VIII-17 West-Central Australian Shelf: LME #44

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The West-Central Australian Shelf LME extends off Western Australia (WA) from Cape Leeuwin (~34.5°S) to Northwest Cape (~22°S). This LME owes much of its biogeographic unity to the respective connecting influences of the West Australian Current, a northward flow coming from the circulation pattern of the counterclockwise Indian Ocean gyre, and the Leeuwin Current (LC), the only west coast poleward-flowing eastern boundary current in the southern hemisphere. The LC is a major southward flow of warm, low nutrient, buoyant tropical water along this LME's relatively narrow continental shelf, and is responsible for tropical reefs and associated marine flora and fauna flourishing further south than anywhere else in the world (CALM, 1994). In addition to these regional scale currents, there are wind-driven coastal counter currents dominating the circulation close to shore mainly during the austral spring/summer period (Pattiaratchi, 2006). Relatively high energy from sea and swell is a major feature of this LME, but there are embayments and lagoons where waves are restricted or effectively blocked, with sheltered highly biodiverse protected habitats occurring behind offshore limestone reefs in many localities (CALM, 1994). The LME has an extremely narrow shelf, in some areas being merely 40 km wide, and covers an area of nearly 550,000 km^2, about 2% of which is gazetted as a marine protected area (MPA) that contains 0.37% of the world's coral reefs (CALM, 2005a; Sea Around Us, 2007; www.dec.wa.gov.au).

The region has a Mediterranean climate with sea temperatures varying from about 15°C in the south in winter to about 29°C in the north in summer, as described in biogeographic overviews contained within management plans for proposed and existing Western Australian MPAs (see for example CALM, 1996, 2002, 2005a, 2005b and DEC 2006, 2007a, 2007b, 2007c). The marine biodiversity of this LME is characterised by a rather special tropical-temperate mix, varying from predominantly tropical in the north to predominantly temperate in the south. Tropical species from the north are carried southwards by the LC, while temperate and sub-temperate species are carried northwards by coastal counter currents, such as the Capes and Ningaloo currents respectively (Pattiaratchi, 2006). The gradation in the biodiversity is exemplified by the latitudinal variation in the relative proportion of tropical versus temperate fish species along WA's coast, which acts as a good surrogate of overall biodiversity variation (Fox and Beckley, 2005). Superimposed on the tropical-temperate distributions is a proportion of the biota endemic to Western Australia, including, for example, 5% endemic fish species and 25% endemic shallow water echinoderms. Overall, about 10% of the shallow water fauna in this LME are endemic to WA (CALM, 1994).

Some of this LME's ecological highlights include the 270 km long fringing Ningaloo Reef (~22°S), which resides within an MPA that has 30% gazetted as sanctuary zone; the World Heritage listed hypersaline inverse-estuary of Shark Bay (~26°S), which is also an MPA and contains 20,000 km^2 of seagrass meadows and extensive areas of stromatolites; the high-latitude coral reefs of the Abrolhos Islands (~29°S); extensive areas of mangal communities; open coast sandy beaches; long shore-parallel intertidal and sub-tidal macro-algal-dominated limestone reefs; and an overall high biodiversity of mixed tropical/temperate marine species. This LME ranks 7th amongst the world's 18 most biologically diverse marine areas and 2nd as a centre of endemism (Roberts et al., 2002). Recent large multidisciplinary studies have made significant advances in the understanding of the region's biophysical, biogeochemical and ecological dynamics (e.g.

Keesing et al., 2006). UNEP (2003) provides further biogeographical information on this LME.

I. Productivity

The West-Central Australian Shelf LME is a Class III, low productivity (<150 $gCm^{-2}yr^{-1}$) ecosystem. Its coastal waters are oligotrophic by world standards, with recent studies by Koslow et al. (2006) recording annual phytoplankton production at 46gCm^{-2} inshore and 115gCm^{-2} on the shelf and offshore. Due to its latitudinal range and confluence of tropical and temperate flows, this LME encompasses diverse pelagic and coastal ecosystems. In the southeast Indian Ocean, the West Wind Drift branches northward as the West Australian Current. However, the presence of the southward flowing Leeuwin Current (LC) closer to the coast of this LME effectively suppresses any broad-scale upwelling of deeper, highly productive water, in contrast to other eastern boundary currents where strong upwelling is typical. However, recent studies are showing that localised productivity from upwelling can be associated with sporadic events and near-shore counter currents (see, for example, the research framework of the Western Australian Marine Science Institution: www.wamsi.org.au). Perth Canyon, an incisive, 100 km long and deep (ranging from 200 to 4000 m) canyon, is a highly productive slope feature off Perth (Rennie et al., 2006) characterised by bouts of eddy-induced upwelling, high primary production, and associated aggregations of marine fauna, from large (e.g. whales) to small (e.g. krill).

The LC flows most strongly in winter, extending all the way down the west coast and then eastward along the southern coast of the Australian continent. Comparatively warmer, lower salinity water flows through the Indonesian Archipelago from the Pacific Ocean to the Indian Ocean, and results in lower density water between Indonesia and northwest Australia as compared with the cooler and more saline ocean waters off southwest Australia (Pattiaratchi, 2006). This density difference results in a sea level change of up to about 0.5 m along the Western Australian coast and is the driving force for the Leeuwin Current. Due to the effect of the earth's rotation, water is entrained from the Indian Ocean into the Leeuwin Current, and the Current cools as it propagates southwards; thus, the Leeuwin Current strengthens as it flows southward. The Leeuwin Current weakens in spring/summer, mainly as a result of the relatively strong opposing wind stresses associated with seasonal wind fields. Ridgway and Condie (2004) provide further information on the seasonal evolution of the LC flow and its influence on sea surface temperature throughout the year.

