloo and Türkay, 2009, *Parasesarma persicum* Naderloo and Schubart, 2010, *Chaenostoma sinuspersici* (Naderloo and Türkay 2011), *Hiplyra ramli* Naderloo and Apel, 2012, *Paratymolus apeli* Naderloo and Türkaym, 2015, *Menaethiops abumusa* Naderloo, 2015, *Palapedia apeli* Naderloo, 2015, and *Palapedia persica* Naderloo, 2015. Naderloo and Türkay (2012) provided an updated checklist of the decapod crustaceans presenting along the Iranian coast of the Gulf and recorded 150 Decapoda. Of which, 83 (55 %) belong to the brachyuran crabs. Comparatively, brachyuran fauna of Iraqi shores has been received less attention. Only recently, few studies have documented brachyuran crabs of Iraq (Ng et al. 2009; Naser et al. 2010, 2012; Naser 2011), but Brachyura of Iraq have still remained largely underrepresented. In addition to the above mentioned studies which merely focused on the Persian Gulf's fauna, there are several new species and new records of Brachyura described or reported from the Persian Gulf in the literatures (Galil 2001, 2005a, 2009 ; Castro and Ng 2010; Galil et al. 2012).

In comparison with the Persian Gulf, general biodiversity of the Gulf of Oman is markedly underestimated. This is mainly because of scarcity of scientific samplings. The brachyuran fauna of the Gulf of Oman, principally initiated by "Danish Expedition 1937/38". As already stated, this expedition has comprehensively sampled along the Iranian coast of the Persian Gulf, with having only 10 sampling stations along northern coast of the Gulf of Oman. In his report, Stephensen (1946) recorded 24 species from the Gulf of Oman, of which 22 were new records to the region. This revealed the fact that fauna in the region was fully unknown. Hogarth (1988) recorded five species of hermit crabs from Muscat, Oman and a year later 19 decapods from the same region (Hogarth 1989). Ismail and Ahmed (1993) performed a sampling in the Khor Kalba in the east coast of UAE and recorded seven brachyuran species. Hornby (1997) made a small collection of decapod crustaceans from the east coast of UAE with reporting 11 crabs. In 1994, Hywel-Davies, in his M.Sc. thesis on biodiversity of mangroves of Muscat, recorded four brachyuran crabs (Hywel-Davies 1994). Moreover, five species of ghost crabs of the genus *Ocypode* were recorded by Clayton (1996) from Oman. In a comprehensive study of Portunidae, Apel and Spiridonov (1998) recorded 29 species from the Gulf of Oman. In his thesis, Apel (2001) made a limited sampling along the east coast of UAE together with reviewing the literatures, he reported 106 species of Brachyura in Gulf of Oman. Ghotbeddin et al. (2012a) collected 34 species of brachyuran crabs from Chabahar Bay in Iranian coast of the Gulf of Oman. Most recently, there are some few records of the brachyuran crabs from the Iranian coast of the Gulf: Fatemi et al. (2011) recorded three species of the family Dotillidae, Ng et al. (2011a) recorded *Calappa exanthematosa* Alcock and Anderson, 1894, Ng et al. (2011b) recorded *Calappa dumortieri* Guinot, 1964, Fatemi et al. (2012) recorded *Cryptopodia echinosa* Chion and Ng, 1998, Valinasab et al. (2012) recorded *Galene bispinosa* (Herbst, 1783), Ghotbeddin and Naderloo (2014) recorded four xanthid crabs, and Naderloo and Fatemi (2015) recorded an alien species, *Percnon affine* (H. Milne Edwards 1853). Finally, Naderloo et al. (2015) provided an annotated checklist of the Decapoda of the Gulf of Oman by examining freshly collected samples and reviewing already published literatures. They recorded a total of 176 brachyuran crabs from the Gulf of Oman.

