7 Intertidal and subtidal sediments

Robin Wilson, Sabine Dittmann and Jeff Ross

Photo courtesy Museum Victoria.

Soft sediments are the prevailing habitat in Western Port, covering about two-thirds of the bay. The area of unvegetated sediments has increased following the loss of seagrass beds. Extensive intertidal flats are important foraging grounds for shorebirds. Several hundred species of infaunal and epifaunal organisms have been recorded, including a high diversity of ghost shrimps, brachiopods that are 'living fossils', rare rhodoliths, and other species listed as endangered. The benthic fauna occurs in defined assemblages subject to sediment characteristics and water depth. A depauperate fauna was found at sites with a history of disturbance and eutrophication.

Most of the research on soft sediments in Western Port is 30-40 years old, and a survey to assess the current biodiversity in comparison with past records and adjacent bays is an urgent task. This information could also inform assessments of various disturbances and invasive species. Further areas requiring research attention are the functional roles of benthic organisms and how they contribute to the productivity, sediment dynamics and nutrient fluxes in Western Port.

Sediments of Western Port

Soft sediments comprise the most extensive environment in Western Port. The most recent survey found that 525.5 km^2 (77%) of Western Port marine environment are unvegetated soft sediments (Blake & Ball 2001). Since the 1970s the extent of bare sediments has been increasing at the expense of seagrass beds, which declined by 70% between 1973–1984 (Shepherd *et al*. 1989), although some seagrass recovery occurred up to 2009 (Figure 6.8).

The tidal divide north-east of French Island, which has extensive intertidal mudflats, is of international significance (Rosengren 1984). About 40% of the Western Port area is intertidal mudflats (Edgar *et al*. 1994).

The geomorphology of Western Port (Chapter 1), along with its broad range of physical processes (Chapter 4) provides a large number of different habitat types within a relatively confined area. These habitats range from reefs typical of the open coasts in the south-west of the bay to sheltered mangroves and mudflats in the north. The large tidal range, particularly in the north of the bay, produces extensive intertidal habitats.

History of benthic studies in Western Port

Soft sediment invertebrates in Western Port were first sampled scientifically in the 19th century (Smith *et al*. 1975). Quantitative investigations have been made in the following studies:

- an intensive survey at Crib Point in 1964–65 (Coleman 1976)
- a bay-wide benthic survey in 1973–74 (Coleman *et al*. 1978)
- a bay-wide survey on the crustacean genus Callianassa in 1977 (Coleman & Poore 1980)
- trophic studies by (Robertson 1984; Edgar *et al*. 1994; Edgar & Shaw 1995a, 1995b)
- a monitoring study of the three Marine National Parks in Western Port (Butler & Bird 2010b)
- study of rhodolith beds north of San Remo (Harvey & Bird 2008)
- a description of the Flinders Aquaculture Fisheries Reserve (McKinnon *et al*. 2004).

A number of other studies listed in a report on benthic communities (EPA 1996) were principally on seagrass environments and are not discussed further here.

Following these earlier studies, which focused on species distributions and biodiversity linkages, more recent investigations have addressed species-specific feeding ecology (Boon *et al*. 1997; Stapleton *et al*. 2002), as well as burrow morphology and bioturbation effects of prominent ghost shrimps in sediments throughout Western Port (Bird & Poore 1999; Bird *et al*. 2000).

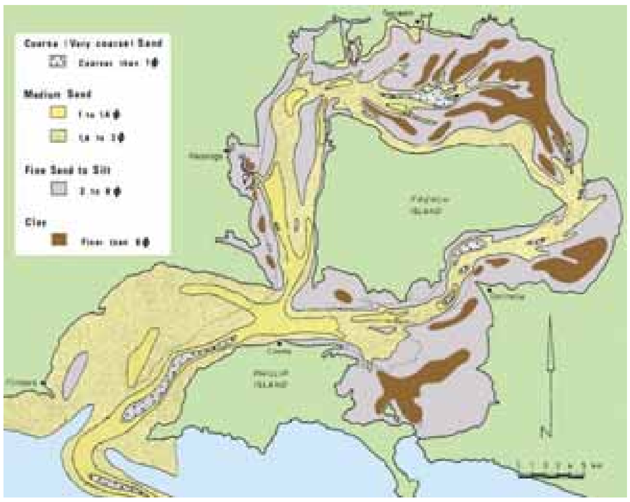
Distribution

Physical description of the sediments

In soft sediments, the strongest influence on the fauna is the physical nature of the sediments. The distribution of sediments around Western Port was first studied by Marsden *et al*. (1979). At that time well-sorted sandy sediments were found in the Western Entrance and in the channels surrounding French Island, and finer muds were found in the North Arm and in the Rhyll and Corinella segments on the eastern side of the bay (Figure 7.1). Edgar *et al*. (1994) suggested that between 1979 and the 1990s muddy sediments were replaced by coarser sands in northern Western Port. Other changes were summarised by (Hancock *et al*. 2001), including three major findings:

- a general trend of increasing sand content in cores from northern sites, representing a span of about 40 years
- the disappearance of clay deposits offshore of Bunyip Drain and Cardinia Creek since 1979
- the appearance of clay-rich deposits offshore from eastern Phillip Island since 1979.

Figure 7.1 Distribution of sediments in Western Port.
(Source: Wallbrink and Hancock 2003, after Marsden *et al*. 1979.)



7 Intertidal and subtidal sediments

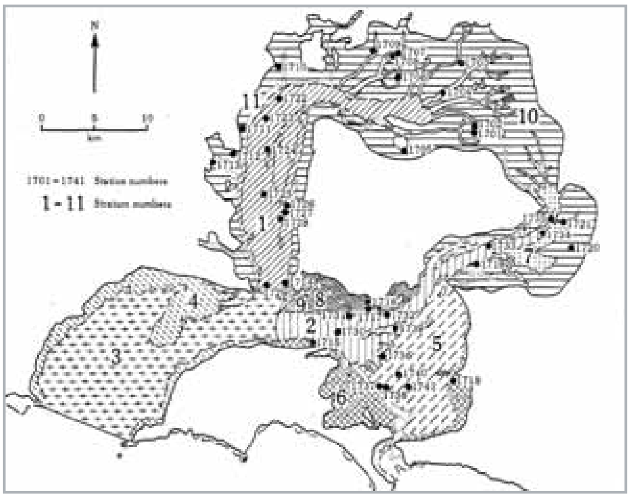
Detailed sediment particle size distributions were presented in Hancock *et al*. (2001), which is the most recent study on Western Port sediments. Most of the terrestrial sediment input to Western Port is to the North Arm via the Bunyip and Lang Lang Rivers, which together account for 69% of the sediment inputs from the Western Port catchments. These sediment inputs are believed to have increased since European settlement (Sargeant 1977), but estimates over that time span are poorly quantified (Wallbrink & Hancock 2003). Sediment input from shoreline erosion is also not well quantified and is a local source of coarser sediments, e.g. at Stockyard Point and Lang Lang, but it is probably a minor input overall (Wallbrink & Hancock 2003). Coarser sands in the Western Entrance Zone are of marine origin. Net movement of water and suspended sediments in Western Port is clockwise around French Island (Wallbrink *et al*. 2003). The export of sediment to Bass Strait has not been quantified (Wallbrink *et al*. 2003). Modelled estimates of sediment deposition rates range from about 0.2 to 0.5 cm/year, with a maximum of 1.6 cm/year for a site in the Corinella segment (Hancock *et al*. 2001).