The dynamics of the LC are influenced to a significant extent by inter-annual variability in the El Niño Southern Oscillation and an important feature is the strong eddy activity associated with the instability in the fast southward flow (Waite et al., 2007). These eddies are typically up to about 300 km in diameter and can generate large productivity pulses, drawing significant amounts of water, heat and biomass from the productive shelf and coastal waters into the open ocean. During winter in La Niña years the LC may have a volume transport of 6 million m^3sec^{-1}, while in winter in El Niño years this is about 4 million m^3sec^{-1} (Feng et al., 2003). It has been calculated that the eddies may flush the entire volume of the southwestern Australian continental shelf twice annually carrying phytoplankton biomass equivalent to 40,000 tonnes of carbon offshore each year (Feng et al., 2007). The dynamics of the LC, particularly the large-scale eddy circulation, is known to also have a profound influence on the LME's coastal and offshore fisheries ecology, for example the predictable influence on the inter-annual variability in recruitment of the commercially important Western Rock Lobster.

Within the LC, a deep chlorophyll maximum is a significant contributor to total water column production. Chlorophyll *a*, as an indicator of phytoplankton, peaks in the late autumn / early winter period on the shelf and shelf break, in phase with the seasonal strengthening of the LC and its eddy field. This is consistent with the recent discovery of a deep water chlorophyll maxima representing high phytoplankton levels around 50 m depth in winter (Koslow et al., 2006). Ongoing studies are examining how enhanced flow of the LC in late autumn might lead to nutrient enrichment and heightened primary productivity. These studies are also examining the role of the extensive and highly productive benthic ecosystems of the region (Babcock et al., 2006) and benthic-pelagic coupling on the biogeochemistry of the region. Nutrient budgeting for the region by Feng and Wild-Allen (in press) indicates that about 80% of nitrogen utilised by annual primary production is retained and recycled on the shelf. For more information on the LC and its influence on this LME see Deep Sea Research II special issue, volume 54.

When the LC is flowing strongly during the winter months, it tends to move onto the continental shelf as it approaches Cape Naturaliste. It generally flows close inshore down to Cape Leeuwin and then eastwards towards the Great Australian Bight. In late spring, however, it moves a little offshore to be replaced by a cool northwards counter-current, recently named the Capes Current. The Capes Current commences near Cape Leeuwin and flows northwards past Cape Naturaliste and on beyond Rottnest Island (Pearce and Pattiaratchi, 1999); there is often an associated upwelling region in the lee of Rottnest Island. This in turn dies away about March/April as the strengthening LC moves inshore again. Similarly, a summer counter current (the Ningaloo Current) has recently been identified along the Ningaloo Reef (Taylor and Pearce, 1999), and similar counter currents are known to exist inshore of the Abrolhos Islands. Pattiaratchi (2006) provides a more detailed overview of these and other general circulation patterns off Western Australia.

For an analysis of the association between oceanic fronts and enhanced marine productivity, see Menon (1998). Shark Bay along the coastline is an inverse estuary: along this arid coastline region, the high evaporation rate from shallow embayments without significant freshwater inflows and with restricted tidal exchange creates an environment with a salinity that exceeds that of the seawater, to a maximum of about 65 ppt in its uppermost reaches, where extensive areas of stromatolites occur (CALM, 1996). For a general understanding of oceanographic processes affecting the nutrient dynamics and productivity of Australian marine ecosystems, read the State of the Environment Report (EPA, 2007). For more information on productivity, see www.ea.gov.au.

Oceanic fronts (Belkin et al., 2009): The Leeuwin Current Front (LCF) (Figure VIII-17.1), described in 1980 by Cresswell and Golding (1980), occurs within this LME, although some source waters of this current/front are found farther north, in the Northwest Australian Shelf LME. The Leeuwin Current, flowing poleward along the outer continental shelf, is a relatively shallow and narrow boundary current by global standards, being less than 300 m deep and 100 km wide. Typical current speeds within the Leeuwin Current and its eddies are about 1 knot (50 cm/s), although speeds of 2 knots are common, and the highest speed ever recorded by a drifting satellite-tracked buoy was 3.5 knots. Tropical warm waters spread along this front toward Cape Leeuwin. There is a northward counter current beneath the Leeuwin Current called the Leeuwin Undercurrent. The Leeuwin Undercurrent flows equatorward in a narrow depth zone (typically 250-450 m) and carries relatively high-salinity, oxygen-rich, nutrient- depleted water northward within this LME.

The North Tropical Front (NTrF) merges with the LCF near 25°S. Farther south, the South Tropical Front (STrF) merges with the LCF near 30°S. The LCF and the associated current extend over the shelf break and shelf. They play an important role in the ecology of many tropical species, particularly lobster, since the Leeuwin Current and its extension carry lobster eggs and larvae into the Great Australian Bight. In addition, the high latitude (29°S) coral reef at Houtman Abrolhos (Abrolhos Islands), with its relatively high coral diversity, is established and sustained by the Leeuwin Current, which is also responsible for the presence of corals as far south as Rottnest Island (32°S). A meso-scale Kalbarri Inner Shelf Front (KISF) extends NNW from the Murchison River mouth at 27.5°S.

