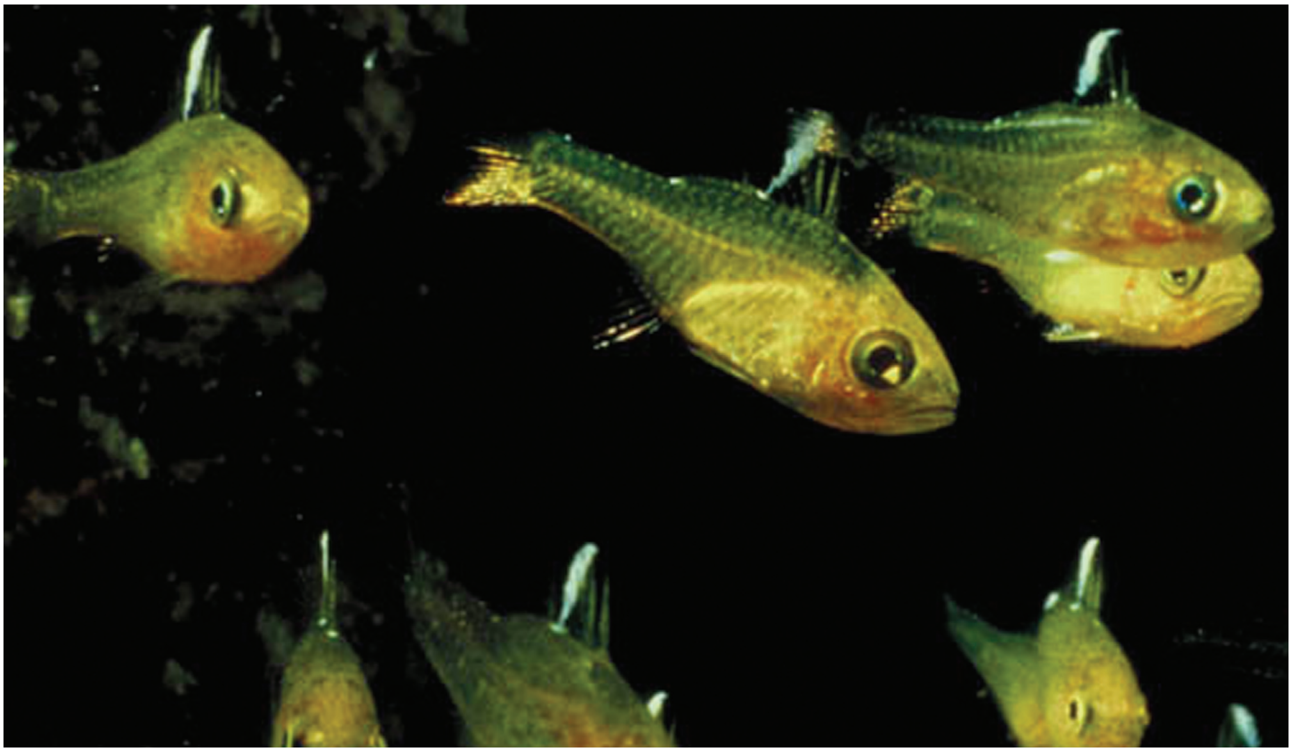
Marine Biodiversity Review of the Arafura and Timor Seas

Ministry of Marine Affairs and Fisheries
Indonesian Institute of Sciences
United Nation Development Programme
Census of Marine Life

2008



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Marine Biodiversity Review
of the Arafura and Timor Seas

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Content

Preface

Chairman of the Agency for Marine and Fisheries Research
Ministry of Marine Affairs and Fisheries
Republic of Indonesia

For many years the Arafura and Timor Seas have received little attention in the scientific literature, including oceanographic surveys. Yet, these areas are important for fisheries as well as oil and gas production that provide economic benefits to the bordering countries. In addition, there are many potential activities that could be developed using the natural resources such as marine tourism and aquaculture.

The Marine Biodiversity Review of the Arafura and Timor Seas is the first publication of the Census of Marine Life (CoML) Indonesia in collaboration with the Agency for Marine and Fisheries Research (AMFR) and the Indonesian Institute of Sciences (LIPI). This has been an important endeavor in raising the profile of Arafura and Timor Seas. The richness of its marine biodiversity in this area is tremendous, but yet it needs to be explored more.

I am convinced that this book will give motivation to other scientists working in the natural aspect of Arafura and Timor Seas to conserve these areas from over-fishing and further environmental declining from activities such as marine debris and marine pollutions. Therefore I commend the initiative to publish this book, with the hope that it will be followed by series of other publication on these highly diverse areas.

The collaboration between AMFR and LIPI is also another highlight of this publication. This book has clearly shown that different institutions in Indonesia should be working together in taking advantage of different expertise and resources that we have to showcase different parts of the Indonesian seas. Our experts and scientists who have worked on this book deserved to be credited. This book is not intended to provide the comprehensive list of Arafura and Timor Seas marine biodiversity, but it is more to give some insights of what we would have seen should we go out and survey the area.

Finally, I wish to thank the research team that have worked on making this book possible, and the assistance from the Census of Marine Life and UNDP.

Jakarta, December 2008

Dr. Gellwynn Jusuf

Preface

Deputy of Earth Sciences
Indonesian Institutes of Sciences

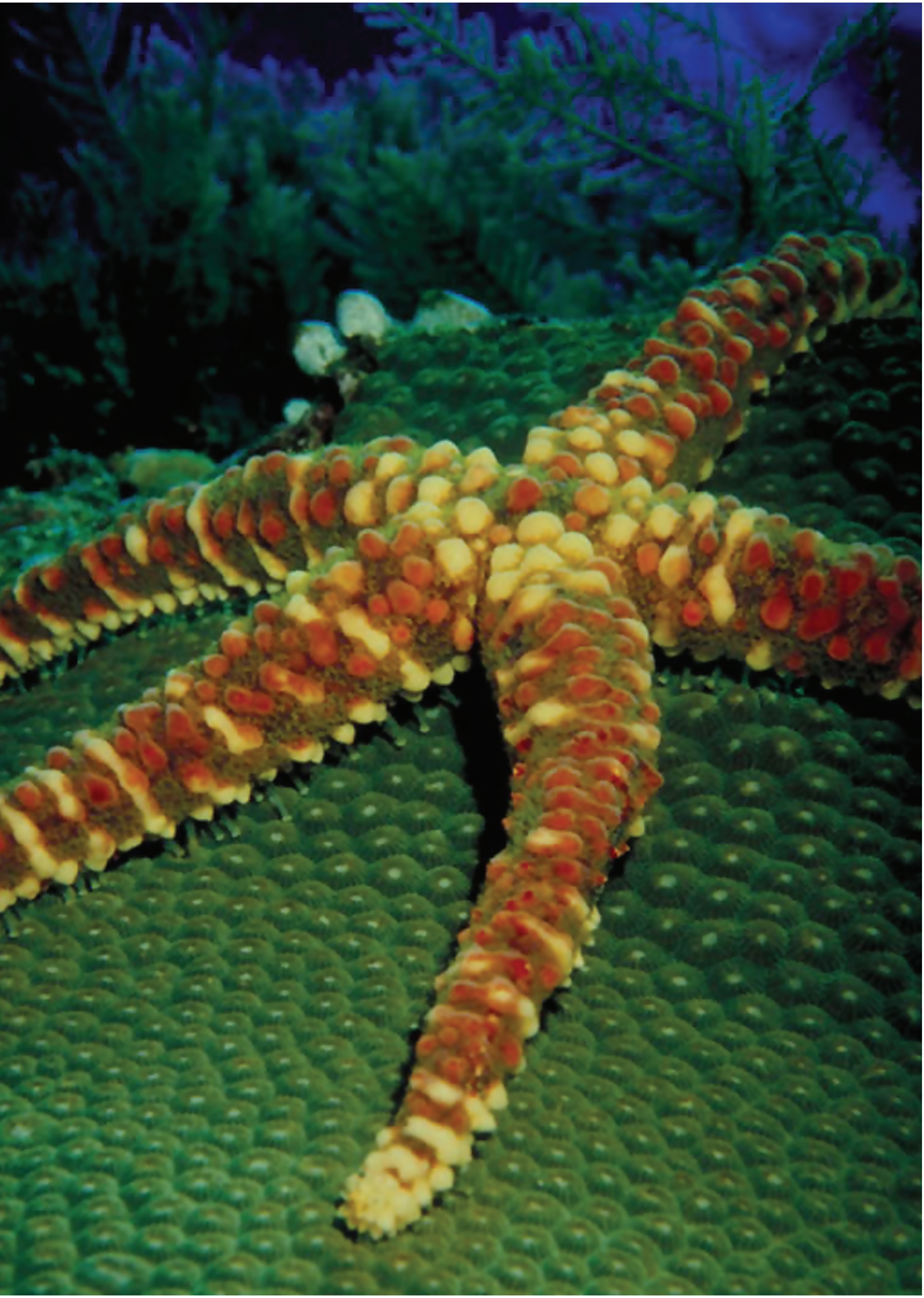
It is a great pleasure to see this book finally published. The marine biodiversity of Indonesia was used to be a program of the research competitive at Indonesian Institute of Sciences (LIPI). The research program was first launched in early 2003 by Prof. Dr. Jan Sopaheluwakan. The marine biodiversity program has been running from 2003 until 2008. The research has published more than 39 scientific papers at national journals, 17 papers at international journals, and at least 7 books on biodiversity aspects.

Due to limited funding at LIPI levels, the program is merged under a program of exploration of natural resources starting from the year 2009. In effort to maintain the marine biodiversity research in Indonesia alive, in mid 2008, a previous chair of Agency for Marine and Fisheries Research, Prof. Dr. Indroyono Soesilo, and I made a consensus to have joint activities in order to have strong communication with Census of Marine Life (CoML)-International Program. This book is fruitful efforts of the secretariat of CoML-Indonesia and several Indonesian scientists who try to describe the rich of marine life in the Arafura and Timor Seas.

As far as I know, there is no available information on marine biodiversity of the Arafura and Timor Seas. Therefore, this first step of compilation about general oceanographic and marine life of the Arafura and Timor Seas becomes an inseparable effort in understanding our marine life. I hope that this book could assist managers and business communities who plan to develop the region. I also hope that this effort will be continued by involving all the Indonesian marine scientists and managers.

Jakarta, December 2008

Dr. Hery Harjono



Chapter 1

Marine Biodiversity in the Arafura and Timor Seas

1.1 Background

The global Census of Marine Life (CoML) is an endeavour by scientists around the world to improve the understanding of the condition, diversity, distribution and abundance of marine biota and biotic communities in terms of time and space. The CoML research programme began with efforts to increase knowledge and understanding regarding which organisms lived in the past, are alive now, and are likely to live or survive into the future. With this in mind, research activities under the CoML programme were carefully planned to provide an overview of what we already know today, identify the most important research issues, and undertake research to make known that which was previously unknown (for example case of the Indonesian Coelacanth). Therefore, as a maritime nation and centre of global marine biodiversity, it is fitting that Indonesia should be involved and make a meaningful contribution to this global effort.

Although Indonesia is renowned as an area of high biodiversity, it is a fact that there is minimal understanding regarding marine biodiversity; available data are not well documented and are held by many dispersed stakeholder groups. Similarly, research activities are often incomplete because of the geographical extent and remote, inaccessible nature of the terrain. This has meant that during the

Fig. 1.1
Map of the Republic of Indonesia

last two or three decades the scientific basis for marine resource use has been relatively poor. Lack of data regarding the biological aspects of marine living resources (such as population dynamics, life-cycles, migratory behaviour), and the high rate of ecosystem degradation are the main constraints to sustainable marine resource use. On the other hand, human activities on land and resource exploitation at sea tend to have increasingly negative effects on the state of marine resources and the quality of the marine environment. Therefore, the research programme at the Census of Marine Life was designed to reduce the gaps in data and information regarding the dynamics of marine biodiversity, socio-technological and human aspects, and efforts to achieve sustainable marine resource use.

As an integral part of the Indonesian waters, the Arafura and Timor Seas also play important role in linking the Banda Sea current with the Arafura Sea (Fig. 1.1). Hence, this study reviews a current situation regarding the knowledge on marine ecosystem, distribution and abundance of some major groups of organism found in the Arafura Sea and its adjacent Timor Sea.