Distribution of soft sediment assemblages

Sediment infauna

The only comprehensive study of the fauna living within in soft sediments ("infauna") in Western Port is that of Coleman *et al*. (1978). That study took grab samples from 41 randomly located stations (Figure 7.2) and provisionally identified 572 species. However, the species richness was much greater than this number, since half of all crustacean species and the majority of polychaete species could not be named below genus level. Of the polychaetes, crustaceans and molluscs, which together accounted for 93% of the individuals and species, only a few species were abundant and recorded at several sampling stations (Coleman *et al*. 1978). Further benthic studies by Edgar *et al*. (1994) documented a prevalence of polychaete species in unvegetated sediments, whereas crustaceans accounted for more of the species found in seagrass beds.

Figure 7.2 Strata on which sampling for the 1973–74 survey was based. (Source: Coleman *et al*. 1978, Figure 2.)



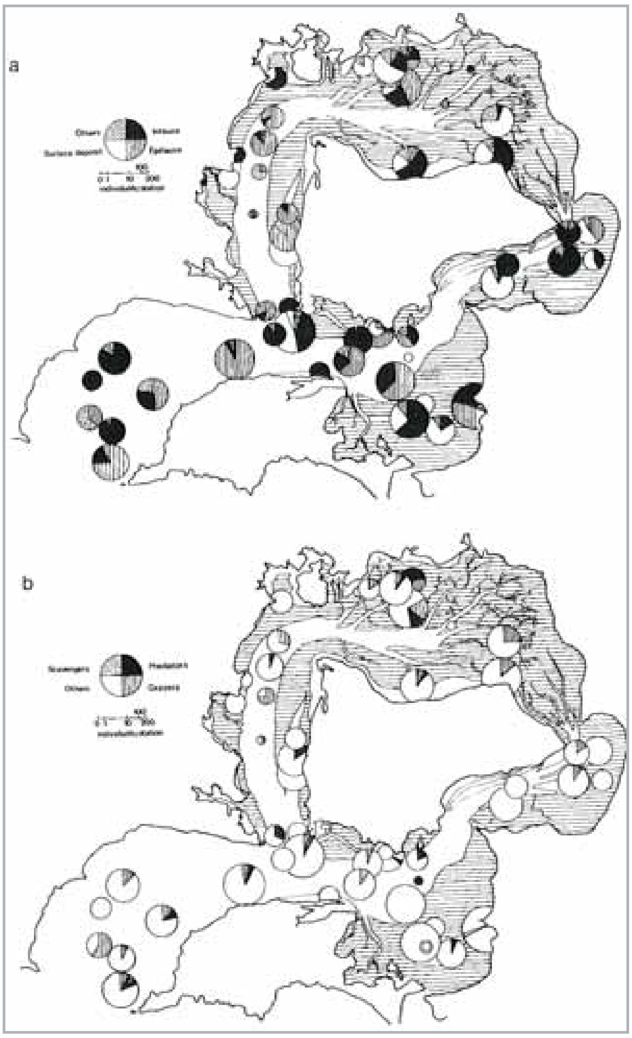
Two major assemblages were identified by Coleman *et al*. (1978), based on multivariate analysis of faunal similarities between stations: a 'clean medium sand' assemblage was found in deeper channel areas, and a 'fine sand and mud' assemblage occurred in intertidal and shallow (< 5.5 m) sublittoral areas. Both of the major assemblages, and the polychaete, mollusc and crustacean species typical of each assemblage, were widely distributed around Western Port Coleman *et al*. (1978). Sediment type and depth were strongly correlated with the two major assemblages. A small group of stations nearest to Hastings was identified as a third assemblage, characterised by a depauperate fauna interpreted as reflecting disturbance (dredging and nutrient input) at Hastings. Within these major assemblages, 13 further groupings of stations could be identified which had a similar fauna and were mostly geographically close stations, referred to as strata. The importance of sediment properties (e.g. mud content, total organic carbon) for explaining patterns in benthic assemblages was further corroborated by Butler & Bird (2010) for the tidal flats in Western Port.

A similar assemblage pattern with depths and sediment properties as defined by Coleman *et al*. (1978) for the entire soft sediment benthos also became apparent by analysing the mollusc data alone, from 96 mollusc taxa, dominated by bivalves Coleman & Cuff (1980). The mollusc fauna from an earlier (1965) intensive study of Crib Point was reported on in a descriptive study by Coleman (1976); in that location the mollusc fauna was dominated by gastropod species. Coleman & Cuff (1980) re-analysed the mollusc data from Coleman *et al*. (1978) using methods less influenced by common species, and found the same assemblages. Their work included an analysis of the distribution of trophic groups of molluscs around Western Port (Figure 7.3). Molluscs that fed on suspended matter or surface deposits (such as *Tellina mariae*) were most abundant, especially in muddier sediments, even though overall mollusc diversity was highest in coarser sediments. Grazing, predatory and scavenging molluscs were less abundant, but accounted together for half of the mollusc species.

Monitoring of benthic communities was conducted in the North Arm for 17 years, commencing in 1972, as part of the environmental requirements for effluent discharge from a cold strip steel mill (Watson 2009). The sampling method in this monitoring was different from that used earlier by Coleman *et al*. (diver-operated airlift samples vs Smith-McIntyre grabs), but the methods were broadly comparable. As in the earlier bay-wide study, there was no attempt at species-level identification (although a reference collection is maintained), but the taxonomic structure of the community was similar: polychaetes and crustaceans comprised 40% and 45% respectively of the taxa present over the monitoring period. Molluscs comprised 10%. Dominant molluscs included large bivalves, particularly *Neotrigonia margaritacea*, *Notocallista diemenensis* and *Sigapatella calyptraeformis*. However, 'Populations of these bivalves declined markedly with increasing water turbidity and deposition of fines on the bed during the seagrass decline period of the 1980s to 1990s.' (Watson 2009).