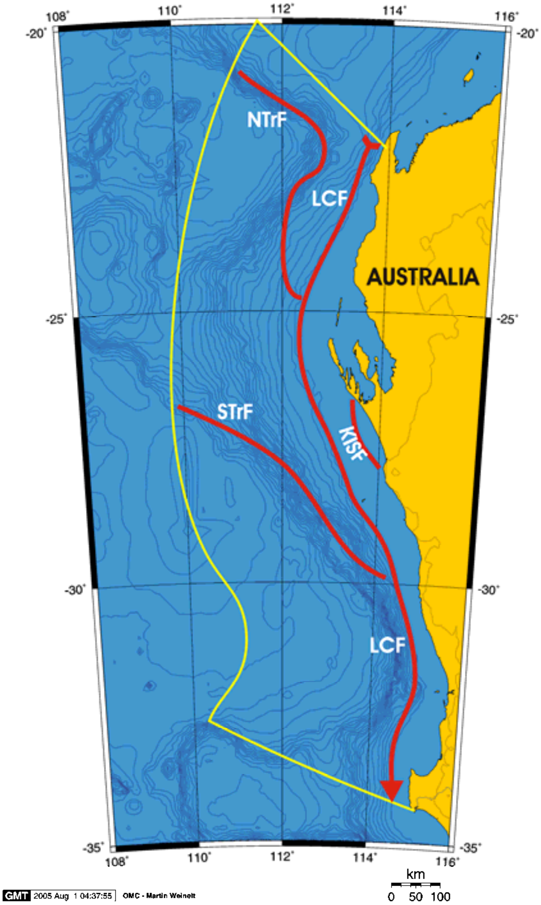

Figure VIII-17.1. Fronts of the West-Central Australian Shelf LME. KISF, Kalbarri Inner Shelf Front; LCF, Leeuwin Current Front; NTrF, North Tropical Front; STrF, South Tropical Front. Yellow line, LME boundary. After Belkin et al. (2009).

West-Central Australian Shelf SST (Belkin, 2009)(Figure VIII-17.2)
Linear SST trend since 1957: 0.82°C.
Linear SST trend since 1982: 0.09°C.

The 25 years since 1957 were rather quiet and relatively cold. The single pronounced cold event of 1968 was also observed in the Sulu-Celebes Sea LME, Indonesian Sea LME, Northwest Australian Shelf LME, and Southwest Australian LME. The cold event of 1968 was preceded by the all-time minimum in the Indonesian Sea in 1967 (and a minimum of 1967 in the North Australian Shelf LME); therefore this low-temperature signal was likely transported by the Indonesian Throughflow from the Indonesian Sea onto Western Australia's shelves, and farther south and east, with the Leeuwin Current, onto the Southwest Australian Shelf LME.

The 25 years from 1982 to 2006, featured strong events with a peak-to-trough amplitude of 1°C. The two warm events of 1983-1984 and 1988-1989 were possibly correlated with moderate El Niños. The all-time maximum of 1998 was likely linked to the extremely strong El Niño 1997-98 (Feng *et al.,* 2003).

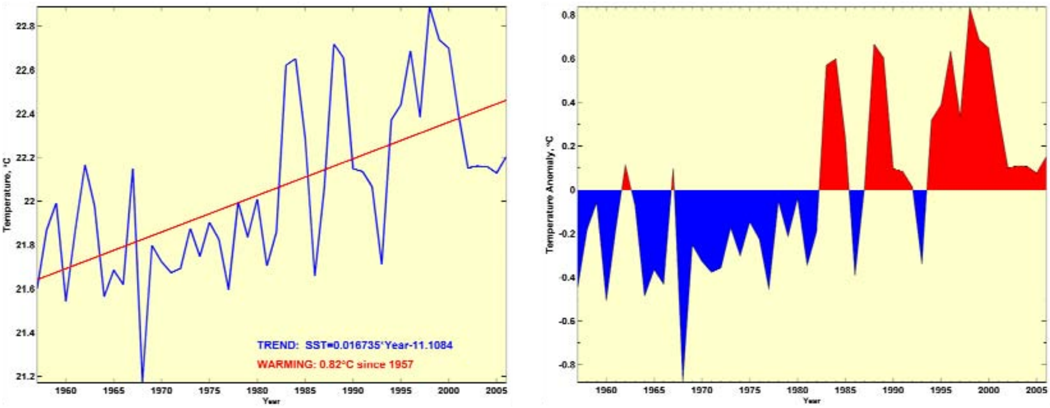

Figure VIII-17.2. West Central Australia Shelf LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009)

West-Central Australian Shelf LME Chlorophyll and Primary Productivity: The West-Central Australian Shelf LME is a Class III, low productivity (<150 $gCm^{-2}yr^{-1}$) ecosystem.