Taxonomy

The Brachyura Linnaeus, 1758, is an infraorder of the order Decapoda Latreille, 1802. Decapoda is an incredibly diverse group and decapod taxonomy is an active field with researchers making constantly new discoveries (De Grave et al. 2009). According to De Grave et al. (2009) the order Decapoda contains 233 families, 2725 genera and 17, 635 species distributed worldwide, finding in any possible habitat. Ng et al. (2008) published "Systema Brachyurum", a valuable catalogue on the extant brachyuran species, with invaluable notes on the taxonomically problematic taxa. According to Ng et al. (2008), Brachyura with 8616 species is the most species-rich infraorder within the Decapoda. Of this number, 6559 are extant, whereas 1781 are exclusively fossils, and 276 have both living and fossil records. Currently there are 256 species of the brachyuran crabs belonging to 144 genera and 37 families from the Persian Gulf and Gulf of Oman. Of which, 223 are recorded from the Persian Gulf and 176 are from the Gulf of Oman. The low number of species recorded from the Gulf of Oman is mainly due to fewer sampling efforts.

This atlas provided the basic taxonomic list for the brachyuran species recorded from the region, but detailed taxonomic revisionary studies are urgently needed in different groups. Examples are the diverse families Leucosiidae, Epialtidae, Majidae, Xanthidae and Pilumindae. Morphologic differences are clearly seen in populations of some taxa occurring in the region. Further morphological and molecular data would be useful to clarify the taxonomic position of the different species in the region. *Pilumnopeus convexus* (Maccagno, 1936) (Pilumnidae) is an outstanding example which has frequently been confused with *Pilumnopeus vaquelini* (Audouin, 1826). Species within several xanthid genera (e.g. *Medaeops*, *Macromedaeus*, *Etisus*) are morphologically poorly differentiated and the members of the family Pilumnidae are taxonomically difficult taxon which all need urgent taxonomic revision.

There are two species recently recorded as aliens to the region. These are *Eriochier hepuensis* Dai, 1991 (Varunidae) from the northern estuarine system of the Persian Gulf (Naderloo 2014) and *Percnon affine* (H. Milne Edwards, 1843) (Plagusiidae) from the Iranian coast of the Gulf of Oman (Naderloo and Fatemi 2015). The brachyuran crabs live in variety of habitats ranging from marshlands, through different intertidal substrates to shallow subtidal coral reefs and seaweeds down to maximum depths in the Persian Gulf and the Gulf of Oman.

Main Characteristics of the Brachyuran Crabs

Carapace (Fig. 1.4a) large, prominent, comprising of 5 cephalic and 3 thoracic somites, with lateral linea brachyura. **Front** prominant, usually separated from orbit**. Eyes** always with distinct stalk, eyestalk with two segments, situated in complete or sometimes incomplete orbits. **First antennae** (antennules) with three-segmented peduncle, with short flagella, longitudinally or transversely folded in distinct hiatus. **Second antennae** (antennae) with three-segmented peduncle, first segment (basal antennal segment) usually immovable, flagella short or long. **Mandibles** intensely calcified, large, with prominant molar and incisor processes. Two biramous **maxillae**. Three **maxillipeds**, third maxillipeds (Fig. 1.4b) well developed, with distinct plate-form ischium and merus, functioning as an operculum in covering buccal cavern. **Pereiopods** (walking legs) uniramous, with seven segments including coxa, basis, ischium, merus, carpus, propodus, and dactylus (Fig. 1.5b); basis and coxa are tightly fused, while ischium is tightly fused to merus; first pereiopod chelate. **Chelipeds** (Fig. 1.5a) with propodus elongate, forming palm and immovable finger, dactylus forms movable finger. Last four pairs of walking legs getting smaller distally; last two or just last ones are sometimes modified for doing specific functions, like swimming (e.g. Portunidaae), object carrying (e.g. Dromiidae), markedly reduced (e.g. Palicidae) or completely missing (e. g. Hexapodidae). **Abdomen** (Fig. 1.6a, b) seven segmented (with telson), some somites fused together in some groups, particularly in males; abdomen of males relatively narrow, tightly folded against sternum, with or without holding mechanism; abdomen of females usually broad, free, without holding mechanism. **Male gonopore** (Fig. 1.6c) on coxa of pereiopod 5 (e.g. Xanthoidea, Pilumnoidea, Potamoidea) or thoracic sternite 8 (e.g. Grapsoidea, Ocypodoidea), supplemented with penis for transferring sperms to G1. **Female gonopore** (Fig. 1.6d) on coxa of pereiopod 3 (section Podothremata) or on sternite 6 (section Eubrachyura). **Pleopods** 1 and 2 (Fig. 1.6c) modified into uniramous gonopods in males, together functioning as sperm transporter to female gonopore, G1 is normally long and robust, while G2 is short in most groups but in some narrow and long (e.g. Menippidae, Oziidae) and used to pump sperms into sperm channel along the G1, pleopods 3–5 are completely missing in males; pleopods of females exist, pleopod 1 uniramous, generally reduced, rarely absent, pleopods 2–5 biramous, setose, are used for carrying eggs.