1.2 Conceptual framework

Up to the present time, marine living resources are and have been a source of cheap protein of high nutritional value. However resource use levels are not yet optimal. Several marine biota are not yet used or hardly touched by current exploitation levels, for example sidat (freshwater-eels)[1], sponges and tunicates; on the other hand, several other species have been exploited to maximum levels such that their exploitation threatens the very existence of these resources, for example flying fish, sharks and rays, napoleon wrasse and sea-cucumbers. High levels of exploitation are driven by there factors, (1) the internal factor, in this case human activities by

[1] Freshwater eels (in Indonesia it is called *Sidat*) – is a freshwater tropical eels that spawns in open sea and migrate to freshwater ecosystems. Sidat has several local names such as, *moa, lubang, masapi,* and *dunu.*

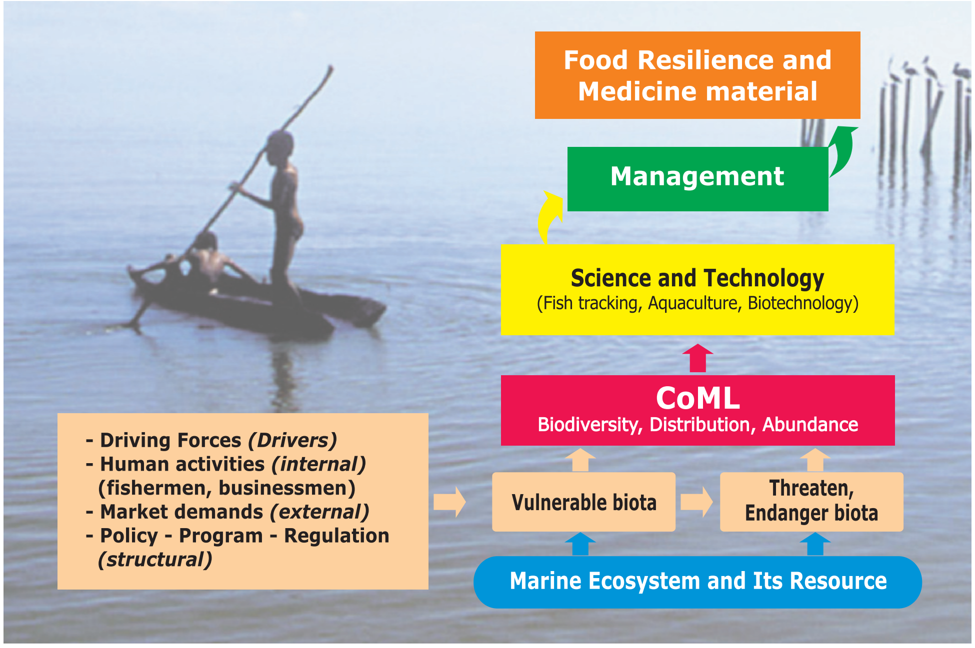


Fig. 1.2
Conceptual framework on research competitive census of marine life

fishers and the fishing industry; (2) the external factor meaning market demand which originates from outside the system; and (3) the structural factor, consisting of policy aspects, programmes, and legislation (Fig. 1.2).

These three driving factors act concurrently and impact the condition of marine ecosystems and living resources (biota). The high level of exploitation endangers the survival of marine biota. Therefore, research into the life-cycle or life history productivity and variability of given marine living resources will provide the basic components for understanding the heart of the matter as regards biodiversity, geographical distribution, and abundance or biomass within the Census of Marine Life programme.

From Indonesian perspective, the Census of Marine Life programme, called *Marine Life in Indonesia*, aims to support the government programme for food security. Therefore marine life census research activities are aimed not only towards taxonomic and distribution aspects, but also towards a better understanding of resource potential, exploitation levels and socio-economic aspects related to coastal communities.

1.3 The marine life in Indonesia programme

The Census of Marine Life of Indonesia “Marine Life in Indonesia” (MarLIn) programme is a research programme studying the changes or dynamics in temporal and spatial scales (over time and in space) of diversity, distribution and abundance of marine organisms which are associated with environmental conditions and human activities.

The scope of the Marine Life in Indonesia programme is based on three integrated approaches which are the research scope, geographical scope and temporal scope. The scope of the Census of Marine Life programme covers six components which are; *Taxonomic component* covering: Fish (Elasmobranches, Deep Sea Lethrinus, Tropical Eels (sidat) and Flying Fish); Crustacea (Coral Shrimp and Penaeid Shrimp); Mollusca (Tridacnidae and Trochidae); Echinoderms (all sea-cucumber species). These priority taxa were selected based on the following criteria: (1) high economic value and high production levels; (2) scarcity or endangered status; (3) potential species commodities, with a promising economic future; (4) high market demand; (5) uniqueness and specificity (local specialties).

Habitat/ecosystem component covering the following ecosystems: estuaries, mangrove forests, seagrass beds and coral reefs as well as their associated biota.

Plankton and hydrological/oceanographically Component covering the media in which marine biota live, including physical, chemical and biological parameters as well as study of plankton as the basis of the marine food web.

"Marine Bioprospecting" Component is a downstream activity which endeavours to study a number of marine species which are potential sources of bioactive compounds and can be considered as *frontier* commodities. In the initial stage, this research will be focussed on macroalgae, sponges and ascidians.

Detection technology development Component which is a programme for the development of detection equipment in the field of marine research, for example equipment to detect the whereabouts of fish, or equipment for continuous (ongoing) real time water quality monitoring.

Social–economy–demography Component which covers the study of social aspects which are considered to influence the exploitation and preservation of marine and coastal resources, including policy, law enforcement, greed, lack of alternative livelihoods, urgent spatial requirements, and lack of caring for the environment and the resource base.

Information System Component which is a supporting activity allocated to the *Earth and Aquatic Information System* (EARIS) programme which is coordinated by the *Deputi Ilmu Pengetahuan Kebumian* – LIPI, which is the Deputy for Earth Sciences of the Indonesian Institute for Sciences. This information system is called ***Indo-MarLInS =*** Indonesian *Marine Life Information System.*

Based on the consideration that the Indonesian territory is very extensive, the scope of this study is to focus on five areas as follows:

- Makassar Straits with a focus on East Kalimantan;
- The waters surrounding North Sulawesi around Bitung, Lembeh Straits and Gulf of Tomini;
- The waters around North Maluku with a focus on Ternate and the surrounding area;
- The South China Sea and Malacca Straits within the Riau area;
- The Indian Ocean with a focus on the islands of West Sumatra, East Nusa Tenggara, and West Nusa Tenggara.

Finally, the main time-frame for the Marine Life in Indonesia Programme is from 2004 to 2010. Overall, the study period will be divided into two stages, which are the initial stage from 2004 – 2008, and the development stage from 2009 – 2010. This is in line with the global CoML which will end in 2010, so that in 2010, it is expected that Indonesia can provide a research report as a contribution to the global and national marine scientific communities.

In the following 5 years (2009 – 2013), the Census of Marine Life–Indonesia programme will face a heavy task, not only because of the factors internal to Indonesia, but also due to global factors such as climate change and sea level rise which threaten to reduce the food sources availability of the Indonesian nation and the loss of important coastal ecosystems which provide much of the nation's food sources. Hence, lost of marine biodiversity, changes in community structure and shifting ecosystem functions are important issues which will determine the success or failure of efforts to achieve national food resilience from marine sector ■

Chapter 2

Geographical and Hydrological Condition of the Arafura and Timor Seas

Based on the United Nations Convention Chapter IX regarding maritime law, it is stated that the Timor Sea and the Arafura Sea, are a semi-enclosed body of water which is defined as….*enclosed or semi-enclosed sea means gulf, basin or sea surrounded by two or more states and connected to another sea or ocean by a narrow outlet or consisting entirely or primarily of the territorial seas and exclusive economic zones of the two or more coastal states*. The position of the Arafura and Timor Seas is as shown in Fig. 2.1 and Fig. 2.2.

From bathymetric, geomorphologic, bio-geographic and chemical criteria, these two seas have many surprising features and are worthy of admiration. With an average sea-surface temperature of 29^{0}C, it can be said that the greater part of these sea areas warm this planet, and are associated with micro-organisms and macro-organisms which have unique features or attributes and are as yet little known.

The Arafura and Timor Seas form part of the Indonesia waters whose boundaries are in direct contact with other coastal nations such as Timor Leste and Australia. The Arafura Sea consists of the waters covering the Arafura continental shelf, between Northern Australia and Eastern Indonesia. This sea is around 1,290 km in length and 560 km wide, with depths mainly in the 50-80 m range.

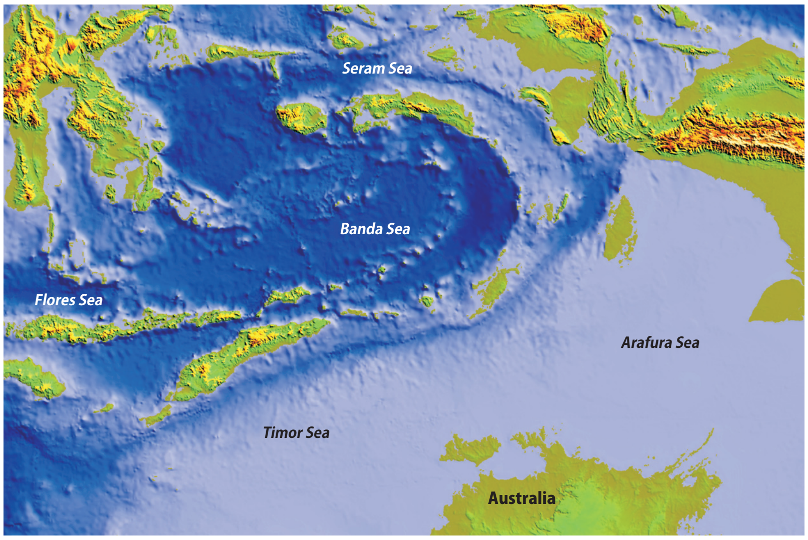


Fig. 2.1
The Arafura and Timor Seas Area
(*based on a satellite image*)

Fig. 2.2
The Arafura and Timor Sea.

The surface area of the Arafura Sea is around $599x10^3$ km^2 consisting of a continental shelf area around $535x10^3$ km^2 and the remaining $64x10^3$ km^2 consists of deep waters (Table 2.1). The substrate of the Arafura Sea mainly consists of mud and a little sand.

The Arafura Sea is bounded to the north by the Southern of the Seram Sea and to the south by the North Coast of Australia from York Peninsula to the Don Peninsula. To the east, the Arafura Sea is bounded by the Banda Sea, and to the west by a line drawn from the Don Peninsula to Tanjung Aro Usu, the south-western point of the Selaru Archipelago ($8^0$20’ S, $130^0$45’ E), and Tanimbar, whereas to the northwest, the Aru *Trough* (3,650 m deep) divides the Arafura Sea from the Western Banda Sea.

The Timor Sea consists of the waters to the Southeast of the Island of Timor and the Northwest of the Australian continent with a surface

	property	
1.	Surface area (10^3 km^2)	599
2.	Continental shelf area (10^3 km^2) (0 – 200 m depth)	535
3.	Average depth of the continental shelf (m)	40
4.	Non-shelf area (10^3 km^2)	64
5.	Mean depth of non shelf area (m)	1,279
6.	Mean primary production (g C.m^{-2} a^{-1})	167

Table 2.1
Some physical properties of the Arafura sea (After Dalzell and Pauly (1990)).

Fig. 2.3
Map of the Timor Sea, Timor Trough and Big Bank Shoals *(Source: Heyward et al., 2001)*

area of around 615,000 km^2 (235,000 mil^2), forming the boundary between Australia and Timor Island, and cover the Sahul continental shelf, part of the Timor shelf and the Timor Trough which reaches depths of over 3,300 m (10,800 feet) (Fig. 2.3). To the north, the Timor Sea is bounded by the islands of Sermata, Leti, Timor, and Roti, and to the West by the western part of the Arafura Sea. To the east, the Arafura Sea is bounded by the Indian Ocean and to the south by the Northwest coast of Australia.