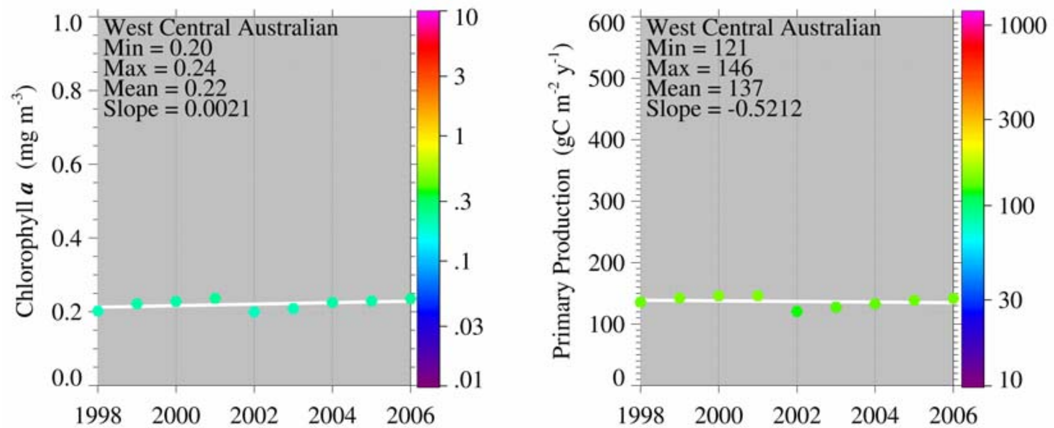

Figure VIII-17.3. West-Central Australian Shelf LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery; courtesy of K. Hyde.

II. Fish and Fisheries

Production in Australian waters is limited by low levels of nutrients and as a result, fish populations are relatively small. Many species are endemic to Australia. Although not productive by world standards, there are numerous commercial and recreational fisheries based in the waters of this LME. The commercial fisheries operating in this area tend to be low-volume, high-value fisheries producing fish and shellfish for local consumption and export. Currently there are 16 State-managed commercial fisheries and 5

Commonwealth commercial fisheries within this LME. For details of WA State fisheries see Fletcher and Head (2006) and for Commonwealth fisheries see Larcombe and McLoughlin (2007).

There are commercial fisheries for lobster, abalone, pink snapper, shark, crab, pilchard, prawn and scallop. Constantly changing ocean conditions affect the abundance and distribution of all species in the marine food chain. The commercial fishery for the western rock lobster, *Panulirus cygnus*, within this LME is the largest single-species fishery in Australia. The important finfish fisheries are the Shark Bay Snapper Fishery and the West Coast Purse Seine Fishery; the most significant prawn and scallop trawl fisheries are concentrated in Shark Bay, with some other trawl fisheries further south. Approximately 45% of the waters of this LME out to the 200 m contour are permanently closed to trawling.

Using global data, total reported landings in this LME peaked at around 16,000 tonnes in 1993, followed by a period of a slight dip in the late 1990s, but have returned to 16,000 tonnes in 2004 (Figure VIII-17.4). However, alternate calculations from this LME's portion of State fisheries (Fletcher and Head, 2006) and Commonwealth fisheries (Australian Fisheries Management Authority, pers. comm.) estimate the annual production of commercial fisheries in 2005 to be 30,055 tonnes, valued at US$340 million. Invertebrates such as lobster, scallops, prawns and shrimps account for the largest share of the landings in the LME. The reported landings were estimated to be valued at about US$120 million in 2000 (Figure VIII-17.5).

All fisheries in the area are subject to management plans which embrace the principles of Ecosystem Based Fishery Management (EBFM) as opposed to single target species management approaches (Smith *et al*., 2007). For the 21 managed fisheries in this region, 15 have published Stock Assessments and 16 have published Ecological Risk Assessments (Fletcher and Head, 2006). Of those with published Ecological Risk Assessments, one fishery had inadequate spawning stock levels, one had moderate bycatch species impacts, one had moderate protected species (marine mammal) interactions, two had moderate food chain impacts and one had moderate habitat impacts.

There are some areas that are of particular concern due to over-fishing; for example, the Shark Bay snapper fishery has experienced very high fishing pressure in the past, and following adjustments to management strategies (including prolonged closures), the population of pink snapper has not recovered as expected (Fletcher and Head, 2006). It is thought that wider environmental factors are playing a significant role (e.g. ocean currents affecting young fish, and perhaps water temperature). The most significant Commonwealth managed fishery in this LME is the Western Tuna and Billfish industry. Southern bluefin tuna, yellowfin tuna and broadbill swordfish are subject to overfishing in the broader Indian Ocean (Larcombe and McLoughlin, 2007). The Australian Government is party to a number of international conventions or agreements for the management of highly migratory tunas and billfishes that range far beyond the Australian Fishing Zone – see Larcombe and McLoughlin, 2007.

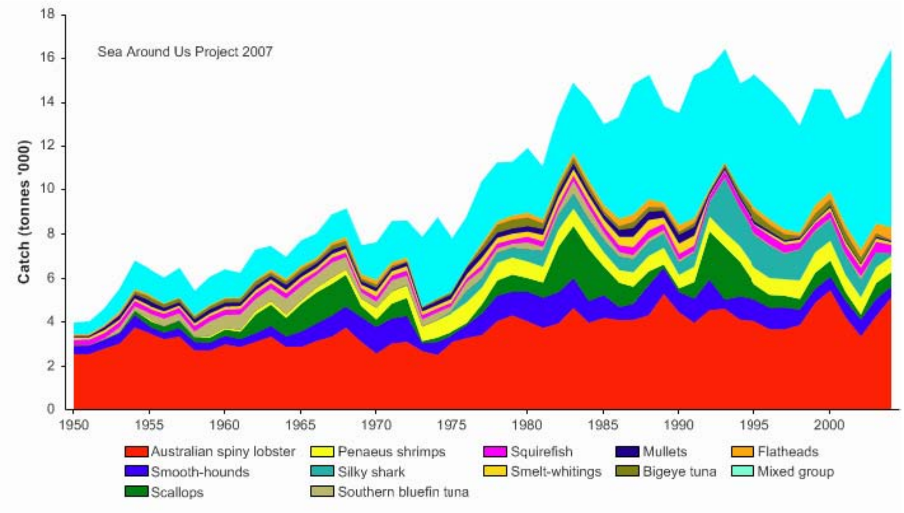

Figure VIII-17.4. Total reported landings in West-Central Australian Shelf LME by species (Sea Around Us, 2007).