Rhodolith bed off San Remo. Photo courtesy DPI Queenscliff

Figure 7.3 Distribution of molluscs by feeding mode from the 1973–74 survey. (Source: Coleman & Cuff 1980, Figure 3.)



Epibenthic macroinvertebrates

The observations from previous benthic studies summarised above pertain to the infauna of soft sediments – predominantly small invertebrates that live on and under the sediment surface and are collected by grab or diver suction sampling. There is also a diverse invertebrate epifauna – animals living on the surface of the sediments – in Western Port, comprising large invertebrates rarely collected during infaunal studies but readily observed in studies by scuba divers. Such a study by Watson (2009) reported on epibenthic macroinvertebrates in the North Arm deep channel system where the fauna consisted of small sponges, the ascidians *Pyura stolonifera* and *Stolonica australis*, the seapen *Sarcophyllum* sp. (Figure 7.4), the brachiopod Magellania flavescens and various species of hydroids and tube-dwelling polychaetes. Most elements of this epibenthic fauna require hard objects on the sediment surface for attachment, such as dead and subfossil bivalve shells exposed by water movement in the channels (Coleman *et al*. 1978).

7 Intertidal and subtidal sediments

Special features

Marine Protected Areas

Yaringa Marine National Park occupies about 930 hectares about 9 km south-west of Tooradin, adjacent to the Quail Island Nature Conservation Reserve. The Park is part of the Western Port Ramsar site. A private marina adjoins the park. Intertidal and subtidal soft sediments are the dominant environment in the park, although saltmarsh, and mangroves are also present (ECC 2000). Although there are few bare mudflats in the park, they are important foraging habitats for shorebirds and form part of the Ramsar wetlands (See Chapter 12 and references therein). Subtidal sediments contain some 'living fossil' brachiopods and molluscs (see below) (Edmunds *et al.* 2010).

French Island Marine National Park occupies 2700 hectares, about 10 km south of Tooradin on the northern shore of French Island, adjoining French Island National Park. The Park is part of the Western Port Ramsar site. Intertidal soft sediments (both mudflats and sandy beaches) and subtidal soft sediments are well represented in the Park, and extensive areas of seagrass beds, mangroves and saltmarsh are also present (ECC 2000; Edmunds *et al.* 2010). Stations WBES 1701, 1702 and 1705 of the bay-wide study by (Coleman *et al.* 1978) are within French Island Marine National Park; the faunal affinities from that study show these stations to be most similar to one another and to station WBES 1719, directly south on the other side of French Island. The intertidal flats are important foraging grounds for migratory waders (Chapter 12 and references therein).

Churchill Island Marine National Park occupies 675 hectares immediately south of Rhyll, including the entire south-west facing shoreline of Churchill Island. The Park is part of the Western Port Ramsar site. Intertidal soft sediments (beaches and mudflats) and subtidal soft sediments are present in the park, along with saltmarsh, mangroves, seagrass beds and rocky intertidal cobble and shingle shores (ECC 2000; Edmunds *et al.* 2010). The intertidal flats are of national significance as feeding grounds for shorebirds (Chapter 12). None of the stations in the bay-wide study by Coleman *et al.* (1978) are within the park.

These three Marine National Parks, declared in 2002, are representative of the species richness and diversity of macrobenthos occurring in intertidal soft sediments in Western Port (Butler & Bird 2010). Five years after the parks were declared, subtle differences were found in abundances within and outside them, but there was no difference in species diversity. As each of the three parks provides different tidal flat habitats with regards to sediment characteristics, distinct benthic assemblages were found for each park, and no consistent pattern as to differences in assemblages inside and outside (Butler & Bird 2010). Several species occurred predominantly within the parks (*Alpheus richardsoni*, *Paragrapsus* sp., *Paratanaidae* sp., *Armandia* MoV sp. 282, *Musculista senhousia*, and *Phoronopsis albomaculata*), while others, such as the ghost shrimp *Trypea australiensis*, were rarely recorded within the protected areas (Butler & Bird 2010). For further monitoring, Butler & Bird (2010) proposed several key variables, including *T australiensis*, *Biffarius arenosus*, *Macrophthalmus latifrons*, *Lumbrinereis* sp. and also total oxygen concentration and sediment temperature.

Special Management Areas

Bass River Delta Special Management Area occupies 635 hectares on the eastern shore of Western Port at the mouth of Bass River, immediately south of Stony Point. It includes extensive areas of intertidal and shallow subtidal soft sediments, along with vegetated sediments (algae and seagrass) (ECC 2000). Soft sediment communities in this SMA support waders and other waterbirds, as well as commercial and recreational fisheries, the principal target species being King George Whiting and flathead. The Bass River delta has been identified as a nursery area for sharks and whiting. The introduced cord grass Spartina is invading the SMA (ECC 2000). Station WBES 1718 of the bay-wide study by Coleman *et al.* (1978) is within the Bass River Delta Special Management Area. The faunal affinities of that station were closest to two other nearby stations along the eastern shore of Western Port.

Figure 7.4 Undescribed species of seapen Sarcophyllum sp., North Arm channel. (Photo: J.E. Watson, Marine Science and Ecology.)

Figure 7.5 Trypaea australiensis, one of several ghost shrimp species occurring in Western Port. (Photo: M. Marmach, Museum Victoria.)

Rhyll Special Management Area occupies 375 hectares immediately surrounding the township of Rhyll. The Area includes large areas of intertidal and shallow soft sediments (mudflat and a dynamic sand spit) as well as rocky reef, mangroves and saltmarsh, and is used by 32 species of migratory waders (ECC 2000). Station WBES 1715 in the bay-wide study of Coleman *et al*. (1978) is within the Rhyll Special Management Area; that station was found to have low faunal affinities with other stations in the study.

Three other Special Management Areas within Western Port — Honeysuckle Reef, Crawfish Rock and San Remo — include small areas of soft sediment (ECC 2000). However, the habitat that is the focus of these SMAs is rocky reef, so they are not discussed further in this section.