2.1 Geomorphology of the Arafura and Timor seas

2.1.1 Topography of the Arafura and Timor Seas

In terms of depth, the Indonesian waters can be divided into two main categories, which are shallow waters covering continental shelf areas and deep sea waters. Continental shelf areas reach from the lowest astronomical low-tide

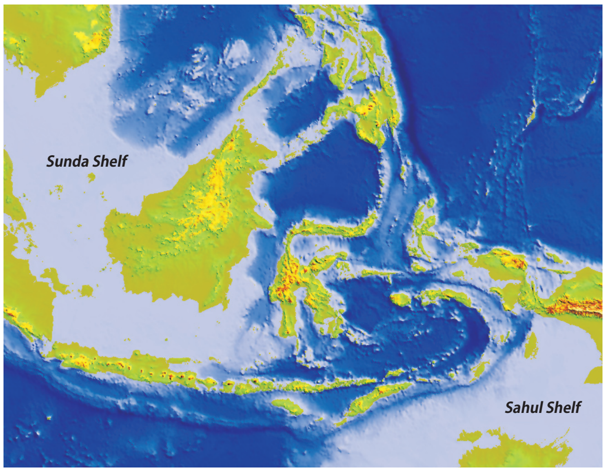


Fig. 2.4
The Sunda Shelf (in the west) and the Arafura-Sahul Shelf (in the east) with depths less than 200 m. *(Source: ATSEF team)*

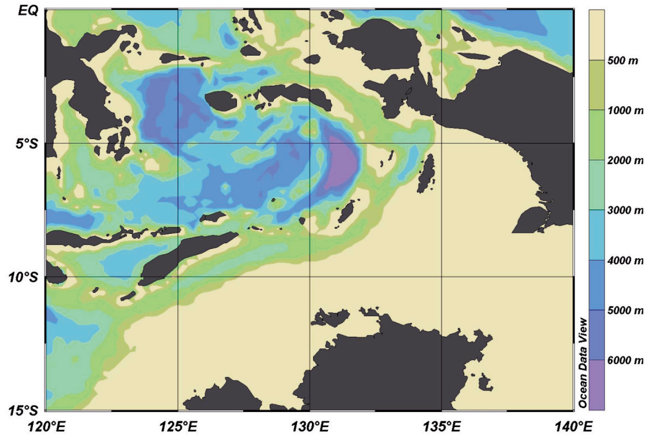


Fig. 2.5
Arafura Sea bathymetric chart *(Source : analysis of In Situ data obtained using ODV)*

line to a depth of around 120 – 200 m, which is generally bounded by a steeper slope leading to the deep sea bed (*Nontji, 2002*). Indonesia has two extensive continental shelves, which are the Sunda Shelf to the west and the Arafura - Sahul Shelf to the east (Fig. 2.4).

The depth of the Arafura Sea ranges from 30 – 90 m (Fig. 2.5). The Aru Archipelago consists of five islands, separated from each other by narrow straits resembling rivers in which the sea bed lies deeper than that of the surrounding continental shelf.

The Arafura-Sahul Shelf is situated to the north of Australia (Fig. 2.6). There are several names which tend to be used for parts of this shelf. The Sahul Shelf (name given by Earl, 1845) is situated between Laveque Point and the Gulf of Van Diemen, whereas the western part is referred to as the Rowley Shelf. The Arafura Shelf (name given by Krummel, 1897) is the area from the Gulf of Van Diemen (Australia) to Irian (Papua). The total area of this continental shelf is around 1.5 million km^2 comprising the Arafura Shelf with around 930,000 km^2 and the Sahul and Rowley Shelves which each have an area of around 300,000 km^2 (Nontji, 2002).

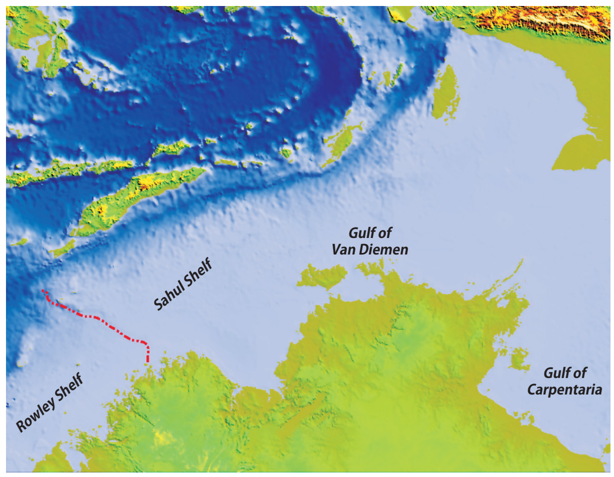


Fig. 2.6
Arafura - Sahul - Rowley Shelves *(Source: Nontji, 2002 and the ATSEF team)*

The Sahul Shelf situated to the north of Australia stretches seawards for 300 to 500 km with depths of 50 to 120 m, and is considered to be a part of the Australian Continent which was fairly recently submerged, around 18,000 years ago. The original coastline before this submersion can still be identified at depths of around 100 – 140 m. The depth increases sharply to around 3,000 m in the Timor Trough, which runs parallel to Timor Island. The vertical profile of the Sahul Shelf can be seen in Fig. 2.7. At the

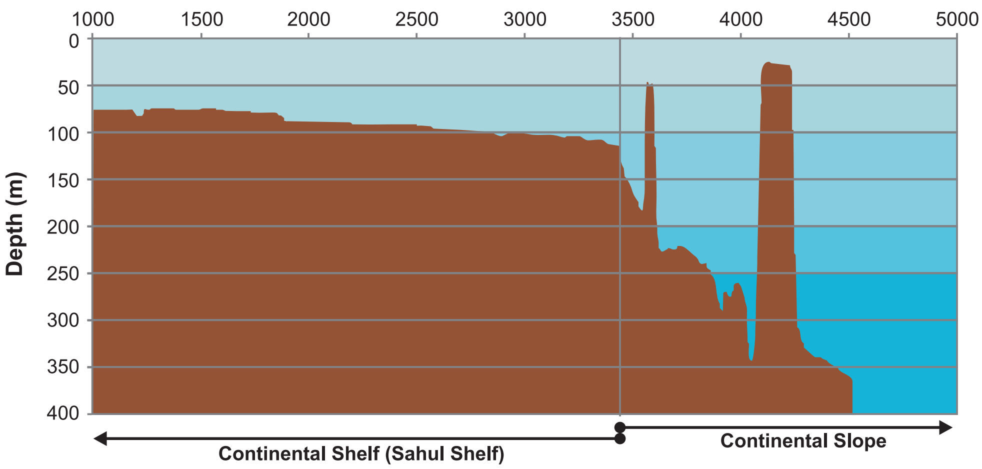


Fig. 2.7
Vertical Profile of the Sahul Shelf *(Source: Heyward et al., 2001)*

outer edge of the Sahul Shelf there are layered carbon deposits.

2.1.2 Surface Temperature of the Arafura and Timor Seas

Sea surface temperatures in Indonesia generally range from 28 – 31 ^{o}C with minimal annual variations. Average annual variations in the equatorial region tend to be less than 2 ^{o}C, however in the Banda, Arafura and Timor Seas the variation tends to be a bit higher, with values from 3 ^{o}C to 4^{o}C. The annual horizontal temperature distribution in the Arafura and Timor Seas areas for each season is shown in Fig. 2.8, while general vertical temperature distribution profile commonly found in Indonesia is presented in Fig. 2.9.

2.1.3 Sea surface salinity of the Arafura and Timor Seas

During the Southeast Monsoon, high salinity water masses with salinity levels over 35 $^{0}/_{00}$ move from Northeast Australia to the Arafura Sea via the Torres Straits. However the straits

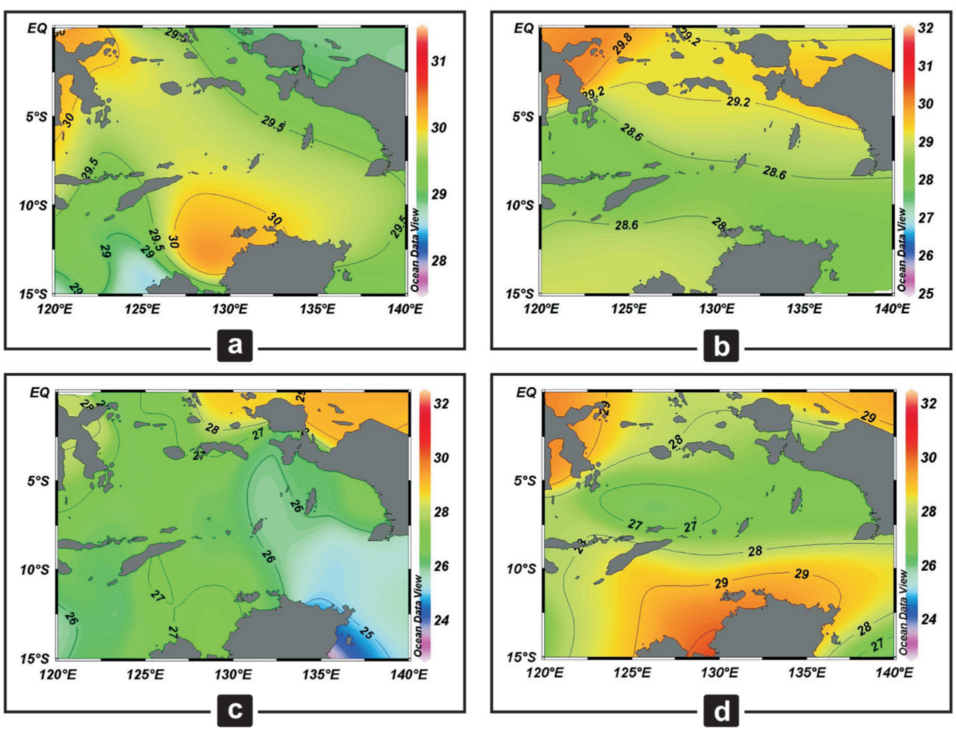


Fig. 2.8
Seasonal Temperature of the Arafura Sea and Timor Sea [^{o}C].
a. West Monsoon (Dec.–Feb.);
b. Change-over season early in the year (Mar.–May);
c. East Monsoon (Jun.–Aug.);
d. Year-end Change-over season (Sep.-Dec.)
(Source: Analysis of In Situ data obtained using ODV)

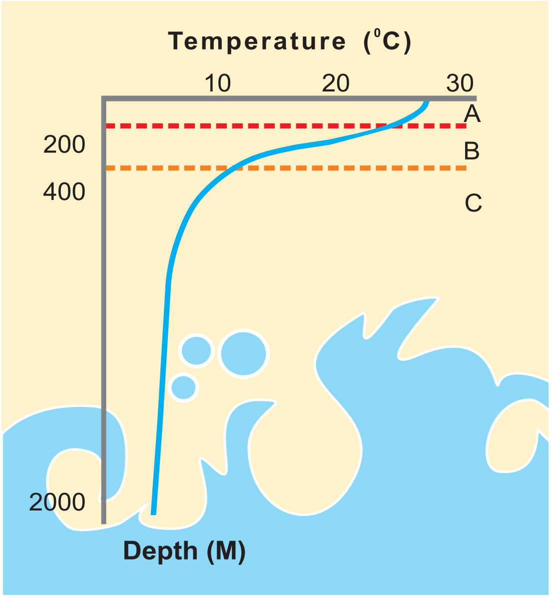


Fig. 2.9
General vertical temperature profile for Indonesian waters.
A. warm layer;
B. thermocline;
C. cold layer
(Source: Nontji, 2002)

are too shallow and narrow, so that the water mass movement is of relatively low volume. The Arafura Sea has a relatively high evaporation rate of 780 mm which is higher still in the Timor Sea reaching up to 1,240 mm. This causes an increase in salinity of 0.5 $^0/_{00}$ – 1.2 $^0/_{00}$ during the dry season.

Salinity in the Arafura Sea begins to fall around the end of February, when water masses from the Java and Flores Seas reach this area. Because of this, salinity is lowest in May at the beginning of the Southeast Monsoon. In the Timor Sea, in spite of an evaporation rate reaching 1,240 mm, the annual salinity variation rarely exceeds 0.5 $^0/_{00}$. In the offshore waters to the South of Timor Island, the Timor Current runs to the Southwest throughout the year, and in the Southeast Monsoon widen to reach the coast of Australia. The through flow of this current ensures that although the Timor Sea does experience variations in salinity, nevertheless local impacts do not cause major local variations in salinity.

The Arafura Sea and eastern part of the Banda Sea are important upwelling zones. During the Northwest monsoon, water masses with salinity around 33. 5 $^0/_{00}$ – 34. 2 $^0/_{00}$ are moved by the monsoon winds and occupy the surface layers to a depth of around 100 m. During the Southeast Monsoon, there is a phenomenon of upwelling which brings colder water masses with high salinity to the surface. The surface layer salinity gradients for the area around the Arafura and Timor Seas are shown in Fig. 2.10.