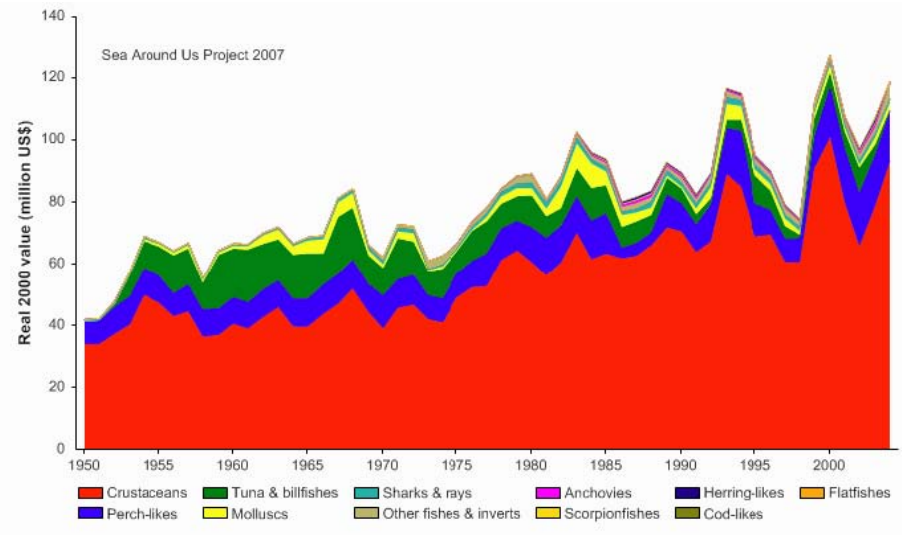

Figure VIII-17.5. Value of reported landings in West-Central Australian Shelf LME by commercial groups (Sea Around Us, 2007).

The primary production required (PPR; Pauly and Christensen, 1995) to sustain the reported landings is very small (less than 1.5%), in line with the low exploitation of the LME (Figure VIII-17.6). Australia has the largest share of the ecological footprint in this LME.

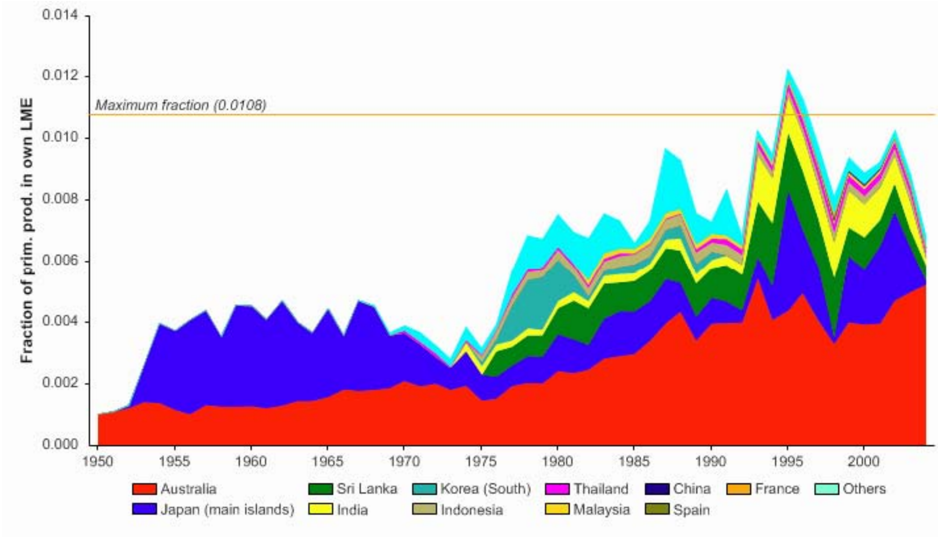

Figure VIII-17.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the West-Central Australian Shelf LME (Sea Around Us, 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level (i.e., expressed through the Mean Trophic Index (MTI); Pauly and Watson, 2005) in the LME was generally low, due to the low trophic level of Australian spiny lobster which accounts for the largest share of the reported landings (Figure VIII-17.7 top). In recent years, however, the MTI is on a rise with the growing share of various fish species in the landings. This transition is also reflected in the Fishing-in-Balance (FiB) index (Figure VIII-17.7 bottom). This LME, thus, shows no sign of a 'fishing down,' in line with the low level of PPR recorded in Figure VIII-17.6.

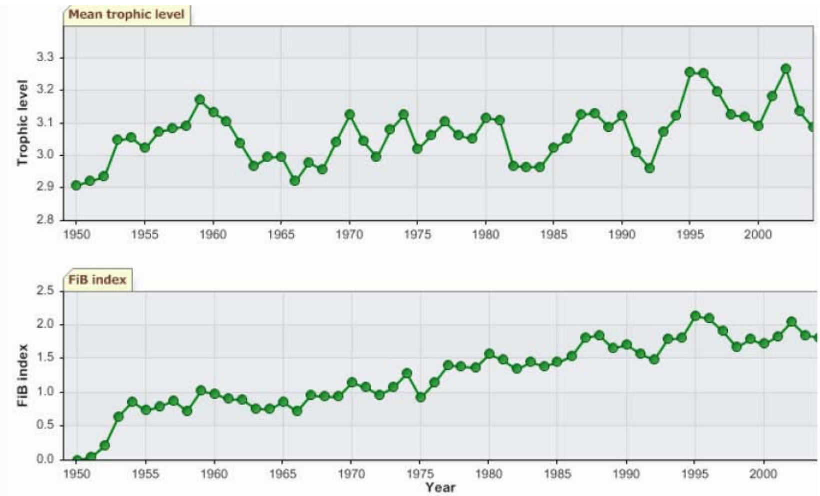

Figure VIII-17.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the West-Central Australian Shelf LME (Sea Around Us, 2007).