Other sites

Rhodolith beds

Rhodolith beds — fields of mobile, roughly spherical coralline red algae — are known in Victorian waters from only a few localities, including a shallow bed up to 4 m deep in Western Port and much deeper beds in Point Addis Marine Park in Bass Strait (Harvey & Bird 2008). While these are the only published records of rhodoliths in Victoria, it is possible that there are other beds in state waters. The Western Port rhodolith bed is about 1.5 km north-east of Newhaven and 1.5 km north of San Remo (38°30′30.0″S, 145 °22′41.4″E). In many other parts of the world, rhodolith beds are protected for their biodiversity value (Harvey & Bird 2008). Preliminary surveys of the bed revealed it covers an area at least 1 km^2, situated close to and including the main shipping channel. The bed is 1–4 m deep on a broken rhodolith, sand and shell bottom. Four species of rhodolith-forming algae make up the bed: *Hydrolithon rupestre*, *Lithothamnion superpositum*, *Mesophyllum engelhartii* and *Neogoniolithon brassica-florida*. These species also occur elsewhere as non-rhodolith growth forms (Harvey & Bird 2008). The Western Port bed was the first place in Australia where *Mesophyllum engelhartii* was found to form rhodoliths, and the first place where *Hydrolithon rupestre* was found to form rhodoliths world-wide. The majority of rhodoliths were dead; no more than 37% were living, a lower percentage than for beds studied elsewhere, possibly a result of temporary burial or high turbidity from suspended sediments (Harvey & Bird 2008). Rhodoliths are here treated as unvegetated sediments because they are not attached. The cryptofauna of the rhodoliths was investigated by Harvey & Bird (2008), who found that the community was different in taxonomic structure from soft sediment communities elsewhere in Western Port: rhodoliths are dominated by polychaete worms (89% by abundance, with Terebellidae the most common family) with bivalve molluscs next in importance. The cryptofauna did not differ between growth forms of rhodoliths. Harvey & Bird (2008) did not attempt species-level identifications, and they did not sample the communities within the soft sediments under the mobile rhodoliths.

Aquaculture zones

The Flinders Aquaculture Fisheries Reserve occupies 440 hectares over a depth range of 7–11 metres immediately north of Flinders. The reserve includes leases for the growth of abalone and mussels (ECC 2000). The Flinders Aquaculture Fisheries Reserve comprises mostly unvegetated sediments, with some sparse seagrass. (McKinnon *et al*. 2004) recorded 76 provisional species in the reserve, but their identifications were only to family rank.

Summary of current understanding

The following discussion includes some general comments, followed by discussion of environmental assets identified as likely to be of interest to stakeholders and environmental managers responsible for the Western Port marine environment.

Unvegetated sediments in Western Port have increased at the expense of vegetated sediments (specifically seagrass), which has experienced an overall decline during the period 1973–2000 (Chapter 10). Since unvegetated sediments have been found to be less species-rich than vegetated sediments (Edgar *et al*. 1994), the decline of seagrass in Western Port can be expected to be associated with an overall decline in benthic species richness. The contrast is more extreme in intertidal environments where seagrass loss has been most evident: 185 species were identified from unvegetated intertidal sediments by Edgar *et al*. (1994) while the same study found subtidal unvegetated sediments (channels) to include 265 species and were thus closer to the diversity of seagrass communities where 300 species were identified. Besides the presence or absence of seagrass, benthic diversity increased also from the intertidal into the shallow subtidal (Edgar *et al*. 1994).

Western Port has a typical shallow marine 'embayment fauna' in southern Australia (O'Hara & Barmby 2000). The diversity of macrobenthos and sediment properties within and outside the Marine National Parks of Western Port was investigated by Butler & Bird (2010), who concluded that species richness and diversity within the parks was representative of that found throughout Western Port. Overall, Coleman *et al*. (1978) estimated from their own studies and museum records that Western Port contains about 2000 macrofaunal species.

Biota

Crustacea

One of the outstanding characteristics of the soft-sediment fauna of Western Port is the high diversity of ghost shrimps. Decapod shrimps of the genus *Callianassa* were reported in detail by Coleman & Poore (1980; Figure 5). *Callianassa* spp. — now recognised as belonging to several genera (Tudge *et al*. 2000) — were more abundant in unvegetated sediments. As with other common members of the main assemblages distribution of individual species of ghost shrimp was strongly correlated with depth and sediment type. *Callianassa* and related genera are significant bioturbators and their burrowing activity substantially affects sediment properties. They are also sought by anglers as bait, and their extraction using bait pumps is known to have impacts (see below). *Callianassid* shrimps also contribute to infaunal production in soft sediments (Robertson 1984; Edgar *et al*. 1994).

Two ghost shrimp species occurring off Crib Point have been listed as threatened species under the Victorian *Flora and Fauna Guarantee Act 1888* because of their very restricted distribution: *Paraglypturus (Eucalliax) tooradin*, a rare species otherwise only known from a single specimen from Swan Bay, and *Michelea microphylla*, a local endemic known only from Crib Point (O'Hara & Barmby 2000; Butler & Bird 2010). A third species, *Laomedia healyi*, occurs from Queensland to Victoria and reaches the south-western limit of its range in Western Port (Butler & Bird 2010). Other crustaceans in the bay, such as the rare *Alpheus australosulcatus*, may be endangered but are considered 'data deficient' at present (O'Hara & Barmby 2000).

Amphipoda are another group of crustaceans represented by a very high number of infaunal species in Western Port, which has led to the suggestion that they have undergone adaptive radiation, such as for the 48 species of Phoxocephalidae (Shapiro 1975; Barnard & Drummond 1978).

Polychaeta

Polychaetes constitute most of the species of macrofauna found in sediments, and many species are abundant and are more widespread throughout Western Port (Coleman *et al*. 1978). Prominent polychaetes recorded in benthic surveys are the capitellids *Barantolla lepte* and *Mediomastus* sp., *Lumbrinereis* sp., *Nephtys australiensis*, *Scoloplos* spp., *Isolda* sp. and *Spionidae* (Coleman *et al*. 1978; Edgar *et al*. 1994; Butler & Bird 2010). On sandier foreshores the beach bloodworm *Abarenicola* sp. occurs in small numbers (Smith *et al*. 1975).

Brachiopoda

Brachiopods are much more widespread and diverse in the fossil record than they are as extant fauna, and some living species are apparently little changed from their fossil forms (Richardson 1997) and are often called 'living fossils'. Brachiopods are more diverse and common on calcareous sediments on the continental shelf, such as Bass Strait (Richardson 1981); one species is known in Western Port:

Magellania flavescens is patchily distributed but widespread in Western Port, requiring hard objects on the substrate for attaching its pedicel. It is unknown in Port Phillip Bay (Museum Victoria collections). Although *Magellania flavescens* occurs widely along the southern coast of Australia, the populations in Western Port are the largest known (Chidgey *et al*. 2009).

Mollusca

Mollusca typically comprise only about 10% of the benthic fauna as measured by individual abundances (Coleman 1976; Coleman *et al*. 1978; Chidgey *et al*. 2009), but they contribute greatly to biomass and productivity, with particular species dominating the biomass in different habitats (Edgar *et al*. 1994). The following species are of note for other reasons.