2.2 Dynamics system in the Arafura and Timor Seas

2.2.1 Winds

Monsoon winds play a key role in Indonesia, and determine the condition of the waters of the Arafura Sea and Timor Sea. The monsoons affect precipitation, with high rainfall to the south of the equator during the West Monsoon, whereas during the East Monsoon there is little rain. In general, the precipitation rates in the Timor Sea and the Arafura Sea are equal to or even less than evaporation rates. Tropical cyclones occur to the south of the equator, in the Eastern Indian Ocean, the Timor Sea and the Arafura Sea. Since 1964 there has been an average of 2.6 cyclones per year in the region bounded by the coordinates 5° S -16.5° S and 121° E - 132° E.

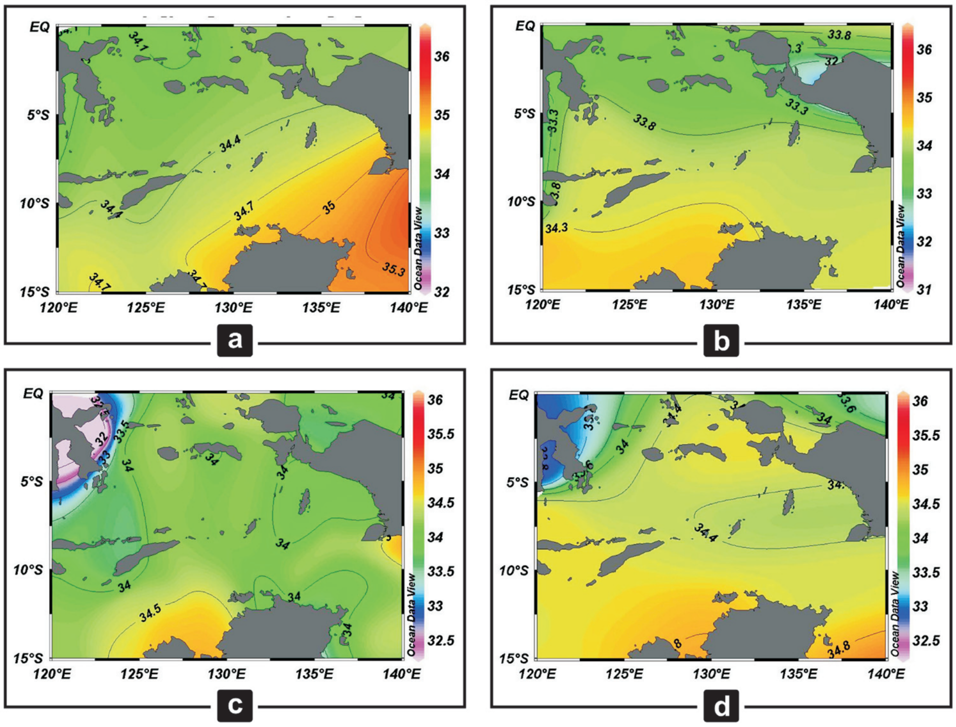


Fig. 2.10
Horizontal Salinity Gradients [psu].

a. West Monsoon (December – February)
b. Change-over season early in the year (March – May);
c. East Monsoon (June – August) ;
d. Year end change-over season (September – December)

(Source: Analysis of In Situ data obtained using ODV)

2.2.2 Water circulation

There are two main currents driving ocean circulation in Indonesian waters: The Indonesian Monsoon Current (Arus Monsoon Indonesia) and the Indonesian Throughflow (Arus Lintas Indonesia). The Indonesian Monsoon Current is in the west whereas Indonesian Throughflow flows through central and eastern Indonesia. The Indonesian Monsoon Current generally flows from the South China Sea to the Java Sea through the Natuna Sea and Karimata Straits. From the Java Sea, Indonesian Monsoon Current flows to deep water areas in the Flores and Banda Seas.

East Monsoon System is the main causal agent of the equatorial current system which comprises the North Equatorial Current and the South Equatorial Current which flow to the west, and the Equatorial Counter Current which flows to the east. The convergence of the strong equatorial currents in the equatorial region of the Western Pacific is balanced by a westerly flow which will go on to become the North Equatorial Counter Current (NECC), and part of this current will eventually reach the Indian Ocean via the Indonesian Throughflow.

Wyrtki (1961) concluded that form the surface to a depth of around 500 m, currents in Indonesian waters between the Pacific and Indian Oceans are driven by the Mindanao Current (MC), an opinion which was shared by Fine (1985), Godfrey (1993) and Gordon (1995). Thereafter, analysis of the water mass in the Makassar Straits revealed that the water originated from North Pacific Subtropical Water, NPSW (above the thermocline S_{max}) and North Pacific Intermediate Water, NPIW (below the thermocline S_{min}) (Ilahude and Gordon, 1996).

Hautala *et al.*, (1996) concluded, based on observations of the effect of precipitation on salinity to a depth of 200 m, that the main source of water transfer from the Pacific to the Indian Ocean via Indonesia is the Northern Pacific. In addition, in a study of mass, heat and salinity budgets (exchange balance) between 10° N and 14° S there was found to be a heavy horizontal transport in the Western Pacific thermocline layer which is received by the Indonesian Throughflow and is dominated by waters from the South Pacific.

In general, the seas of Indonesia play an important role in low-latitude transfer of heat and low salinity water from the Pacific Ocean to the Indian Ocean. The Indonesian Throughflow plays an important role in thermo-haline circulation and other phenomena related to global climate regulation (Sprintall et al., 2001 and Gordon, 2001). Heat and fresh water carried by the Indonesian Throughflow have a large effect on the exchange balance between these two oceans (Bryden and Imawaki, 2001; Wajsowicz and Schneider, 2001). Within Indonesian waters, observations and modelling indicate that the main source of the Indonesian Throughflow is North Pacific Thermocline Water which flows through the Makassar Straits. An additional contribution to the Indonesian Throughflow comes from lower thermocline water and deep water masses originating in the South Pacific, via the eastern parts of the Maluku and Halmahera Seas, while heavier waters flow through the Lifamatola Straits. The Indonesian Throughflow enters the Eastern Indian Ocean with the major flow passing around the Sunda Strait.

The recent research programme entitled "INSTANT" (Gordon *et al.,* 2002) which encompasses research by five nations, to whit the USA, Australia, France, the Netherlands and Indonesia, has produced a map of the Indonesian Throughflow route which is shown in Fig. 2.11, and can be explained as follows: the thick arrow represents *North Pacific Thermocline Water*, the dotted arrow(s) represent *South Pacific Deeper Water*. The volume of water transported in Sv (10^6 m^3s^{-1}) is given in red letters. The Fig. 2.8.5 Sv in italics (Fig. 2.11) is the total of all current flows through the Sunda Strait. Superscripts indicate the source of reference including: 1. the volume of water transported through the Makassar Straits in1997 (Gordon et al., 1999); 2. the volume of water transport through the Lombok Strait from January 1985 to January 1986 (Murray and Arief, 1988; Murray et al., 1989); 3. the volume of water transport through the Timor Strait (between Timor and Australia) measured from March 1992 to April 1993 (Molcard et al., 1996); 4. the volume of water transport through the Timor Strait in October 1987 and March 1988 (Cresswell et al., 1993); 5. the volume of water transport through the Ombai Strait (to the North of Timor, between Timor and Pulau Alor) from December 1995 to December 1996 (Molcard et al., 2001); 6. water transport between Java and Australia using XBT data from 1983 to 1989 (Meyers et al., 1995; Meyers, 1996); 7. water transport above 470 m SEC in the Eastern Indian Ocean in October 1987 (Quadfasel et al., 1996); 8. and the average for the Indonesian Throughflow in the SEC as established by 5 WOCE WHP (Gordon et al., 1987). The white arrow represents the volume of heavier water from the Pacific flowing through the Limatofola Strait towards the Banda Sea with a volume of water transported averaging 1 Sv (Van Aken, 1988).

It can be concluded that the main flow of the Indonesian Throughflow from the Pacific Ocean to the Indian Ocean passes through the Makassar Straits, then turns east through the Flores Strait to the Banda Sea. In the southwest Banda Sea the current turns southward to the southwest, entering Timor Sea and continuing to the Indian Ocean. The most important contact between the Pacific and Indian Oceans is that through the Timor Sea. The volume of water transported towards the Banda Sea during the West Monsoon is considerable, and is not in balance with that coming from the Maluku, Seram and Arafura Seas. This causes a piling up of water in the Banda Sea resulting in a downwelling and an outflow in the direction of the Indian Ocean at depths of around 1000 m through the narrow channel of the Timor Trough. The opposite happens during

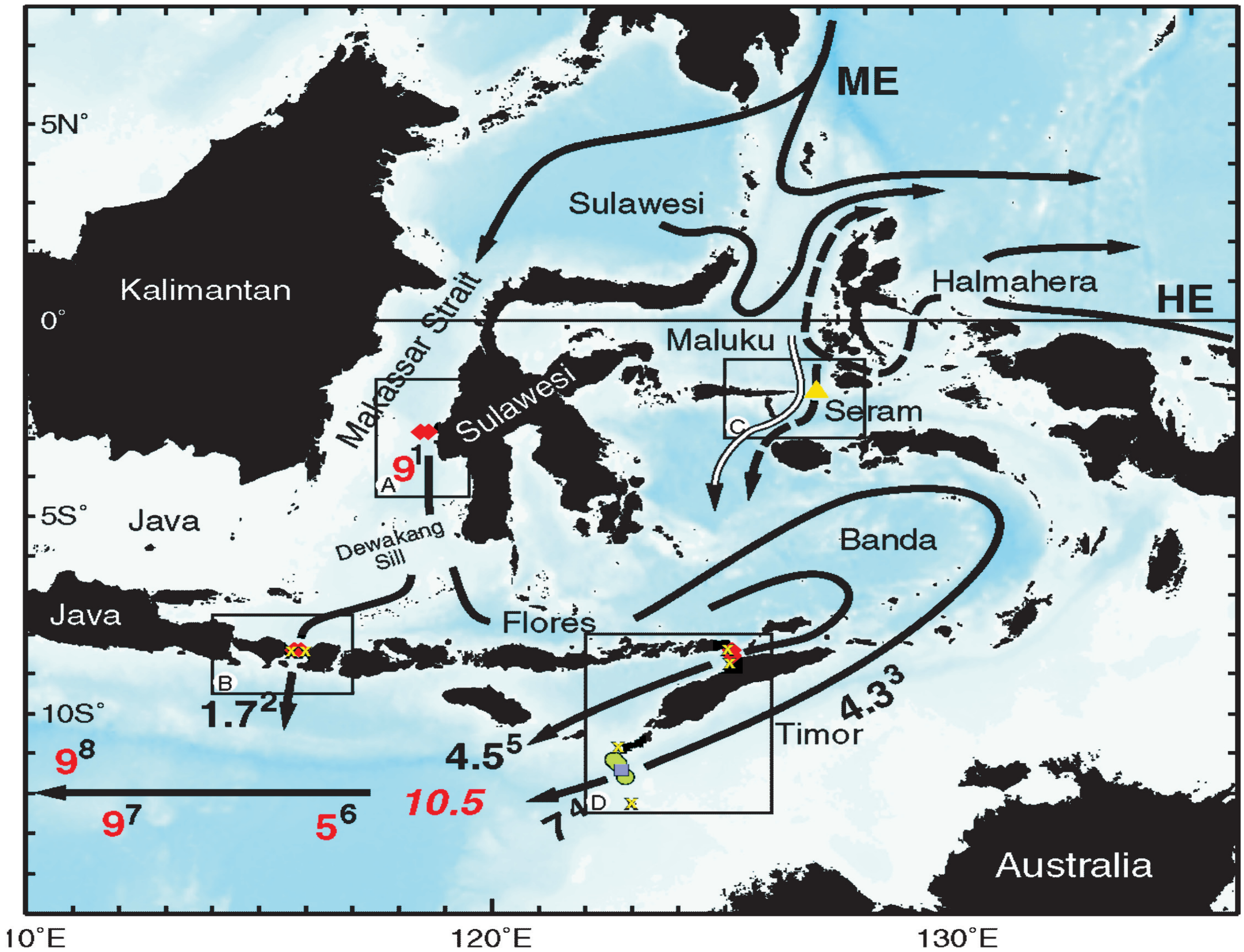


Fig. 2.11
Sketch of the Indonesian throughflow
(source: Gordon, 2002)

the East Monsoon. The excess of water leaving the Banda Sea towards the Flores and Timor Seas causes a vacuum which cannot be totally filled by the surrounding surface waters. As a result, there is an upwelling of deep waters from depths of around 125 – 300 m.