The infraorders Brachyura is primarily divided into two sections based on the position of the genital opening of males and females; section Podothremata or “primitive” crabs (genital opening of males and females coxal) and Eubrachyura or “advanced” crabs (genital opening of females sternal and males coxal or sternal). The section Eubrachyura is subsequently divided into two subsections Heterotremata (genital openings of males on coxa of fifth pereiopod) and Thoracotremata (genital opening of males on eighth sternum) (Guinot 1968;

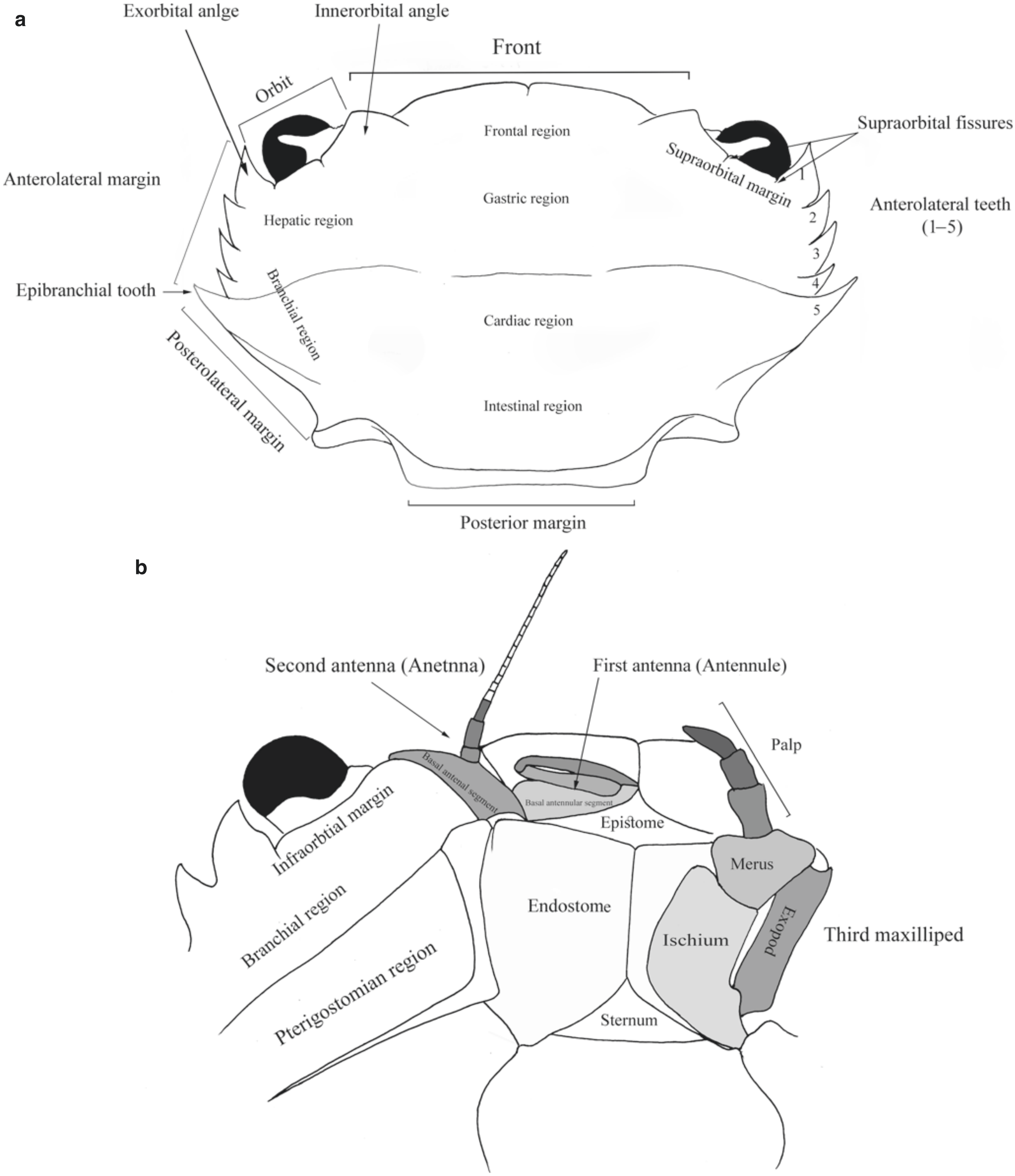

Fig. 1.4 Schematic drawing of the carapace indicating important diagnostic characteritics and the terms used in the text. (**a**) dorsal view, (**b**) anteroventral view. The illustration is from *Thalamita iranica* (Portunidae)