Neotrigonia margaritacea belongs to the superfamily Trigoniacea, a group of bivalves that dominated shallow inshore seas worldwide during the Mesozoic (250–265 mya); there are six Australian members of the group, and *N. margaritacea* occurs widely in south-eastern Australia (Smith *et al*. 1975; Morton 1987). Genetic divergence east and west of the Bass Strait land bridge indicates recent recolonisation from the west into areas like Western Port (Glavinic 2010).

Anadara trapezia is a large and conspicuous ark shell that is prominent in mudflats and seagrass sediments, often in association with *Tellina* spp. (Smith *et al*. 1975; Coleman & Cuff 1980; Edgar *et al*. 1994). It is not particularly abundant but has a large biomass. It is common along Australia's east coast but rare in Victoria, except in Western Port (Smith *et al*. 1975).

Neotrigonia margaritacea, *Notocallista diemenensis* and *Sigapatella calyptraeformis* were dominant in North Arm when monitoring commenced there in 1973, but populations declined markedly with increasing water turbidity and deposition of fine particles during the seagrass decline period of the 1980s to 1990s (Edgar *et al*. 1994; Watson 2009). *N. margaritacea*, *Barnea australasiae* and *Spisula (Notospisula) trigonella* contribute most to the biomass in unvegetated sediments (Edgar *et al*. 1994).

Echinodermata

The brittle star Amphiura triscacantha has been found in northern Western Port; the only other occurrences in Victorian waters are in Corner Inlet (Butler & Bird 2010). It is listed as threatened under the Flora and Fauna Guarantee Act, yet classified only as vulnerable for by the Victorian Department of Sustainability and Environment (Edmunds *et al*. 2010). O'Hara & Barmby (2000) judged that the Western Port population is possibly extinct.

Fish

Fish are treated in detail in Chapter 11, and in Chapter 10 in terms of the seagrass environment on which fish production is primarily dependent (Edgar & Shaw 1995a, 1995b, 1995c). Unvegetated sediments are most likely to be significant to fish communities in Western Port during autumn, when the lower production of crustaceans in their preferred seagrass habitat cannot support fish production (Edgar & Shaw 1995b). Crustaceans were found to be such important dietary items for fish in Western Port that their availability may be limiting fish production, while fish predation may affect the species composition and size structure of benthic assemblages (Edgar & Shaw 1995b).

The meiofauna has not been studied in Western Port, apart from Foraminifera (Bell 1971, cited in Shapiro 1975), and size-specific productivity estimates by (Edgar *et al*. 1994). The latter study revealed an almost continuous relationship between body size and production from meiofaunal to macrofaunal size categories, unlike previous studies in northern temperate areas.


Photo courtesy Michael Keough.

Comparison of Western Port with other Victorian embayments

Soft sediment communities are the dominant environment within Western Port and also in Victoria's other significant embayments, each of which has been the subject of benthic studies of soft sediment communities: Port Phillip Bay (Poore *et al*. 1975; Poore & Rainer 1979; Wilson *et al*. 1998), Corner Inlet (Morgan 1986; O'Hara *et al*. 2002) and Gippsland Lakes (Poore 1982). However, the focus of each of the above studies has been on investigation of patterns within each embayment. Nonetheless (Coleman *et al*. 1978, p. 460) commented: 'Some of the commonest species in Western Port (e.g. *Neotrigonia margaritacea*) are rare or entirely absent in Port Phillip Bay and vice versa. Western Port also has a greater species diversity, average values of the Shannon–Weaver diversity index (H′) per station being 2.93 in Western Port and 2.36 in Port Phillip Bay.'

(Kott 1976) compared the ascidian faunas of the two bays and found that 26 species occurred in Port Phillip Bay but not in Western Port, while 45 species were found in Western Port but were absent from Port Phillip Bay. The Western Port ascidian fauna was also more diverse and contained a high percentage of species at the southern limit of their range. However, the Western Port ascidian collections studied by Kott were taken from both reef and soft sediments, whereas the Port Phillip collections were largely from soft sediments alone.

Anecdotal evidence and observations of individual species suggests that the soft sediment benthos of Western Port also has distinct faunal elements. Species that are present in Western Port but are absent from Port Phillip Bay include the bivalve mollusc *Neotrigonia margaritacea* and the brachiopod *Magellania flavescens*, which both occur in Bass Strait and elsewhere in eastern Australia (Darragh 1986, Museum Victoria unpubl. data).

Other than the above anecdotal comments and the inconclusive study by (Kott 1976), and the difference in zooplankton communities of Port Phillip Bay and Western Port reported by Kimmerer and McKinnon (see Chapter 5) the question 'How distinct is the benthic fauna of Western Port?' has not been the subject of any quantitative analysis (nor has the question been addressed for the other major Victorian embayments). Progress with understanding the taxonomy of benthic fauna, especially of crustaceans and polychaetes, means that some limitations of the data collected by Coleman *et al*. (1978) could now be addressed, and all samples are still available in the Museum Victoria collection. A re-examination of specimens of selected taxa from this material would be required if a second benthic study of Western Port were to be conducted.

Spatial variation in soft sediment assemblages within Western Port

Spatial patterns of distribution of soft sediment communities are well understood (Coleman 1976; Coleman *et al*. 1978; Coleman & Cuff 1980a; Coleman & Poore 1980) and discussed above (see 'Distribution of soft sediment assemblages'). In summary, they are as follows:

- Two assemblages of species can be recognised, one from well-sorted sediments > 5.5 m depth, mainly in channels, the other from intertidal and shallow fine sand and mud < 5.5 m depth.
- Common species in each assemblage are widely distributed.
- The distribution of well-studied species is typically strongly correlated with depth and sediment type.
- A greater similarity of assemblages at stations reflects geographic proximity; depauperate communities typify disturbed sites.

Temporal changes in soft sediment communities of Western Port

Few of the studies of soft sediment communities in Western Port had a temporal component, and each of the studies listed above had other goals and sampled different sites with different methods. There is thus little information on change over time in the composition and distribution of components of the soft sediment community. Shapiro (1975) mentioned sampling between 1966 and 1970 that revealed considerable variation in species numbers and abundances between seasons and years. Edgar *et al.* (1994)

resampled some of the areas sampled by Coleman *et al*. (1978) two decades later, and found large changes in the presence and abundance of several species from both seagrass and unvegetated sediments, including a decline in the abundance of the bivalves *Notocallista diemensis* and *Katelysia rhytiphora*. Temporal variation can be impact-related or reflect natural variability; for example, the recruitment of many benthic macroinvertebrates occurs in winter and spring (Edgar *et al*. 1994). Butler & Bird (2010) also found differences in benthic abundances between their two consecutive study years and identified a subset of physical and biological variables that could be used to monitor change over time in benthic studies. To date there has been no monitoring using the variables identified by Butler and Bird (2010).