2.2.3 Upwelling

Upwelling occurs in the Arafura Sea as well as in the Banda Sea. This phenomenon was first reported by Wyrtki (1958). *Upwelling* occurs during the East Monsoon, from around May to September. This is because at this season the East Monsoon drives the surface water out of the Banda Sea at a rate far greater than that which can be compensated for by movement of surrounding surface waters so that water is drawn up from lower levels to fill the gap. The upwelling causes a drop in sea surface temperatures, on average around 3^{O}C lower than during the West Monsoon, accompanied by a rise in salinity of around 1 $^{0}/_{00}$.

Based on research in the Arafura Sea, the upwelling in the Banda Sea can reach the edge of the Arafura Shelf. Indicators include a drop in sea surface temperatures accompanied by a rise in salinity and high phosphate levels accompanied by low oxygen levels during the East Monsoon ■

Chapter 3

Ecosystems

Based on depth, Indonesian waters can be divided into two main categories, which are shallow waters covering continental shelves and deep waters. The Arafura Sea falls into the shallow-water category, with depths ranging from 30-90 m, whereas the Timor Sea consists of both shallow waters and deep waters. In the Timor Trench, the depth can reach to about ± 3000 m. As in other sea areas, these seas have a full complement of ecosystems including open-ocean which is divided horizontally into a neritic zone and oceanic zone. This chapter will discuss the marine ecosystem in both the neritic and oceanic zones using previously collected oceanographic information and data as well as approaches based on specific assumptions in order to determine the condition of the marine ecosystems in the Arafura Sea and Timor Sea.

The neritic pelagic waters of the Arafura Sea and Timor Sea, as in the neritic zone of other sea areas, are the waters which receive light and are generally occupied by an abundance of marine organisms. The high level of organisms associated with this zone is related to the presence of typical neritic or shallow water zones which are a feature of tropical ecosystems such as mangrove forests, seagrass beds and coral reefs. These three ecosystems are found in the intertidal zone, where the coral reef habitat is comprised of extensive sandy areas, fringing corals and coral rock, sand and muddy substrates which are found in many mangrove and seagrass ecosystems. An examination of the depth profile of the Arafura Sea reveals that this area is only representative of shallow-water marine ecosystems, whereas in the Timor Sea deep water ecosystems can be found as well as the typical tropical shallow-water ecosystems.

3.1 Tropical shallow-water ecosystems

3.1.1 The mangrove ecosystem in the Arafura Sea

The Southern Papua boasts the most extensive mangrove ecosystem in the world with a high degree of biodiversity. This area is in direct contact with the Arafura Sea beyond it via the Mimika River and several other rivers which carry high sediment loads and cause fluctuations in the salinity of the shallow waters of the Arafura Sea into which they flow. The mangrove ecosystem consists in part of the community of mangrove trees which constitutes the original vegetation of the coastal wetlands (saline and brackish water). These plants form a pioneer generation which grows along the coast with a gradation in composition from the land to the sea. Their growths are excellent in areas which are protected from wave action. The mangrove communities which form the mangrove ecosystem in the coastal areas of South Papua consist of the genera *Avicennia, Sonneratia, Rhizophora, Bruguiera, Ceriops, Nypa* and *Xylocarpus* (Petocz, 1989). Mangroves are unique among

Fig. 3.1
Avicennia community along the coast of the Arafura Sea

plants becuase they combine the characteristics of terrestrial and marine plants. This uniqueness can also be seen in their morphology, for example the shape and form of the roots, leaves and fruit, which can be used to distinguish one mangrove species from another.

Mangrove flora may be divided into two groups as follows:

1. The true mangroves, which include the Avicenniaceae, Bombacaceae, Combretaceae, Meliaceae, Myrsinaceae, Myrtaceae, Rhizophoraceae, Rubiaceae and Sonneratiaceae.
2. The mangrove associates, which include the Acanthaceae, Aizoaceae, Apocynaceae, Araliaceae, Baringtoniaceae, Cyperaceae, Euphorbiaceae, Fabaceae, Convolvulaceae, and Chidaceae (Arroyo 1977 *in* Zamora and Quimbo (1987).

One type of mangrove flora which is commonly found in the waters bordering the south side of the Arafura Sea is *Avicennia*, commonly known as grey mangrove or white mangrove, and is one of the mangrove species belonging to the *Avicennia* family. Like other mangrove trees, this plant type can be found in the intertidal zone or around estuaries. The distribution of *Avicennia* comprises the eastern coast of the African Continent right down to the southern tip and Southeast Asia right down to the northern coast of Australia. Therefore it is not surprising that this species group is found in the coastal zone of the Arafura Sea. *Avicennia* mangroves can grow to a height of 3 m. The bark of these trees is silvery greyish in colour, with a top layer

Fig. 3.2
Sonneratia trees are one of the mangrove types associated with the coastal zone of the Arafura Sea.

which is thin, stiff and breaks easily. The leaves are thick and around 5 to 8 cm long, with a shiny bright green upper surface and a pale whitish or greyish underside. All *Avicennia* species have breathing roots (*pneumatophores*); these roots can grow to a height of around 20 cm and a diameter of one centimetre. The flowers vary in colour from white to golden yellow, measure less than one centimetre and are generally grouped in bunches of three to five flowers. The fruit of these mangrove species is fleshy in texture. The fruits generally begin to sprout while still attached to the parent tree, then fall to the ground as seedlings. The *Avicennia* community (Fig. 3.1) can grow in conditions of high salinity as well as in areas where the saline concentration is reduced due to the mixing of salt and fresh waters.

Avicennia trees are not the only species to be found in the mangrove ecosystem around the Arafura Sea, *Sonneratia* species can also be found here. *Sonneratia* trees have pneumatophores which are wide and taper to sharp point (Fig. 3.2). These pneumatophore roots serve as ultra-filtration units to reduce the excessive concentration of salt. *Sonneratia* are tolerant of fluctuations in salinity and generally grow in areas which are exposed (to the open sea/sea water). The substrate where *Sonneratia* species grow tends to consist of muddy sediment which is fine and unstable. These mangrove species have special characteristics and habitat preferences and it is known that they can store excess salt in old leaves which drop and fall to the substrate. The bark of young *Sonneratia* trees is covered with a waxy layer, which it is thought may help to reduce water loss through transpiration as well as providing protection from attacks by animals large and small. A number of mangrove associated animal and plant species depend on the *Sonneratia* trees. The leaves of *Sonneratia* provide food for several terrestrial mammals.

Many insects and other small animal species also eat the *Sonneratia* leaves or other parts of the tree. In general, the *Sonneratia*-based community is the first to grow (get established) on muddy substrates. In their natural habitat, *Sonneratia* trees play an important role in stabilising the substrate and providing a safe environment for many other plants to grow.

Rhizophora or red mangroves are also found in the coastal ecosystem of the Arafura Sea. These mangroves can be found in the coastal zone of both tropical and sub-tropical areas. The preferred habitat of *Rhizophora* mangroves is in areas where the average temperature is 28^{0}C. The *Rhizophora* community is generally found in brackish waters and swampy salt marshes. The ability to live in habitats with high salinity is based on effective adaptations to these environmental conditions. *Rhizophora* can often thrive and grow in areas where other plants cannot survive so that it often forms an ecosystem apart. Red mangroves is the most common expression used to designate *Rhizophora* communities which are commonly found in close proximity with communities of *Laguncularia racemosa* or white mangroves, *Avicennia germinans* or black mangroves, and *Conocarpus erectus* or buttonwood. This group of mangrove communities are often found close together because of ecological similarities between them. In the mangrove ecosystem, the *Rhizophora* or red mangrove is most often the dominant community. In it's natural habitat, this plant community can stabilise the surrounding substrate, therefore it can be said that *Rhizophora* communities such as that shown in Fig. 3.3, create habitat for other plants and animals (for example mud crabs) to live in permanently or temporarily. The roots of *Rhizophora* arch down to the ground, and are often completely submerged form some hours at high tide. The roots grow down deeply into the sand or mud/clay soils so that these trees can withstand considerable wave action.

Fig. 3.3
Rhizophora sp mangrove communities which form an important part of the mangrove ecosystem in the Arafura Sea.

Fig. 3.4
Knee roots (*kneed pneumatophores*)
(a) showing above a sandy substrate
(b) knee roots of the species *Bruguiera cylindrica.*

The next group of mangroves to be found in the coastal waters of the Arafura Sea are the white mangroves, Bruguiera sp. Bruguiera mangroves belong to the Family Rhizophoraceae. In general, these trees can be found in coastal areas across Southeast Asia to Australia. Bruguiera trees can reach a height of 20 m being supported by pneumatophores called knee roots (Fig. 3.4). The bark of these trees is greyish and fine-textured, the leaves are set opposite one-another, bright green in colour and relatively thin.

This mangrove community tends to grow behind communities dominated by *Avicennia* mangrove species with a muddy substrate. Their growth can result in the formation of new land areas which can then be colonised by other mangrove species. This land formation role is possible because one of the functions of mangrove ecosystems is to retain sediment or substrate.

Mangroves of the *Ceriops* species can also be found in the intertidal ecosystems around the Arafura Sea. The distribution of these mangrove species reaches from South Africa through Southeast Asia to Australia and Melanesia. Communities of this mangrove species are often more shrubby than tree-like, and can reach heights of up to 7 m with fine terminal branches or twigs formed from several stipules. *Ceriops* has bunches of dark-coloured leaves which are greenish in colour and the leaves area set opposite one-another as shown in Fig. 3.5 below.

Fig. 3.5
Ceriops communities growing in the coastal waters of the Arafura Sea

Fig. 3.6
Nypa palms which can be found in the coastal waters of the Arafura Sea.

Nypa palms are another type of mangrove which can be found in the coastal ecosystem of the Arafura Sea. Members of this plant community belong to the Palm Family, and there is only one species of the genus *Nypa* which grows in Southeast Asia and Northern Australia, so that it is not surprising that this species is found in the coastal waters of the Arafura Sea. *Nypa* palms (Fig. 3.6) grow in fine mud soils in areas with slow currents where nutrients are borne by the flow of rivers. The habitat preferences of Nypa palms mean that this community is generally found in areas closer to the shore and forms a typical part of coastal and estuarine vegetation.

The mangrove forests which form the low-lying coastal zone along the southern Coast of Papua have a muddy substrate built up from alluvial particles which have been stabilised but are low in oxygen. One sign of this lack of oxygen is the rotten stench which assails the nostrils when entering the area, which is caused by the formation of Hydrogen Sulphide gas during anaerobic processes occurring in the substrate (Muller, 1998).

The fauna associated with these mangrove forests includes: crabs, water birds, many bivalve and gastropod molluscs and fish, however information regarding the species of biota associated with these areas is still limited. These mangrove communities are situated in the northern part of the Arafura Sea for which there is limited biological information regarding the biota of which they are comprised. In view of their functions as nursery grounds and feeding grounds, the mangrove forests along the southern coast of Papua provide a permanent nursery and furthermore a place in which many fish and aquatic invertebrates can live. Many commercially valuable species including various shrimps and prawns, fish such as barramundi and mackerel, snappers and breams use this area as a nursery ground or refuge throughout their growth. Muller, (1998) observed that the

Fig. 3.7
The mud crab *(Scilla serrata)* which has high commercial value *(source: Australia's Marine Science and Technology Plan, 1999)*

mangrove forests were one of the places in which the indigenous Komoro tribe sought food such as fish, crabs and shrimp. This demonstrates that the existence of the biota associated with the mangrove forests has high economic value. One valuable commodity is the mud crab (Fig. 3.7).

Based on information from Ramsar Wetland (1998), there is a mangrove forest around the Cobourg Peninsula, an area which is still within the bounds of the area Arafura Sea, which forms a coastal wetland of around 220 - 700 hectares in extent at the northernmost tip of the northern Australian Territory between the geographical coordinates of 11°07'-11°44'S and 131°45'-132°45'E. This peninsula is situated between the Arafura Sea to the north and the Gulf of Van Dieman to the south. The geological composition of this peninsula consists of thin layers of sand, gravel and alluvium. The mangrove communities are found all along the southern coastline of the peninsula. This mangrove forest comprises 31 species of mangrove flora, dominated by *Avicennia marina* and *Rhizophora stylosa* whereas *Nypa fruticans* is very scarce.

Several plant species in this area require special attention because they are increasingly rare or threatened with (local) extinction include *Gossypium cunninghamii, Eriachne bleeseri, Nypa fruticans, Fatoua pilosa, Xylocarpus granatum* and *Habenaria hymenophylla*, whereas 58 species of fauna are listed as requiring special attention because they are increasingly rare or in danger of extinction, and include 4 species of darters and cormorants, 12 herons and related species (for example the Eastern Reef egret *Egretta sacra),* 23 species of shorebirds (for example the Eastern Curlew *Numenius madagascariensis*) and 6 species of gulls and terns.