There are high levels of recreational fishing but negligible levels of artisanal or indigenous traditional fishing in this LME. The key target species of recreational fishing are western king and school prawns, blue manna crabs, abalone, rock lobster and a variety of finfish including herring, salmon, tailor, whiting, snapper, dhufish and a variety of other highly sought after reef fish species.

The Stock-Catch Status Plots indicate that about 70% of the stocks are deemed as collapsed or overexploited (Figure VIII-17.8, top). It appears that the majority (over 70%) of the reported landings is supplied by fully exploited stocks (Figure VIII-17.8, bottom). However, the editors and Australian contributors wish to acknowledge and advise caution that there are several reasons possible for the apparently reduced status of some species. Among them, Australian management authorities have in many cases limited catches and effort to protect the species from overfishing. Landings of these stocks are therefore lowered, giving the appearance of an overfished condition status in Figure 8. In addition, productivity of some of these fisheries is tightly coupled to environmental variability, in particular ENSO, and this also reduces catches in some years in ways not due to exploitation rate. Catches of all species are subject to annual active management intervention and often include temporally and spatially explicit adaptive management measures to prevent overfishing.

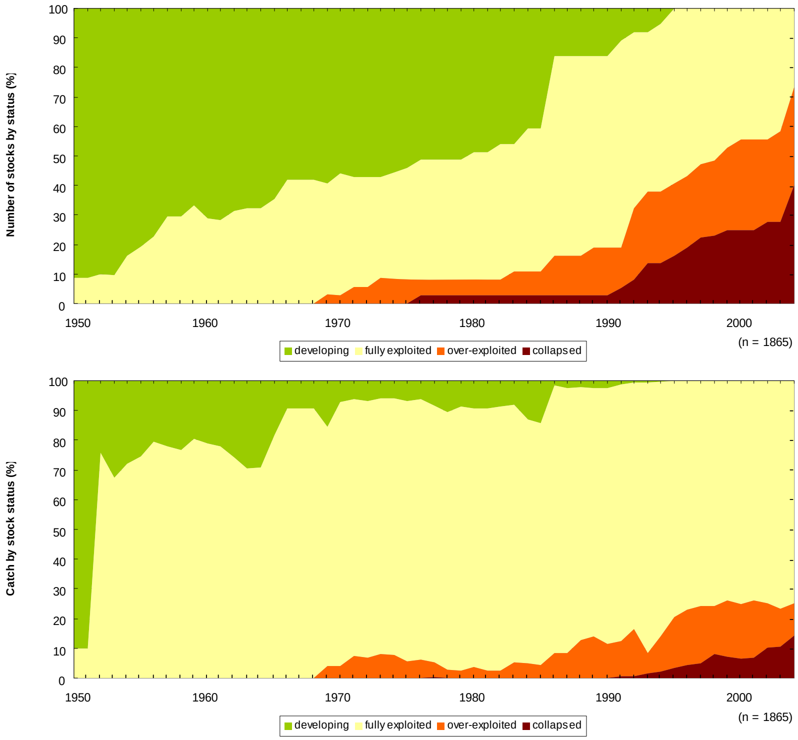

Figure VIII-17.8. Stock-Catch Status Plot for the Western Central Australian Shelf LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

III. Pollution and Ecosystem Health

The shallow water marine environments of this LME are recognised as having some of the highest marine biodiversity and endemism in the world. Roberts *et al*. (2002) ranked this area 2nd in the world among 18 centers of endemism. Of those 18, this area ranked among the least threatened, ranking 15th in terms of threats from coastal development, overexploitation and pollution. This is in part due to the region's sparse population and relatively low associated level of threatening activities, but also due to the strong legislative framework (see Governance section) and a mature planning framework for marine natural resource management that embraces and includes multiple-use MPAs and Ecosystem Based Management of Fisheries. The State of the Environment Report (EPA, 2007) assessed the condition of the marine environment against a selection of broad indicators in the categories of Degradation of the Marine Environment, Marine Contamination and Introduced Marine Pests. Marine contamination issues affect only a small proportion of the waters of this LME, mainly near ports. Heavy metal contamination is low in the areas where it is monitored. Overall, the report expresses concern that too few places are routinely monitored for degradation and contamination against environmental quality management frameworks. The condition of WA's coastal and shelf waters has historically been poorly monitored, with the exception of certain highly pressured areas, such as Albany harbours, North West Shelf (particularly Dampier Archipelago) and areas which lie on the southern boundary of the LME such as Cockburn Sound and Perth metropolitan coastal waters (EPA, 2007). Relevant reports are available through the Western Australian Department of Conservation and Environment (www.dec.wa.gov.au) and the Environmental Protection Agency (www.epa.wa.gov.au). Western Australia's overall marine and coastal monitoring framework is undergoing a significant expansion as part of the State's MPA implementation and management programs, as discussed in Section V.