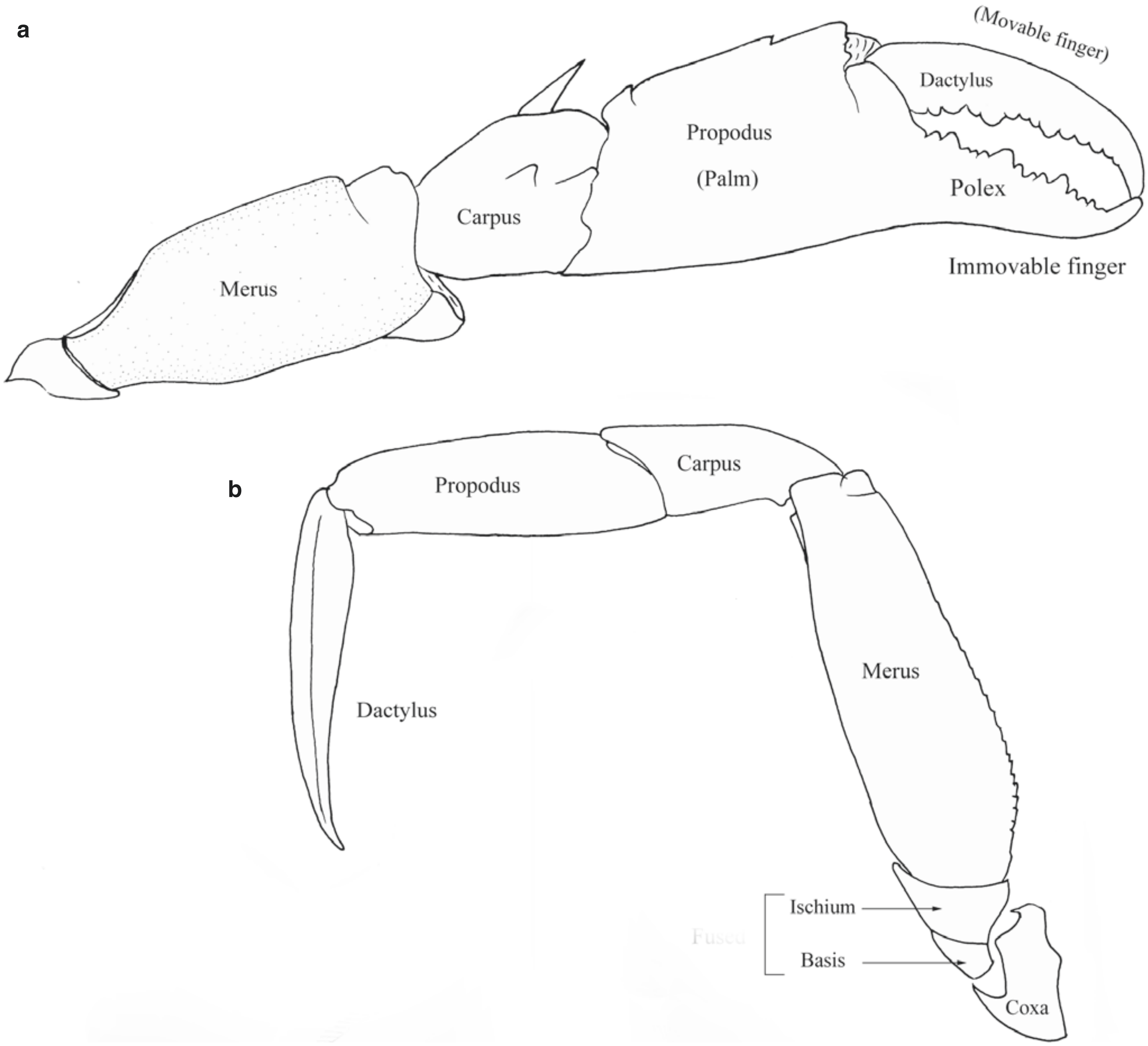

Fig. 1.5 Schematic drawing of the pereiopods indicating important diagnostic characteritics and the terms used in the text. (**a**) cheliped, (**b**) walking leg