3.1.2 The seagrass ecosystem in the Arafura Sea

The seagrass ecosystem is generally found between mangrove ecosystem and coral reefs. The main component of seagrass ecosystem comprises higher plants which live in the marine environment and grow in several substrate types, ranging from muddy bottoms, through sandy mud to sand. The seagrass plants which are the key feature of this ecosystem comprise a number of species, of which 12 species are found in Indonesian waters. The special feature of this group of plants is the ability to pollinate underwater. Ecologically speaking seagrass play a role in stabilising the substrate and entrapping sediment so that they reduce the murkiness (increase the clarity) of the waters in the ecosystem is in front of them, the coral reef ecosystem.

The seagrass ecosystem in Indonesia and several related aspects only began to receive public attention a few years ago. Up to the year 2000, discussions regarding the coastal zone generally related to mangroves, coral reefs and coastal wetlands (marshes). The seagrass ecosystem was not mentioned, indeed could be said to be forgotten. Maybe this was because seagrass resources were not considered important, because up until now there has been no concrete example of the usefulness of seagrass for human interests or needs. Because of this, currently available information regarding seagrass resources in Indonesia is limited to the past few years.

The information which could be compiled regarding seagrass in the Arafura Sea is very limited. One area for which there is comprehensive information regarding this typical coastal ecosystem is the Cobourg Peninsula which is still part of the Australian national territory. The seagrass around this peninsula is found along the northern coastline. The species composition of the seagrass flora found on the part of the northern coast of Australia which directly faces the Arafura Sea is given in Table 3.1

The existence of these seagrass communities is an indication that this area is a feeding ground used by marine mammals specific to seagrass beds. The marine mammal species which has been recorded in this area is the dugong (*Dugong*

Table 3.1
Seagrass species found along the northern coast of Australia

Family	Genus-species
Potamogetonaceae	*Cymodocea rotundata* Ehrenb.and Hemp. Ascher *Cymodocea serrulata* (R.Br.) Magnus and Ascher *Halodule uninervis* (Wide- and narrow Leaf) (Forsk.) Ascher *Halodule pinifolia* (Miki) den Hartog *Syringodium isoetifolium* (Ascher.) Dandy *Thallasodendron ciliatum* (Forsk.) den Hartog
Hydrocharitaceae Jussieu	*Enhalus acoroides* (L.f) Royle *Halophila decipiens* Ostenfeld *Halophila minor* *Halophila ovalis* *Halophila spinulosa* *Halophila tricostata* *Halophila ovata* *Thalassia hemprichi*
Zosteraceae Drummortier	*Zostera capricorni*

dugon). In addition to marine mammals, several species of marine turtles are known to nest on the northern coast of the Cobourg Peninsula, although infrequently or in relatively small numbers. The four species in question are the green turtle *Chelonia mydas* (Nv), hawksbill turtle *Eretmochelys imbricata* (Nv), olive ridley turtle *Lepidochelys olivacea* and leatherback turtle *Dermochelys coriacea* (Nv).

Putrawidjaja (2000), referring to the results of a survey carried out in the coastal area of Pantai Jamursba Medi, in Sausapor Sub-District, Sorong District, Irian Jaya Province (now is West Papua Propince) reported by Bakarbessy (1999), states that turtles are hunted and that eggs are collected by people from local and urban communities, so that nesting activities in several turtle nesting beaches around the Arafura Sea have been affected. The taking of turtle eggs by local people was quite intensive and extensive some while ago. During the period 1984-1985, around 4-5 boats regularly visited the nesting beaches and each of them generally collected around 10,000-15,000 eggs. The effect of this activity has been a significant reduction in the population, however there has been a reduction in egg collection since 1993.

Turtle hunting and egg collection is also undertaken by fishers from other nations from areas near to and around the Arafura Sea. Putrawidjaja (1997) reports the sale of turtle flesh and eggs on the local fish market in Nabire. Around five turtles with an average weight of 5 kg tend to be sold with prices of Rp.6,500-10,000 (US$ 0.85-1.30) per kilogram. Most of the turtles which are hunted are leatherback and green turtles. The sale of turtles reaches as far afield as Bali Province, the main market for turtles in Indonesia. Eggs are sold for around Rp. 10,000 (US$ 1.30) per 10-12 eggs. Turtles can also be found for sale in the towns and cities around the Arafura Sea such as Biak, Serui and Manokwari (Putrawidjaja 1997). Management plans for turtle conservation are necessary in order to protect nesting beaches and should include training and education, law enforcement, surveillance and patrols, economic development at community level to change exploitation patterns and target resources which are more rapidly replenished or which can be cultured (farmed) such as seaweed and sea cucumbers.

3.1.3 The coral reef ecosystem in the Arafura Sea

Coral reefs are the shallow-water marine ecosystem which is the furthest from the shore. This ecosystem is comprised of hermatypic and ahermatypic coral animals. Hermatypic corals are corals which live in symbiosis with unicellular alga called zooxanthellae whereas ahermatypic corals do not have symbiotic zooxanthellae. The coral reef ecosystem is very valuable from both ecological and economic view points.

Coral reefs form a unique marine community. In this ecosystem natural structures and creativity can be seen such that the coral reefs are often referred to as “the rainforests of the sea”. Coral reefs are a tropical marine ecosystem which is very productive and diverse. Reefscape diversity results from the processes of inter-intra species competition to fulfil their respective needs from the same resource base and has caused the coral reef biotic communities to form extremely varied groups with high abundance. Various species of corals are spread across all the oceans of the world, specifically in tropical and sub-tropical areas. The coral reef formations can be found in coastal areas of the tropics and sub-tropics in the Atlantic and Indo-Pacific Oceans. The historical origin and process of coral reef formation in various sea areas differs, however at present the accepted theory is still the subsidence theory put forward by Charles Darwin.

Indonesian coral reefs are renowned as a major global biodiversity centre with a reef area of around 50,875 km² (Burke *et al.*, 2001). The results of monitoring by Research Centre for Oceanography of the Indonesian Institute for Science (Pusat Penelitian Oseanografi-Lembaga Ilmu Pengetahuan Indonesia, PPO-LIPI) are that by December 1999 only around 6.69 % or coral reefs in Indonesia are in very good condition, of the remainder 26.59 % are in the good condition category, 37.58 % in average condition and 29.16 % in poor condition (Moosa, 2001).

These waters stretch for 1,290 km/800 nautical miles east to west and 560 km/350 nautical miles from north to south. The climate of the whole of this area is tropical with relatively stable trade winds for half of the year and an intermittent monsoon during the Australian summer. The Arafura Sea has warm water masses which originate in the Pacific Ocean and flow to the Indian Ocean. This current has an important effect on the seasons in the surrounding areas because this warm water mass carries heat and humidity to the Indian Ocean. Because of historical and geographical factors, the sediment on the Arafura Sea bed is rich in calcium carbonate ($CaCO_3$) with a substantial fraction being composed of carbonate sand and sub-fossil shell fragments. The shells found in sediment samples include the shells of shallow-water organisms such as oysters, a variety of tropical molluscs, corals, bryozoans, coralline algae, and foraminifera. These components very likely indicate a shallow-water environment such as mangroves, coral reefs and seagrass.

Much of the Arafura Sea is shallow with poor water clarity (turbid) and in these waters there is little coral reef growth. Fringing reefs are reported to be found in the waters of the far western extremity, but very little detail is available regarding these reefs. The results of a biological survey reported in *A National Ocean Office, Australian Museum* and *CSIRO Project* (2005) covering an area which is included in the Australian Exclusive Economic Zone (5% of the Arafura Sea) shows that some parts of the Arafura Sea contain high populations of large filter feeding organisms such as sponges, octocorals and crinoids. The biological biodiversity resources collected by this team included 245 species of macro-fauna including a variety of marine invertebrates such as sponges, corals, sea anemones, tunicates, worms, crustacea, starfish, feather star and 6 species of small fish. A survey in the Arafura Sea by CSIRO in 1980 managed to record 55 species of fish from one voyage and only recorded one marine invertebrate, which was the swimming crab *Portunus sanguinolentus* (Fig. 3.8). Biological research efforts which were recorded (including a visual record) by the Survey Voyage SS05/2005 undertaken by experts from the Australian Museum and CSIRO (2005) produced a list of 130 distinct species including a number of filter feeders from the phylum Cnidaria. The benthic samples were taken using three sampling equipment (Fig. 3.9). According to Karen Gowlett-Holmes (2005) several of the species found are similar to those found in the Darwin Harbour, so that she concluded that the organisms collected during this survey are typical of the shallow-water fauna. Several different species of Crinoids (feather stars, members of the Echinoderm Phylum) were collected and additions were made to the list of ophiuroid (brittle stars, members of the Echinoderm Phylum) species collected from the area. Other organisms collected such as sponges, corals, sea anemones, tunicates, worms, crustaceans, sea stars, feather star and 6 small fish species give an idea of the state of the coral reef ecosystem in the Arafura Sea. At least 36 species of octocorals belonging to the phylum Cnidaria were collected, along with 15 Echinoderm species and decapod Crustaceans consisting of five shrimp species from the Family Apheidae and six Thalassanidean ghost shrimp species from two distinct families, the Callianassidae and the Upogebidae.

Fig. 3.8
Swimmer crab (*Portunus sanguinolentus*).
(Source : A Biological Survey by A National Oceans Office, Australian Museum and CSIRO Project)

Fig. 3.9
Sampling equipment used during the Voyage SS05/2005 undertaken by the Official Australia Museum and CSIRO Project Team, from left to right *: Smith-Macintyre Grab, Small Epibenthic Sled and Diamantina Dredge (at different scales) (Source: G. Wilson)*

The samples such as octocorals, anemones, sponges and crinoids (feather stars; Echinoderm Phylum) which were collected consisted of organisms which settle on the rocky and hard areas of the substrate or sea bed of the Arafura Sea.

Marine biological data consisting of pelagic and demersal fish collected by the *CSIRO Division of Marine and Atmospheric Research* - Hobart Australia Soela Voyage SO 7/80 1980 Expedition to the Arafura Sea, Gulf of Carpentaria and Coral Sea consisted of 16 species of fish from the Carangidae family, 9 species from the Clupeiforme fish group, 12 species from the Leiognathidae family, 4 species of Scrombroid fish, 13 species of sharks, 2 species from the Sphyraenidae family, 1 species from the Trichiuridae family, and 1 species from the Parastromateidae family. Surface (on-board) observations included baitfish, tuna, mammals and 35 species of sea birds. From the Arafura Sea in particular, over 1,000 fish specimens from 239 different species were collected to be preserved and placed in the collection of the Australian Museum. Also collected during this 1980 expedition were sea snakes, and 48 samples of bacterial cultures which were inoculated from bioluminescent fish.

The shallow waters of the Arafura Sea with typical coastal ecosystems can be found all along the Southern coast of Papua. The coral reefs which can currently be found in the southern coastal zone of the Island of Irian Jaya or Papua are categorised as fringing reefs. According to Suharsono (1998) the coral reefs along the Southern coast of Papua are poorly developed, with most of the reef development being situated in Cendrawasih Bay, Padaido, Auri and Mapia Islands and in the Raja Ampat Archipelago. This is because of the water quality to the south of Irian Jaya or Papua Island with low salinity and poor clarity with high levels of sediment, so that the conditions are not conducive to the healthy growth of (hermatypic) corals.