Although relatively infrequent, accidental discharges of contaminants, such as from spills and shipping accidents, also place pressure on the region's marine environment. Port and industrial development, pipelines, mining and dredging cause direct physical damage to the marine habitats. Tributyltin (TBT) contamination (a highly toxic ingredient of anti-fouling paint applied to ships and coastal vessels) was widespread throughout the Perth metropolitan region in areas near marinas and ports; however following complete bans in 1991 on the use of TBT on boats less than 25 m long, the effects of contamination have been decreasing (Wells *et al.,* 2008). Another major pressure in the Perth area marine environment is excessive nutrient loads from sewage wastewater outfalls, as well as from industrial and agricultural sources. To a lesser degree, there are also contaminated groundwater and river and estuary discharges.

In respect to the threat from introduced marine species, significant numbers have been recorded along the coast, such as in the port of Geraldton, as well as in certain localities within the Carnarvon and adjacent Shark Bay areas. The most likely vectors are thought to be international and domestic shipping, fishing and recreational vessels (EPA, 2007). The West-Central Australian Shelf LME is therefore threatened by an increase in shipping, especially from ballast water. Ballast water discharges are of concern because of their potential to transport species from their native habitat to new habitats where they may become invasive. Ballast water from shipping has been responsible for introducing more than 250 species, and possibly as many as 500 species, into Australian waters. In response, Australia has introduced mandatory ballast water management requirements to reduce the risk of introducing more unwanted marine species. More than 99% of the approximately 12,500 annual voyages that arrive in Australia comply with these requirements (Beeton *et al.,* 2006).

Tourism, urban development and associated commercial and recreational use along the coastal strip are also placing stress in populated areas of this LME, through coastal development and recreational fishing in particular. Natural embayments along WA's extensive coastline make ideal locations for human settlements, ports and marinas, but this places pressure on shallow water marine habitats from the associated ecological forcings that accompany human usage. Large numbers of people are engaged in recreational activities that have the potential to affect the environment through pollution of the water by boats and the disturbance of species and habitats. For more information on marine and coastal pollution issues see Pogonoski *et al.* (2002), annual State of the Environment reports (EPA, 2007) and Zann (1995).

Recent advances in the understanding and prediction of climate change impacts, places this amongst the most concerning of all fundamental pressures on the marine ecosystems in this LME. The WA region has been subjected to a significantly greater warming trend over the last 50 years than many other parts of the Indian Ocean (Feng *et al.,* 2005; EPA, 2007). Climate modeling under the IPCC A2 greenhouse gas scenario predicts that continued warming will occur and that the warming is a result of local air-sea fluxes, not hydrodynamic structure (Feng *et al*., 2007). The advancing establishment of GOOS (Global Ocean Observing System) in the region, facilitated by the Intergovernmental Oceanographic Commission, will continue to improve the characterization of broadscale hydrodynamic and climatic impacts within WA's LMEs. This is being achieved through, for example, the Indian Ocean Observing System (IndOOS) of the Indian Ocean Panel of CLIVAR/GOOS (www.clivar.org/organization /indian/indian_reference.php), Australia's recently implemented Integrated Marine Observing System (www.imos.org.au) and a number of long-term monitoring networks established and maintained under the auspices of State and Federal natural resource management and maritime transport agencies. Furthermore, Australia's operational ocean forecasting facility, Bluelink, that currently provides ocean forecasts at 10 km grid resolution out to 7 days, is underpinned by data assimilation progressed under the international GODAE program (www.bom.gov.au/bluelink).

IV. Socioeconomic Conditions

The most populous sections of the WA coast are in the city of Perth and two smaller cities, Geraldton and Bunbury. As an island nation, Australia depends heavily on its marine environment for transport and shipping. Fishing is an important marine industry and its highly distributed nature along the coast makes it important socioeconomically for many rural communities. FAO provides information on the characteristics and socioeconomic benefits of Australia's fishing industry (www.fao.org). Aquaculture is a relatively minor activity, except for important pearling operations. The dry, hot climate of this area makes it ideal for solar salt production. Extensive evaporation ponds have been established adjacent to Shark Bay, and there are several other large-scale evaporative salt plants. Marine and coastal-based tourism are important in this LME, both in terms of domestic and international tourism, with recreational fishing a very significant component, in addition to scuba diving, surfing, wind surfing, sailing and boating. Tourists prize the LME's coral reefs and the general natural and unspoiled marine environment. The coral-dominated Ningaloo Reef is an important tourism location with over 200,000 tourists visiting each year. Shark Bay is one of only six World Heritage Areas in Australia that have a marine component. This LME is a breeding ground for the Antarctic-feeding humpback whale. Other cetaceans (including many whale species and large numbers of dolphins), dugong, sharks (including whale sharks), sea lions, sea turtles (six species), sea snakes, manta rays, seabirds, shorebirds, migratory waders and little penguins are amongst the key marine values of this LME. The region is also notable for extensive stands of seagrass meadows, involving many species of seagrasses. In addition to commercial and recreational fishing, this LME supports other important cultural and economic marine values which include aquaculture (e.g. pearling), indigenous and maritime (European) heritage, seascapes, wilderness, marine tourism (e.g. diving, swimming, sailing, water sports), and petroleum development.