De Saint Laurent 1980a, 1980b; Ng et al. 2008). The unity and monophyly of the sections and subsections have frequently been questioned by authors (e.g. Brösing et al. 2007; Ahyong et al. 2007; Ng et al. 2008). I prefer to use the high level classification in the presently accepted form, although it does not convey phylogenetic history, it shows only distinguishable shared characters of the members of the groups. I found out that it is not necessary to use superfamilies, due to the instability of most of the groups like Ocypodoidea, Grapsoidea and Goneplacoidea.

Ng's (1998) work is a good starting point for students beginning to basically understand brachyuran crabs. This work is thought to largely deal with commercially

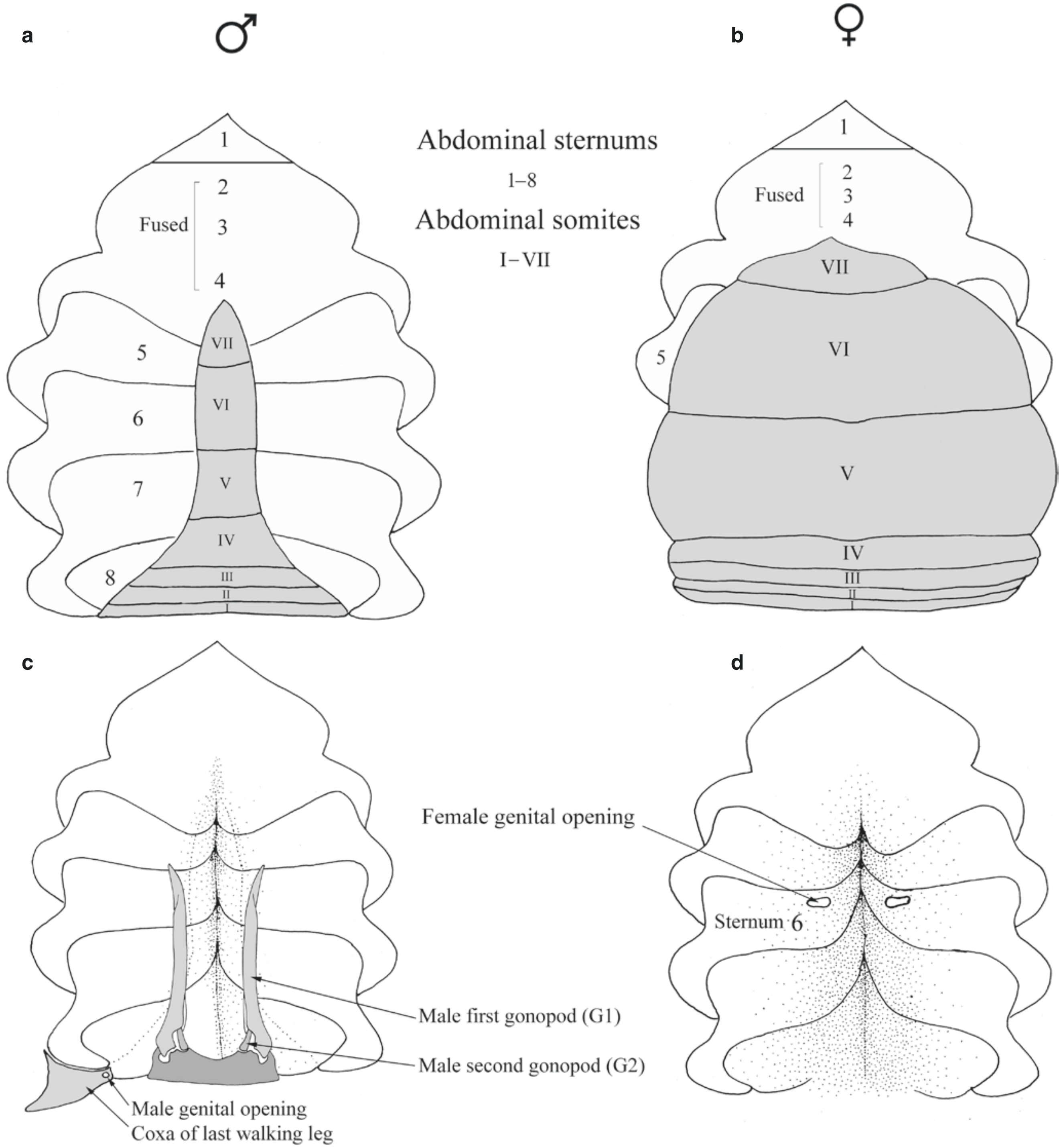

Fig. 1.6 Schematic drawing of the abdominal part with important diagnostic characteritics and the terms used in the text. (**a**) abdomen of male, (**b**) abdomen of female, (**c**) gonopod and gonopore of male, abdomen removed, (**d**) gonopore of female, abdomen removed

important species, nevertheless it provides a basic descriptions and illustrations of the crab's external morphology, accompanying with landmark identification keys for known extant families. Ng et al. (2008) is a key catalogue of extant brachyuran species, which is indispensable to any scientists working on the taxonomy of this group. Any scientist has to have a hardcopy of this book on his/her desk or a PDF file on his/her desktop!

About the Atlas

The Atlas is first provided for crustacean taxonomists working on the taxonomy and biodiversity of the group in the region, with providing a valid list of the species and their synonymies. Secondly, the Atlas with identification guide and discriminative photos can also help general marine scientists, ecologists and students to readily identify the species in the fields and in the labs as well.

Classification systems and hierarchical nomenclatures used in this atlas are mainly based on Ng et al. (2008) and De Grave et al. (2009). Sections and families are arranged according to their evolutionary relationships and superfamilies are not used in this work in order to avoid the complexity of the taxonomic hierarchies. Genera and species are arranged in alphabetical order. Identification keys are provided for all families, genera and species using main synapomophies. Short but precise descriptions containing the main characteristics are also provided for every family. Descriptions and key of the families are mainly based on the three main literatures including Ng (1998), Davie (2002) and Števčić (2005). Wherever available, references specifically contributed for a certain family are used, e. g. family Palicidae (Castro 2000a), Euryplacidae (Castro and Ng 2010), Portunidae (Apel and Spiridonov 1998), and Trapeziidae and Tetraliidae (Castro et al. 2004). The descriptions are supplemented with remarks, mainly with taxonomic notes if there is a necessity.