3.1.4. The mangrove ecosystem in the Timor Sea

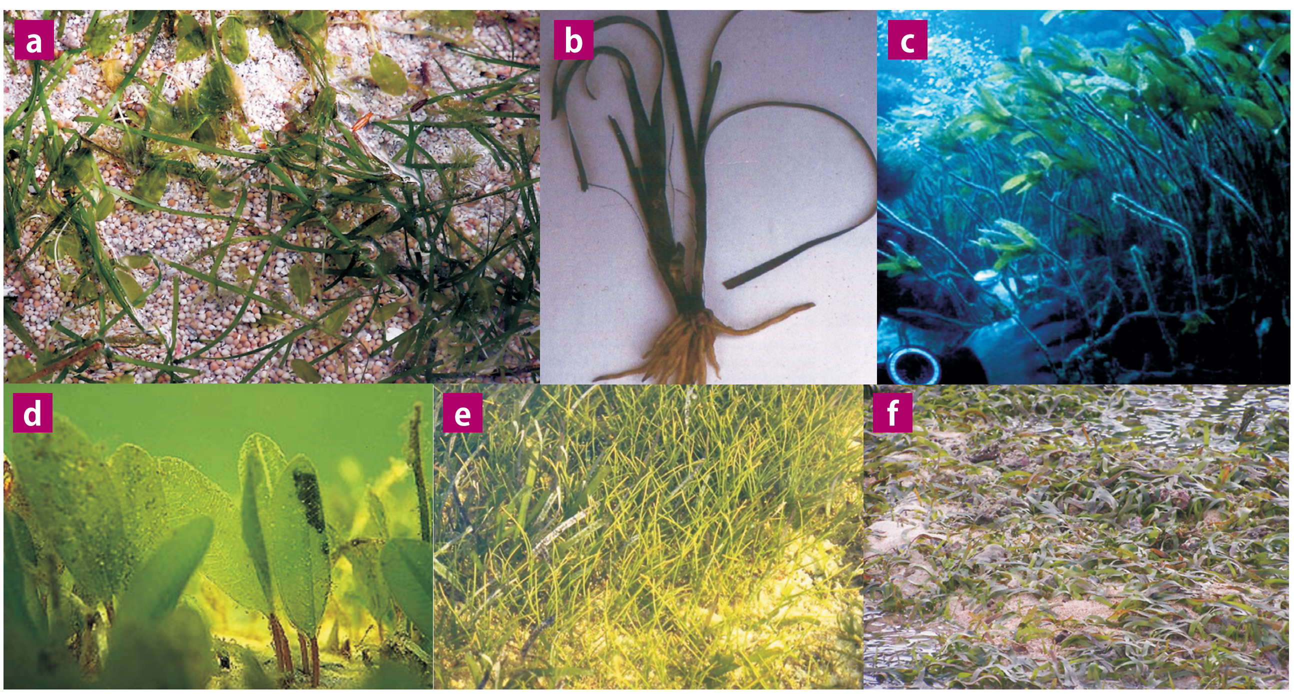
Mangrove forests are a typical feature of the coastal zone of an island. The Timor Sea is situated between Timor Leste and East Nusa Tenggara (Indonesia) and the Australian Continent. The mangrove communities along the coasts of Timor Leste Island and East Nusa Tenggara cover an area of around 7,500 acres. Compared to the mangrove forests along the southern Coast of Papua this is a very small area. According to Silva (a Bachelor of Agronomics) this area has low rainfall (precipitation), with an extended dry period, low temperature and humidity so that the dominant natural vegetation of this area is grass (grassland biome). The configuration of this area differs from that of other parts of the Indonesian coastline because there is no salinity contour in the coastal zone. The vegetation of this island consists of meadows with tall grasses. The extent of mangroves in this area is truly limited mainly by inlets which can provide a source of fresh water, and the littoral strip which is affected by salt water. Mangroves are more in evidence on the North coast in areas such as Metinaro, Tibar and Maubara, whereas on the South coast this vegetation type does not occur along the whole of the river mouth (estuarine) areas. As a result, mangrove communities are generally limited to small groves comprising only one tree species. Almost all of these consist of mangroves from families which are not in contact with the land, and have similar environmental adaptation characteristics such as: roots with pneumatophores, short leaves and branches, extremely complex root systems and fruit adapted for propagation via water currents where the seeds can grow in areas outside or far from their place of origin. These characteristics determine the main species to be found in this area which are *Rhizophora conjugate* or *Bruguiera parviflora*. If the physical and geographical conditions are suitable, then more than one species may be found, generally (in zones which are) parallel to the coastline up to the high tide mark. In waters with high salinity, which are submerged on a permanent or temporary basis, mangroves of the *Sonneratia alba* and *Bruguiera parviflora* species may grow in sandy substrates whereas *Rhizophora conjugata* and *Bruguier*a are found on muddy substrates. If the water is stagnant with high salinity and temporary flooding then *Rhizophora conjugata* and *Avicennia marina* grow on muddy substrates, and finally there are a few more species which are thought to form part of the mangrove communities in this area, which are *Aegiceras corniculatum, Acanthus ilicifolius, Lumnitzera racemosa* in areas where the soil is very dark in colour (black) or a little muddy whereas in areas which are infrequently inundated then *Heritiera litoralis* and *Acanthus ilicifolius* are more often seen.

The mangrove ecosystem in the coastal waters of Kimberley which face the Timor Sea and Indian Ocean are found in the tidal zone in areas with sandy substrate (Gueho 1999). A wide variety of typical coastal flora and fauna are associated with the coastal ecosystem of Kimberley which is part of the Australian Territory. One tree which is typical of the coastal vegetation in this area is the Baobab (*Adonsonia greggorii*). *Adonsonia greggorii* is a unique tree which is only found in Kimberley, North Australia and similarly in Africa and Madagascar. This tree is a source of food for other organisms which share the same habitat and is an indicator of seasonal changes. *Adonsonia greggorii* indicates the start of the wet season by the growth of new leaves as humidity rises, whereas when the leaves of this tree start to fall it is a sign that the dry season is about to begin. Mangrove communities along the Kimberley coastline play an important role in maintaining the ecosystem stability of the intertidal area which is a physical feature of the area. The existence of this typical mangrove ecosystem turns this area into a productive coastal ecosystem with a high diversity of associated species. Mangrove leaves which fall are one source of ecosystem productivity due to their role in maintaining the food web. At low tide a layer of brown-coloured water can be seen above the surface of the sediment, indicating the presence of diatoms in these waters which will be consumed by other invertebrates in the mangrove ecosystem.

3.1.5 The seagrass ecosystem in the Timor Sea

In the Timor Sea, seagrass meadows are generally found in lagoonal areas with a sandy substrate. The presence of seagrass and algal beds in the Timor Sea makes this area a feeding ground for sea turtles and marine mammals such as *Dugong dugon*. Marine turtle species associated with these seagrass and algae are the green turtle (*Chelonia mydas*), the loggerhead turtle (*Caretta caretta*) and hawksbill turtle (*Eretmochelys imbricata*) whereas the main mammals which feed in the area are dugongs, *Dugong dugon*. The dugong population has fallen sharply in recent years, mainly due to environmental of the habitat in which they live, especially in the Timor Sea which has become an area for natural gas exploration. The high rate of coastal development has a severe impact on all the ecosystems within the coastal zone, not excluding the seagrass ecosystem. According to Russell (2005), seagrass form fragile communities which are easily disturbed, so that they make good bio-indicators especially as regards the condition of organisms associated with this ecosystem. Degradation of seagrass beds in the Timor Sea is also caused by pollution entering the marine environment due to the high level of coastal development. All the species of marine turtle which can be found in the Timor Sea are endangered species which are listed in Appendix I of CITES (*Convention on the International Trade in Endangered Species of Wild Flora and Fauna*). There are seven species of seagrass which can be found in this ecosystem which is affected by the rise and fall of the

Fig. 3.10
Several species of seagrass which are found in the coastal waters of Timor Sea.
(a) Halophilla and Halodule, (b) Enhalus acoroides, (c) Thalassodendron sp, (d) Halophilla sp, (e) Syringodium isotifolium, (f) Thallasia hemprichii



tides, which are *Halodule uninervis, Halophila decipiens, Halophila ovalis, Enhalus acoroides, Syringodium isoetifolium, Thalassodendron ciliatum* and *Thalassia hemprichii* (Fig. 3.10). *Halodule uninervis* and *Halophila ovalis* are seagrass species which live in coastal waters with sandy and muddy sand substrates. In the Timor Sea, *Thalassia hemprichii* and *Thalassodendron ciliatum* are found on reef flats and around islands with rocky shores. Seagrass can grow in almost all substrate types, ranging from muddy bottoms to rocky shores. However, wide expanses of seagrass are most often found in areas with deep sandy mud substrates between mangrove forests and coral reefs. The seagrass ecosystem has high organic productivity, and provides a place where many varied marine organisms can live including fish, crustacea, molluscs, and worms.

3.1.6 The coral reef ecosystem in the Timor Sea

Underlying this Timor Sea is the amazing Sahul Shelf, making this area rich in marine organisms, many of which have commercial value so it is not surprising that this area has the highest level of marine biodiversity. Because of the Timor Trough and Slope there is still relatively little research which has been done on the marine organisms in the area, so many species are still unknown to science, and in addition the chemical substances which occur naturally in this area make it very attractive to companies in the fields of biotechnology and bio-prospecting.

The steep slopes of the Timor Trough are covered with a phenomenal biotic community with vast expanses of *Halimeda*. This *Halimeda* coralline alga forms algal beds which produce calcium carbonate (limestone) which effectively supports a community of seaweed, sponges, and other valuable organisms because of the capacity to fix carbon. The chemical compounds which they produce are a form of defence against predation by herbivorous fish in order to survive. Based on the history of geological evolution it can be inferred that the presence of *Halimeda* was the first stage in the development of a coral reef ecosystem in the Timor Sea. The composition and dominant benthic communities in the Big Bank, one area of the Timor Sea, is presented in a histogram (Fig. 3.10). The dominant community is commonly *Halimeda* followed by sponges, hard coral and other communities.

Based on a major survey of scleractinian corals in Western Australia which was carried out by the Australian Museum, Veron (1993) reports that in one part of the Timor Sea which is called Ashmore Reef and is situated at 12⁰17'S, 123⁰02'E, the expedition managed to collect scleractinian corals for the Museum Collection. Corals which Veron managed to identify from

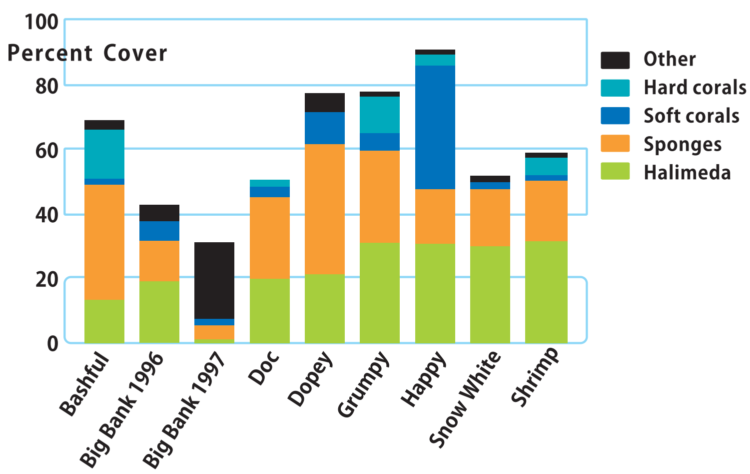


Fig. 3.10
Histogram of several dominant communities in the Big Bank area of Timor Sea *(Gallaway and Buchanan 2003)*

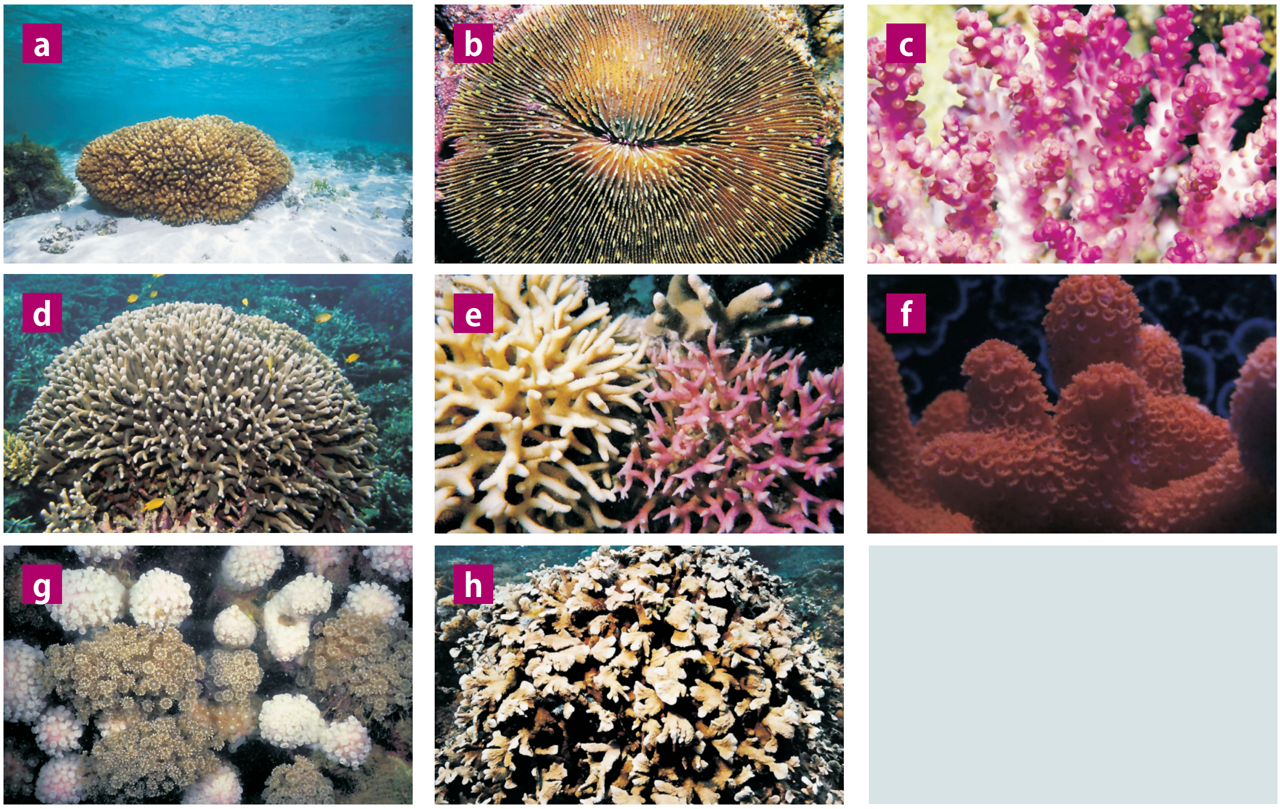


Fig. 3.11
Some species of hard (scleractinian) coral found at Ashmore Reef in the Timor Sea
(a) *Pocillopora damicornis* (b) *Fungia fungites* (c) Seriatopora caliendrum (d) Montipora digitata
(e) Acropora cerealis (f) Porites cylindrica (g) *Goniopora pandoraensis* (h) *Psammocora*