V. Governance

Australia has a federal system of government with the states forming the Australian Commonwealth federation. This LME lies adjacent to the State of Western Australia (WA). Australia's exclusive economic zone (EEZ) extends out 200 nautical miles. Within the EEZ, WA State waters generally extend 3 nm offshore, or greater in some areas to encompass islands and archipelagos. The Commonwealth Government's *Environment Protection and Biodiversity Conservation Act 1999* is the principal national instrument for managing human usage and impacts, and for conserving biodiversity in Australia's territory. It is employed in conjunction with the WA State Government's *Environmental Protection Act 1986, Wildlife Conservation Act 1950* and *Conservation and Land Management Act 1984*, the latter of which was amended by the *Acts Amendment (Marine Reserves) Act 1997*, establishing the Marine Parks and Reserves Authority (MPRA) as the vesting body for Western Australia's marine conservation reserves.

Australia is committed to the protection of marine biodiversity and ecological processes and the sustainable use of marine resources through the goals and principles of Ecological Sustainable Development (ESD). This commitment has been ratified through Australia's international responsibilities and obligations under the Convention on Biological Diversity and implemented at a national level by the States and Territories under the Intergovernmental Agreement on the Environment (IGAE), through the development of national strategies. Biodiversity conservation is managed by a strong legislative and planning framework and an extensive system of marine conservation reserves, which, when fully implemented, will cover approximately 35% of this LME's coast length.

In the early 1990s, at a national level, Australia identified a need to protect representative examples of the full range of Australia's marine ecosystems and habitats in marine protected areas. The respective State Governments agreed to establish a comprehensive, adequate and representative system of protected areas covering Australia's Exclusive Economic Zone. As a first step over the past 10 years, a spatial framework was developed and established, named the Integrated Marine and Coastal Regionalisation of Australia (IMCRA), for classifying Australia's marine environment into bioregions that make sense ecologically and that are at a scale useful for regional planning (Commonwealth of Australia, 2006). This captures all Australian waters from the coast to the edge of the Exclusive Economic Zone, excluding Antarctica and Heard and Macdonald Islands. These IMCRA bioregions are consolidated into regional groupings to form a smaller set of Marine Bioregional Planning Regions under Australia's Oceans Policy (www.environment.gov.au/coasts/mbp). This LME encompasses parts or all of 4 of the 7 provincial bioregional units making up the South-West region and 3 of the 8 provincial bioregional units making up the North-West marine bioregional planning region. Development of a Bioregional Profile, identifying the important ecological, conservation and socioeconomic values of the region for the South West, has been released (Department of the Environment and Water Resources, 2007); that of the North West was expected to be released in mid-2008 (see www.environment.gov.au/coasts/ mbp/north-west).

Such marine bioregionalisations and descriptive profiles help managers to understand complex ecosystems and their specific management needs. These bioregions are consistent with the development of a National Representative System of Marine Protected Areas (NRSMPA) which aims to establish and manage a system of marine protected areas to contribute to the long-term ecological viability of marine and estuarine systems, in order to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels. The Western Australian Government's existing and proposed system of Marine Protected Areas contributes to the Australian

National Representative System of Marine Protected Areas (www.dec.wa.gov.au) and, when fully implemented, will also result in MPAs situated within all of the LMEs covering Western Australian coastal zone.

Western Australia's MPA framework focuses on the maintenance of marine biodiversity, but also considers socioeconomic marine uses allowing for managed fishing and general tourism as important social uses (CALM, 1994). The framework includes explicit provision for marine sanctuary (no-take) zones and other special purpose zones (e.g. for scientific reference and education) to ensure biodiversity conservation requirements can be met. Often, State and Commonwealth instruments are used to provide contiguous zones of protection. For example, the Ningaloo Marine Park is a state-managed marine park extending 3 nm from the coast, and a Commonwealth Act has been used to extend the effective area of the MPA seaward through the establishment of an adjoining Commonwealth MPA.

Natural resource management (NRM) for the area comes under the jurisdiction of an integrated (State and Federal) national framework, facilitating scientific and institutional consistencies in NRM science and governance. The socioeconomic uses incorporated in NRM regimes centre around fishing, coastal use, nature-based tourism, water sports, scientific research, education and petroleum activities. A best-practice, outcome-based NRM model for adaptive management is employed (ANZECC, 1997). This is supported by a statewide marine science program that services a statutory adaptive management framework based around zoning, compliance (patrol and enforcement), public participation (education/communication/interpretation), management intervention, visitor infrastructure, research, and monitoring (www.calm.wa.gov.au). Key planks of the NRM model are the designation of performance measures (indicators of management effectiveness), management targets (the end points of management) and key performance indicators (quantitative measures of overall management effectiveness), which are regularly and formally assessed under Government legislation, in respect to the effectiveness of management (www.dec.wa.gov.au) by the State's Marine Parks and Reserves Authority.

Fisheries management is also implemented at State (www.fish.wa.gov.au) and Commonwealth (www.afma.gov.au) levels, underpinned by ecosystem-based frameworks rather than more traditional single-species stock management methods. The *Offshore Constitutional Settlement* (OCS) agreement defines the jurisdiction of Commonwealth and State governments, with management of most fish stocks out to the 200 nm limit of the Australian Fishing Zone being managed under state legislation (*Fish Resources Management Act 1994*). Offshore fisheries and those extending across state borders are managed by the Commonwealth Government (*Fisheries Management Act 1991*). Integrated State/Commonwealth institutional instruments are also in use for the management of marine values focusing on maritime and indigenous heritage, tourism, science, education, shipping and extractive industries such as mining, oil/gas exploration and production.

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