Productivity

The annual macrofaunal production in Westernport was lower in unvegetated soft sediments (57.3 g/m2, 3.3 g of which was epifaunal) than in seagrass beds, where epifaunal production was high (17.2 out of a total production of 79.2 g/m2; Edgar *et al*. 1994). Yet infaunal biomass and production was higher than of epifauna at most sites (Edgar *et al*. 1994). The planktonic-to-benthic ratios of unvegetated sediments ranged between 2.5 and 3, similar to the range reported in the literature, including an earlier study at Crib Point (Robertson 1984; Edgar *et al*. 1994).

Bioturbating infauna

Several species of ghost shrimp occur in Western Port (Coleman & Poore 1980). Ghost shrimps are ecosystem engineers, with burrows stretching > 50 cm into the sediment and forming complex underground structures with branching tunnels (Bird & Poore 1999; Bird *et al*. 2000; Butler & Bird 2007). These physical structures and bioirrigation by the ghost shrimps create a deeper extension of aerobic surface sediment conditions, facilitating aerobic microbial activities (Bird *et al*. 2000). When ghost shrimps were removed by experimental bait pumping, the sediment became more anaerobic and muddier, with less porosity and organic matter (Contessa & Bird 2004). Ghost shrimp densities were significantly reduced by bait pumping and recovered slowly (Contessa & Bird 2004). Ecosystem processes relating to the bioturbation are addressed further in Chapter 14.

The co-occurrence of species with seemingly similar ecological roles raises questions about niche differentiation. Although species-specific distributions based on sediment properties and water depth have been found (Coleman & Poore 1980), coexistence has also been reported, even to the extent of burrow sharing (Butler & Bird 2007). The two most studied species, *Biffarius arenosus* and *Trypea australiensis*, appear to differ in their feeding behaviour and preferred particle size, allowing coexistence (Stapleton *et al*. 2001). Competition is further reduced by diet ranges; stable isotope studies have shown that *B. arenosus* feeds on a diet of detritus derived from seagrass and its epiphytes, while *T. australiensis* can also incorporate further algal matter (Boon *et al*. 1997). However, when ghost shrimp species co-occur, one may become dominant (Coleman *et al*. 1978).

Major threats

Major threats to soft sediment ecosystems are related to habitat loss or modification, or to directly effects on the biota from unnatural inputs (e.g. toxicants) or extractions (e.g. bait-pumping). Altough the threats are addressed individually here, they are often concurrent (Thrush *et al*. 2008b). Our evaluation of the threats relies largely on studies carried out elsewhere.

Water and sediment quality

Risks

Further deterioration of water or sediment quality will increase the risks to soft sediment biota. Community structure will be affected and species richness is likely to be depressed wherever extensive nutrient or pollutant input occurs, as has already been demonstrated locally at Hastings (Coleman *et al*. 1978) and in other embayments (Pearson & Rosenberg 1978; Warwick *et al*. 1987; Jackson 2008). Nitrogen and phosphorous, as well as pesticides, enter Western Port, although loads were lower than neighbouring Port Phillip Bay in the 1970s, apart from some more intensive localised input (Shapiro 1975). Individual species and communities may be at risk, especially those that have local distributions within Western Port, such as the rhodolith bed north of San Remo, and the localised ghost shrimp species currently only known from near Crib Point.

Consequences

Nutrients

Chapter 14 discusses eutrophication in detail. The loss of larger, deeper-dwelling benthic organisms with increased eutrophication reduces bioturbation, further accelerating degradation of sedimentary conditions (Pearson & Rosenberg 1978; Gray *et al*. 2002). A dominance of capitellid polychaetes is typical of such disturbed environments; sibling species of *Capitella* spp. are world-wide indicators for nutrient enrichments in sediments (Tsutsumi 1990; Chareonpanich *et al*. 1994; Ramskov & Forbes 2008). In extreme cases of eutrophication, only microbial mats remain on the sediment surface (Pearson & Rosenberg 1978; Jones & Pinn 2006).

Sediment input and resuspension

The effects of sediment input depend on the type of sediment (e.g. marine, terrigenous) the grain size composition, and whether a gradual or pulsed addition of sediments occurs (Miller *et al*. 2002; Widdows & Brinsley 2002; Thrush *et al*. 2004). Smothering is possible if large deposits occur in a short time so that organisms (e.g. suspension-feeding bivalves) cannot maintain a connection to surface (Newell *et al*. 1998; Norkko *et al*. 2002). Resuspension of fine material can also remobilise pollutants accumulated in sediments, increase turbidity and thus reduce productivity of the microphytobenthos, and inhibit the filtration efficiency of suspension feeders. Gradual changes in sediment properties are likely to cause a shift in assemblage structure (Miller *et al*. 2002; Lohrer *et al*. 2004; Thrush *et al*. 2004).

In Western Port, the sedimentary environment has already seen major changes over the decades following terrestrial inputs, shoreline erosion and loss of seagrass beds (Hancock *et al*. 2001; Wallbrink & Hancock 2003), and Edgar *et al*. (1994) relate some of the changes in benthic assemblages between 1970 and the 1990s to these modified sediment conditions. Changes in sediment quality and associated biota can have wide-ranging effects. The relative abundances of dominant taxa in soft sediment communities is polychaetes > crustacea > molluscs at most sites (Coleman *et al*. 1978), but the relative importance of the same taxa in fish diets is crustacea >> polychaetes + molluscs (Edgar & Shaw 1995a, 1995b, 1995c). Thus, an increase in sedimentation rate that is sufficient to transform vegetated sediments, or rocky reefs, into unvegetated sediment is likely to have a negative impact on fish production in Western Port.

The rhodolith bed north of San Remo is likely to be particularly vulnerable to sedimentation and increased turbidity. It is possible that this community (one of only two rhodolith beds known in Victoria, and the only one in a shallow embayment) is already impacted by sedimentation, since (unlike other known beds) most rhodoliths in the San Remo bed were dead, with living rhodoliths make up only 37% of the bed, possibly because of temporary burial or increased turbidity from suspended sediments (Harvey & Bird 2008).

Heavy metals, TBT, toxicants, pathogens and pesticides

Toxicants can enter soft sediments by source input and deposition as well as resuspension of polluted sediments. Heavy metal concentrations in Western Port can be locally high, and their effect on benthos is species specific (Ahsanullah 1976; Ahsanullah *et al*. 1980). The amphipod *Allorchestes compressa* was more sensitive to Cadmium and Zinc than the polychaete *Neanthes vaalii* or the crab *Paragrapsus gaimardii* (Ahsanullah 1976). With species specific threshold existing and ecotoxicological studies showing tolerances as well as toxic effects, generalisation of heavy metal effects on soft-sediment benthos cannot be made (King *et al*. 2004; King *et al*. 2005; King *et al*. 2006). Any bioaccumulation of heavy metals in benthic organisms will affect assemblages and food webs, as benthic organisms are important prey for higher trophic levels (Stark 1998; Reish *et al*. 1999; Waring *et al*. 2006).