these collected samples consisted of 255 species of scleractinian (hermatypic) corals from 56 different genera, in addition to which 747 species of fish, 433 mollusc species and 192 echinoderm species were identified. The results of a previous survey reported by Hoeksema (1989) include the finding of several species from the Family Fungiidae in the Ashmore Reef area. The total number of species recorded from this 1989 survey was 251 species of scleractinian corals from 55 genera. This area also has a high sea snake diversity compared to other coral reefs, with 12 species of sea snake which have been identified from the Ashmore Reef. In addition to high marine biodiversity, the coastal area of the Ashmore Reef is a very important area for sea birds. There are 17 species (with around 50,000 pairs) of sea birds which use the Ashmore Reef as a nesting area.

The number of coral species found at Ashmore, in the Timor Sea which were classified by Veron indicates that the scleractinian corals of the Ashmore reefs are highly diverse in comparison to the coral reefs in Western Australia. Furthermore, Griffith (1997) reported that all species he collected were species contained in the list of scleractinian corals which had been collected from the Ashmore Reef in the Timor Sea as is shown in Appendix 1. Pictures of several hard (scleractinian) corals which were found in the Timor Sea are shown in Fig. 3.11.

This survey not only collected hard or scleractinian coral, soft corals (Alcyonacea) were also collected from Ashmore, in the Timor Sea Although only 39 specimens were collected this does not mean that the area is poor in soft corals, but is because the equipment used was

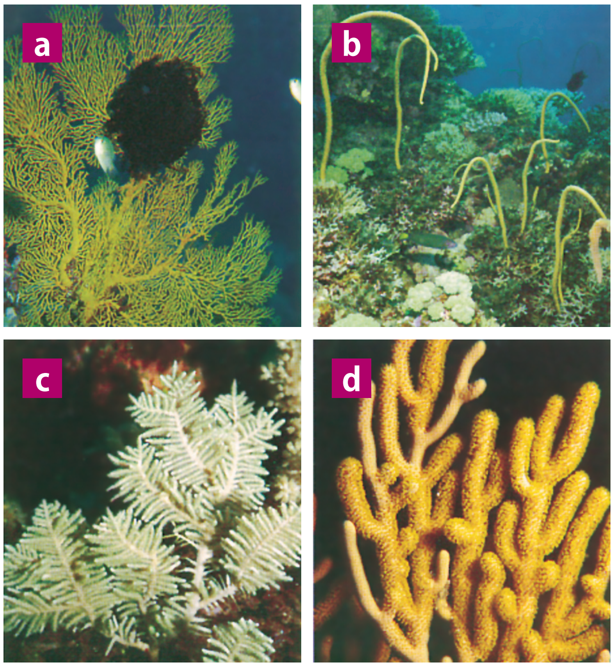


Fig. 3.13
Some soft corals from the genus Gorgonacea
(a) gorgonian fan (b) sea whip *(Juncella sp),*
(c) Plexaura sp, (d) sea fan *(Isis sp)* (K. Fabricius).

not designed to collect soft corals. From these 39 specimens, 32 species from 16 genuses were identified as shown in Appendix 2. Photographs of several soft coral species found in the Timor Sea are shown in Fig. 3.13.

Other biota (flora and fauna) found in the coral reef ecosystem of Ashmore in the Timor Sea include: benthic organisms such as Polychaeta, crustaceans (shrimps, crabs, lobsters), as well as other animals such as the diverse fauna contained in the Echinoderm Phylum (sea stars, feather star, sea urchins etc.), the Phylum Mollusca (bivalves as well as gastropods), the Phylum Nemertina, the Sponges (Porifera) and a great variety of coral reef associated fish species. Overall the Timor Sea still contains high marine biodiversity with much that has not yet been properly researched from biological and ecological aspects. This is in spite of the fact that the Timor Sea is the habitat of many diverse fish species of high economic value such a pelagic fish and many shark species. The Timor Sea also supports the existence of six species of marine turtle which are the flatback turtle (*Natator depressus*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), leatherback turtle (*Dermochelys coriacea*), loggerhead turtle (*Caretta caretta*), olive ridley turtle (*Lepidochelys olivacea*) and several cetacean species.

Epibenthic fauna are extremely abundant and diverse. It cannot be denied that the deep sea community living in the water column of the deep sea generally plays an important role. Species found in this part of the sea include sponges, gorgonians (sea whips and sea fans), ascidians (sea squirts), echinoderms, crustaceans, bryozoans (lace corals), and soft corals. Several types of sponges which are found in the Timor Sea based on their form are shown in Fig. 3.14.

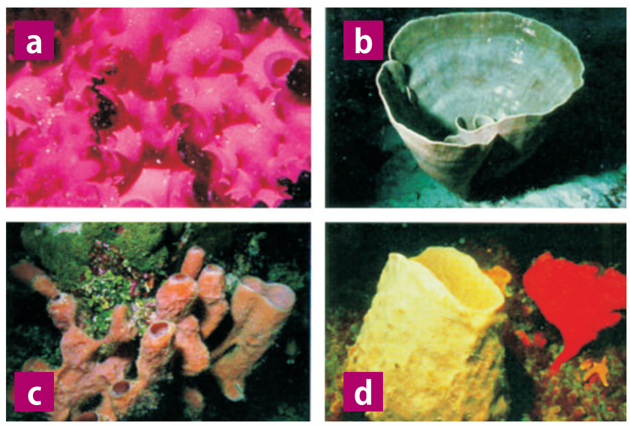


Fig. 3.14
Several types of sponge which are found in the Timor Sea, based on their form (a) encrusting (b) vase (c) columnar and (d) cup. *(Source: AIMS - BIG BANK SHOALS OF THE TIMOR SEA - Filter-feeding Ecosystems, Biology and Ecology of Sponges, Timor Sea).*

3.1.7 Deep sea ecosystems

The waters of the Arafura Sea have depths ranging from 30-90 m so that deep sea areas are not found in these waters. Moving westward, one enters the waters of the Timor Sea. Several areas of this sea have depths which are categorised as deep sea. Areas of the Timor Sea which are

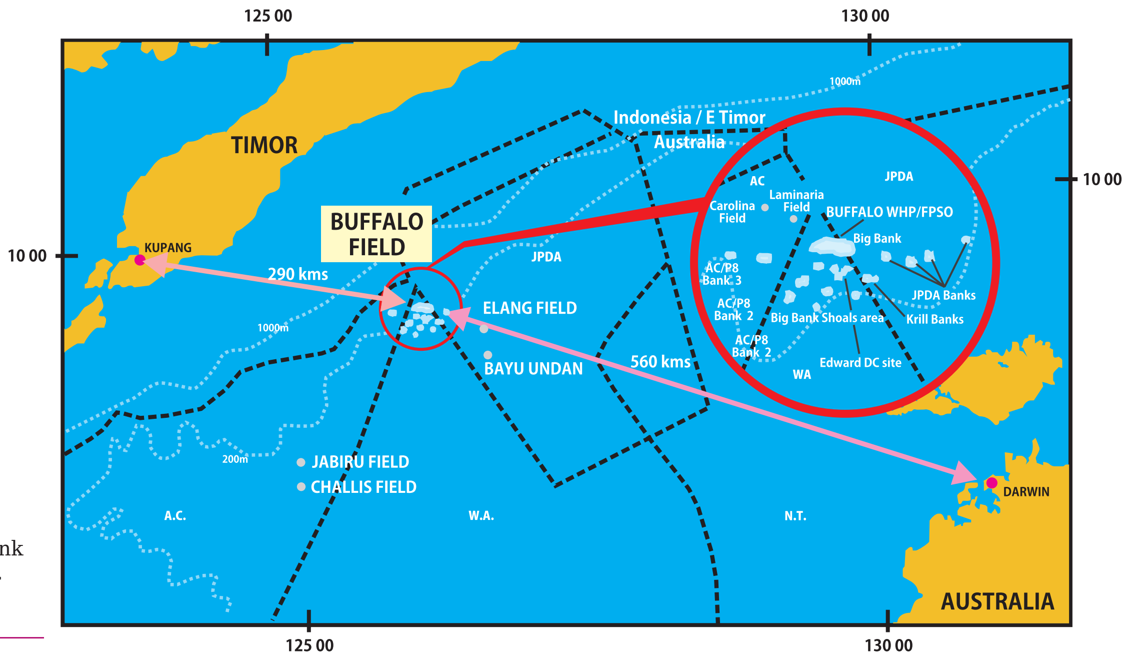


Fig. 3.15
Chart of the Big Bank Shoals in the Timor Sea.

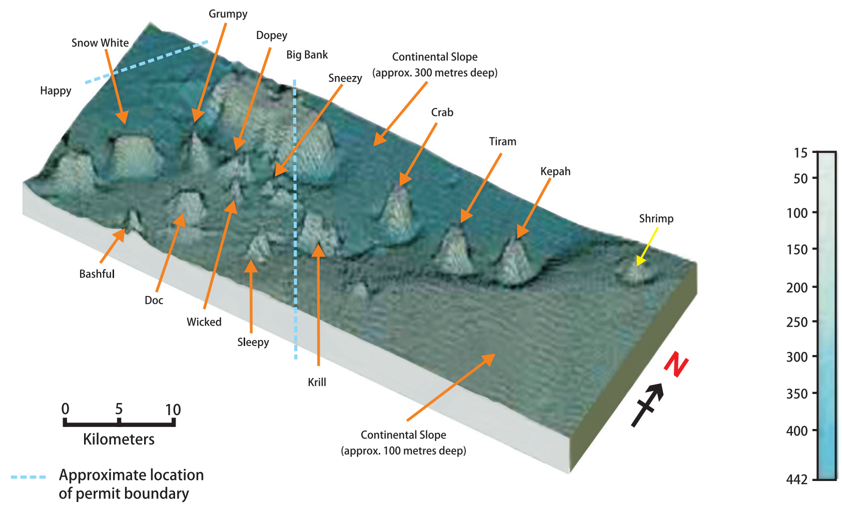


Fig. 3.16
Three dimensional map of Big Banks Shoals with depth changes being indicated by changes in colour.

included in the deep sea category include the Big Bank Shoals with depths of 300 m as shown in the chart Fig. 3.14. The deep sea part of this area can also be seen in the three dimensional map shown in Fig. 3.15.

Deep sea ecosystem is also found in the Timor Sea in the area between Ashmore Reef and Troubadour Shoals which is a continental slope where the depth increases from 200 m to 400 m. As in the case of other deep sea areas of the Timor Sea, this ecosystem is very dark right down to the sea bed. Deep sea ecosystems make up around 80% to 90% of the marine ecosystems on the face of the earth. The vast extent of these deep sea ecosystems is not in proportion with (not matched by) the information which can be obtained about these areas.

This is because there has as yet been little research and few expeditions concentrating on the deep sea areas. Reasons include the scarcity of equipment for sampling and the challenges which must be faced in such locations. Deep sea ecosystems with special features include seamounts, hydrothermal vents and ecosystems based on deep sea bacteria (on the sea bed). As yet little is known about the types of deep sea life-forms which can be in the depths of the Timor Sea ■