"Synonymies" encompass the regional works, including those from the Persian Gulf, Gulf of Oman and Arabian Sea, and sometimes references from the Red Sea and Gulf of Aden are included. Further, original descriptions, overall revision of given taxa and monographs are also listed under synonymies in order to provide additional detailed taxonomic accounts. "Taxonomic remarks" for species are just given when are necessary.

Measurements for the specimens in the figures are included in the legends. These are carapace length (CL) which was measured from the middle of the frontal margin to the middle of the posterior margin of the carapace, and carapace breadth (CB) which was measured across the widest breadth of the carapace, in most cases between the longest anterolateral or epibranchial teeth.

Color photograph from dorsal view of the carapace is provided for all species. Some species are provided with additional photos, particularly ventral view, showing discriminative characters. As in the Brachyura, the male first gonopod is most important discriminant character, line drawing of the character was made for the majority of the species. Drawings of abdomen, carapace, cheliped and third maxilliped were made for few species where the photos do not properly help for readily distinguishing the species.

Distribution within the Persian Gulf and the Gulf of Oman are given based on the records from localities defined in the Fig. 1.1. Unfortunately, because of paucity of the sampling, many species have been recorded from limited localities, therefore point distribution are provided for all the species. Some species have already been recorded from the Persian Gulf and the Gulf of Oman, by non-taxonomists. These are mostly from Basson et al. (1977), Titgen (1982), and Hogarth (1989). I neither could re-examine the material nor can easily rely on the records, therefore the 28 species with doubtful and questioned records are not in taxonomic list but listed in a table (Table 1.1). In addition, Alcock's (1895–1905) records are based on the material collected by "Investigator" which possibly were not in the inner the Persian Gulf. Therefore, if there was no further finding of the Alcock's (1895–1905) records, the records are also included in the list of doubtful species (Table 1.1).