Species-specific responses to tributyl tin (TBT) contamination are also known (Reish *et al*. 1999). Among gammaridean amphipods, some Haustoriidae have a rapid uptake of TBT, leading to a quick death, while Phoxocephalidae had a slower uptake and show sublethal effects, including changes in their burrowing behaviour (Meador *et al*. 1993). Amphipods of these families are prominent in Western Port sediments, yet no species-specific toxicity studies have been carried out on them. The muricid snail *Lepsiella vinosa* has been severely affected by imposex in the vicinity of major ports in South Australia, and snails found in Western Port (on rocky shores) showed the phenomenon as well, with further laboratory experiments indicating that not only TBT but heavy metals and environmental stress contribute to this condition (Nias *et al*. 1993).

Organics (oil)

Oil pollution can be chronic or the result of a particular spill, and soft-sediment benthos may be affected by the oil as well as dispersants used to clear spills. Oil can penetrate into the sediment, where it can accumulate for a long time, and it can also seal the surface and prevent any exchange of oxygen or dissolved nutrients between the sediment and the water column (Kuiper *et al*. 1984; Peterson *et al*. 2003). Some bacterial breakdown of oil in sediments is possible, but this has not been investigated in any detail.

Salinity

The salinity in much of Western Port is close to fully marine, and the benthic fauna is typical of a southern Australian embayment, with truly estuarine species restricted largely to river mouths, especially Bunyip River and Lang Lang River (Coleman *et al*. 1978). Salinity is lowered during floods, whereas hypersaline conditions are associated with depressed rainfall and rising watertables in the catchment. The majority of the Western Port benthic fauna is thus probably exposed to salinity changes, so that both prolonged lower salinities or hypersaline conditions may alter the abundance or even the presence of some species. Changes in community structure, and possibly ecosystem function, are expected consequences of any significant change in salinity (Rosenberg & Möller 1979; Chainho *et al*. 2006).

Acidity

Soft sediments can become acidic if hydrodynamic patterns in wetlands have been modified, allowing the build up of organic matter in sediments that are exposed during drought. Oxidation in acid sulfate soils can lead to a significant decrease in pH, and rewetting can release heavy metals and acidity into the overlying water (Simpson *et al*. 2008). Soft sediment fauna thus may be subject to simultaneous changes in water saturation, salinity, acidity, hypoxia and heavy metal concentrations. A lower water pH affects calcification rates, causing shells of molluscs to become brittle or dissolve, and most other non-calcifying benthic macroinvertebrates are killed by a pH below 5 (Knutzen 1981; Corfield 2000). Changes in water pH from acid sulfate soils are more severe than those predicted from ocean acidification resulting from global warming (Doney *et al*. 2001). DPI (2003) considered the risk from acid sulfate soils in Western Port to be minimal.

Extraction and disturbance

Risks

Dredging and spoil disposal

Dredging has occurred in Western Port since the 1920s (Wallbrink & Hancock 2003), for port development, maintenance and deepening of harbours and shipping channels, and until 2000 for commercial fishing (see Chapter 11).

Consequences

Excavations lead to habitat loss and the destruction or burial of organisms and biogenic structures (e.g. rhodolith beds, brachiopod beds, ascidian clumps), which in turn affect biodiversity and community structure. Predicted consequences include increases in populations of scavengers as a result of dead or damaged organisms in the dredge path (Newell *et al.* 1998). Recovery can take years, and a return to the previous assemblage is not always accomplished (Thrush & Dayton 2002). The effects also depend on the scale and frequency of dredging operations.

Dredging also causes remobilisation of sediment and can increase turbidity. In addition, spoil disposal can effect benthic organisms by turbidity and smothering, similar to sediment effects described above. A monitoring program in the North Arm from 1972 to 2009 showed that, although there was no extinction of species, the 1980s – 1990s sedimentation in the North Arm channel bed resulted in decline of populations of infauna and epibenthos, and also found dredging impacts on seagrass and pier pile faunas (Watson 2009).

Bait collection (intertidal sediments)

A six-month study by Contessa and Bird (2004) found that bait pumping for ghost shrimp (Thalassinidae) caused sediment disturbance, which has been shown to reduce sediment porosity, increase the proportion of fine particles in sediments, increase surface algae and decrease organic carbon. The recovery of ghost shrimp populations was slow during the six months of the study. Wider impacts on benthic communities are to be expected if densities of the ecosystem engineering ghost shrimps change (Coleman & Williams 2002; Skilleter *et al.* 2005). In Western Port, a ban on bait pumping is suspected to have resulted in higher abundances of polychaetes within the Marine National Parks (Butler & Bird 2010).

Habitat loss and fragmentation

Risks

The quality of soft sediment habitats in Western Port is affected by drainage inputs and shoreline erosion from mangrove loss, and land reclamation leads to irreversible habitat destruction (Wallbrink & Hancock 2003). Seagrass decline has contributed to an increase in unvegetated sediments in Western Port (Chapter 10).

Consequences

Given the extent of sedimentary habitats in Western Port, the loss of this broad habitat category is unlikely. But on a smaller scale, habitat loss may occur if particular biogenic structures are destroyed. This will have consequences similar to those for sediment quality and extraction and disturbance. Urban and industrial development may result in the loss of muddier high intertidal sites, which can be a refuge for juveniles of benthic organisms and important for certain stages of their life cycle, and fragmentation could affect species that have a limited dispersal capability (Thrush *et al.* 2008a). Most benthic organisms have pelagic larvae and many are also able to enter the water column as adults, so the effects of fragmentation have to be considered in a wider context of habitat mosaic and connectivity (Eggleston *et al.* 1999).

Sea-level rise, temperature increase, UVB

Risks

The predicted rise in sea levels is undeniably a consequence of human-induced emissions that are causing climate change (Domingues *et al.* 2008). In coastal areas, ultraviolet radiation and sea temperature changes driven by climate change are also predicted to affect large areas (Halpern *et al.* 2008). For embayments and other coastal systems, predictions may have to be adjusted for site-specific geomorphology and site history, as broad-scale climate patterns can be modified by smaller-scale weather variability (Hewitt & Thrush 2009).

Consequences

Sea-level rise will change the ratio of intertidal to subtidal areas in Western Port. As intertidal areas are important foraging grounds for migratory shorebirds, their landward retreat would need to be facilitated to prevent increasing loss of intertidal area.

Higher temperatures could change the distribution patterns of species and facilitate the establishment of species from warmer regions, including invasive species from tropical or subtropical origins (see below). Temperature changes could also affect the annual recruitment pattern of benthic species, but baseline information in this regard is missing for southern temperate regions.

Some benthic organisms, e.g. nemerteans, can be UV-sensitive and are only active at night (Nordhausen 1988), but some others can prevent damage from UVB by producing pigments (Dahms & Lee 2010).

Marine pests

Risks

Western Port, like all harbours, is exposed to the risk of accidental introduction of non-native marine species through commercial and recreational shipping, as hull-fouling organisms and organisms in ballast water. Any escalation of shipping activity will increase the risk of such introductions.

Consequences

The high diversity of benthos in Western Port is unlikely to protect it from the establishment of exotic species. Eighteen exotic species have been recorded in Western Port, of which 12 were considered likely to have established self-sustaining populations — three ascidians *Ascidiella aspersa*, *Ciona intestinalis*, *Styela clava*, *Styela plicata*, two bryozoans *Bugula neritina* and *Watersipora subtorquata*, a crab *Carcinus maenas*, two algae *Codium fragile tomentosoides* and *Ulva lactuca*, two bivalves *Musculista senhousia* and *Theora lubrica*, and a toxic dinoflagellate *Alexandrium tamarense* (Parry & Cohen 2001). However, a monitoring program in the North Arm from 1972 to 2009 did not find any of the large introduced epibenthic species that are common in Port Phillip (Watson 2009). Four other exotic species are present in Western Port but not as self-sustaining populations: two bivalves *Corbula gibba* and *Crassostrea gigas*, a polychaete *Sabella spallanzanii* and a kelp *Undaria pinnatifida* (Parry &

Cohen 2001). To that list must be added the Pie Crust Crab *Cancer novaezelandiae*, native to New Zealand but known from a few specimens collected at Flinders (Museum Victoria unpubl. data). Ecological impacts from these species in Western Port are likely but have not been demonstrated.

In Port Phillip Bay recent research has failed to demonstrate any impacts on community structure because of the presence of introduced suspension feeders, at least at naturally occurring densities of those suspension feeders (Ross *et al*. 2007), although clumps of *Sabella*, which are common, affect macrofauna and geochemistry (J. Ross, M. Keough & A. Longmore, unpublished data). Nevertheless, depending on which species may arrive, changes to entire communities and their functions cannot be excluded.

Cumulative impacts

Cumulative effects of the various threats to soft sediment habitats and biota in Western Port are very likely, as several stressors are usually acting at once (Thrush *et al*. 2008b). At present the interaction and possible intensification of multiple stressors on benthic assemblages are not well understood, and temporal and spatial scales of effects of single versus multiple impacts remain to be evaluated (Thrush *et al*. 1999). Furthermore, any impacts on soft sediment organisms will affect higher trophic levels (Chapters 11 and 12) and reverberate with functional implications in the bay (Chapter 14).

Research to fill key knowledge gaps

To mitigate the threats outlined in the previous section, improvements are needed to the water quality.

The evaluation of threats in this report relies heavily on studies carried out elsewhere in Australia or overseas, and the validity of transferring that insight to Western Port, with its extensive sedimentary environments and high benthic biodiversity, is uncertain. Furthermore, the assessment in this chapter is largely based on studies carried out in Western Port several decades ago, and no recent evaluation of the full biodiversity in soft sediments has been made. Other areas in southern Australia, such as Port Phillip Bay, have seen major changes in species composition and dominance, including the prevalence of introduced species (Wilson *et al*. 1998), yet for Western Port no attempt has been made to identify the current biodiversity and compare it with previous records or nearby embayments. If Western Port proves to be as different in its macroinvertebrate biota compared to adjacent bays at is appears, it must be given special attention.

Based on the studies from the 1970s, a high diversity on species level exists in Western Port (Barnard & Drummond 1978; Coleman *et al*. 1978), more akin to tropical. Both evolutionary backgrounds as well as ecological implications of the diversity need to be understood to properly address conservation measures for the soft sediment biota of Western Port.

A further step needed to inform future threat mitigation is habitat mapping to identify areas of functional importance, based for example on the occurrence of ecosystem engineering species. Knowledge on the occurrence, density and spatial and temporal variations of biogenic structures, together with accompanying studies on associated ecosystem processes, would allow us to prepare targeted mitigation measures and reduce the effects of threats outlined above. Such insights could also allow modelling of possible effects and efficiency of mitigation measures.

With a range of environmental changes and threats occurring simultaneously, knowledge on tolerance ranges of benthic species will further support mitigation, especially towards effects of single and combined stressors.

To evaluate the benthic biodiversity in unvegetated sediments of Western Port in comparison to earlier surveys, a historical repetition of studies by Coleman *et al*. (1978) and Edgar *et al*. (1994) should be carried out; that is, revisiting the same sites and applying the same methodology. This would provide knowledge on benthic diversity and assemblages, which can be compared on various spatial (within Western Port, with Port Phillip Bay) and temporal scales (over about two and four decades). Given the environmental changes that have occurred in Western Port over those time frames and the further seagrass loss, this research would help to answer how different the unvegetated sediment assemblages in Western Port now are compared to the historic situation. A comparison with Port Phillip Bay would also enable us to assess the relevance of ecological and historic factors in changes in benthic fauna, and would provide a new assessment of marine introduced species in Western Port, which has not been surveyed for a decade.

In addition, insight from this research can contribute to answering the question 'Why is there such a high benthic biodiversity in Western Port?' It may also lead to further phylogeographic investigations to unravel the biogeographic history, especially linkages with the biota of the eastern coast.

Ecological functions

Related to research into biodiversity are investigations into ecological functions of benthic species, in order to evaluate the roles of particular species, and to enumerate their contribution to ecosystem scale processes (see also Chapter 14), such as the role of soft-sediment fauna for nutrient cycling, especially on the extensive shallow mudflats.

Experimental field and laboratory studies could enable us to understand why several species of ghost shrimps can coexist and how they differ in their ecosystem engineering properties. Similar experiments could address whether the high benthic diversity facilitates resilience towards disturbances, or whether there is redundancy in the ecological functions realised by (related or unrelated) species, all of which would inform conservation management.

Further experiments should aim to evaluate whether it is the greater habitat diversity on a smaller scale provided by ecosystem engineering species that provides so many niches and supports a higher biodiversity.

On a larger scale, soft sediment habitats need to be evaluated as one part of a mosaic of habitats, and linkages with adjacent habitats for foraging or certain life history stages need to be assessed. This would contribute to an evaluation of the importance of habitat heterogeneity and connectivity in Western Port and other coastal ecosystems.