Chapter 35. INTERACTIONS BETWEEN PHYSICAL, CHEMICAL, BIOLOGICAL, AND SEDIMENTOLOGICAL PROCESSES IN AUSTRALIA'S SHELF SEAS (30,W-S)

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1. Introduction

Australia is an island continent extending from tropical to midlatitude waters with an Exclusive Economic Zone of some 8.6 million square kilometres. Its regional seas are exposed to climatological conditions ranging from the westerly Roaring Forties winds in the south, to monsoon and tropical cyclone conditions in the north. It also encompasses regions of extreme biodiversity, with 80 percent of southern temperate species endemic to the region.

The focus of marine research in Australia is becoming more interdisciplinary in response to factors such as the national government's recent Oceans Policy, which emphasises sustainable development and ecological based management (Reichelt and McEwan, 1999). However, historically there have been relatively few major interdisciplinary studies in Australian waters. Initiatives, such as the Leeuwin Current Interdisciplinary Experiment (Smith et al., 1991) might be more accu-

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rately described as multidisciplinary, with very limited effort devoted to integration. Interdisciplinary work that has been undertaken has tended to be concentrated in a few regions. Most notably in the Great Barrier Reef where there has been a strong interest in terrestrial inputs and larval exchange between reefs, in the Tasman Sea adjacent to Sydney where the East Australian Current has a strong influence on upwelling and primary productivity, and off the west coast where larval dispersion impacts recruitment levels in high value fisheries.

Because an interdisciplinary review could in principle include most of the marine science undertaken in Australian waters, it has been important to limit its scope. The focus is therefore restricted to shelf scale processes, including major coastal and offshore influences, but excluding the surf zone, intertidal zone, estuaries and bays. This distinction is important since a large proportion of the interdisciplinary marine research conducted in Australian waters has been undertaken in these coastal environments. The other significant limitation is that the review is largely restricted to the mainstream scientific literature. In exceptional cases where reports have been cited, web access details have been provided where possible.

This review will begin in Section 2 with an overview of the broad-scale characteristics of Australia's shelf seas, considering physical, chemical, biological, and sedimentological aspects of both its tropical and temperate regions. Interdisciplinary studies will be reviewed on a regional basis in Section 3, along with recent attempts to synthesize information at the national scale. Research directions and emerging scientific issues will then be discussed in Section 4.

2. Characteristics of Australia's Shelf Environment

This section provides general descriptions of the geomorphological, sedimentological, physical, chemical, and biological properties of the shelf-slope seas around Australia. These descriptions will be based on bathymetric and sediment datasets, hydrographic climatologies, satellite imagery, biogeographic descriptions, and key in situ observations.

2.1 *Geographical and Geomorphologic Setting*

The shape of the Australian continent owes its origin to the rifting apart of the Gondwanaland super-continent. About 65 million years ago Australia was still a part of Gondwanaland, connected along its southern margin to what is now Antarctica. Rifting and seafloor spreading caused the splitting away of Australia and its last connection with Antarctica, at the southern edge of Tasmania, was severed about 50 million years ago. Australia moved northward until 10 to 15 million years ago when the northern margin collided with the Pacific Plate causing tectonic uplift, volcanic activity and eventually the creation of Papua New Guinea. Today, Australia is bounded by three oceans (Pacific, Indian and Southern) and four marginal seas (the Timor, Arafura, Coral, and Tasman Seas; Fig. 1).

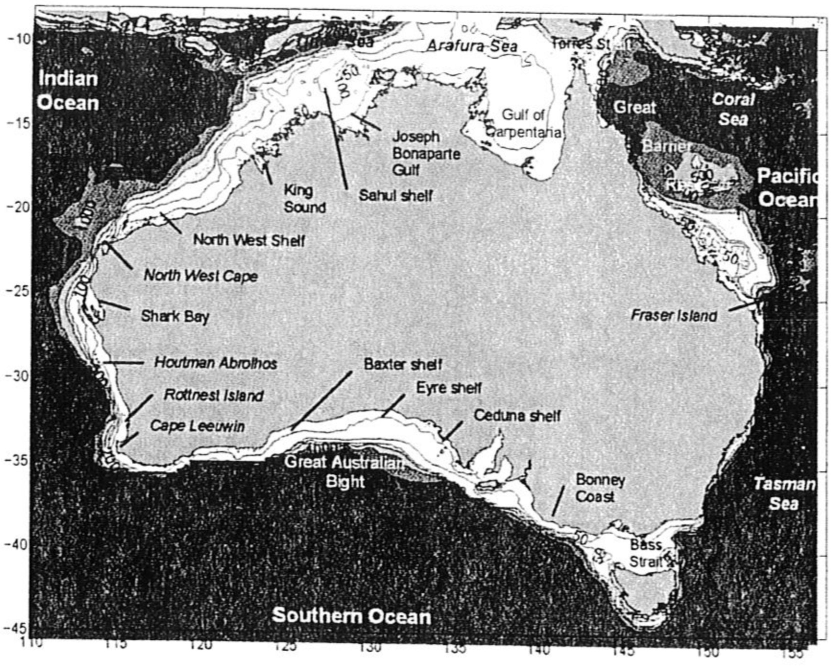

Figure 35.1 Bathymetry and location map for the Australian continent.

Australia's continental shelf is highly variable in terms of its width, depth and profile. The shelf break is located about 10km offshore from Fraser Island and North West Cape, but the Arafura Shelf is over 500km wide. In vertical profile, most of Australia's shelf is a relatively smooth and dips gently seawards (Fig. 1). In contrast, some parts are rimmed by shelf edge barrier reef systems, such as the Great Barrier Reef. During Pleistocene periods of lower relative sea level, the shelf was exposed and the Australian mainland was joined to several of the adjacent large islands such as Tasmania and Papua New Guinea. Such "land bridges" are considered to have facilitated the migration of animals and humans in the late Pleistocene ice age. The shallow seas comprising Bass Strait, the Sahul Shelf, Gulf of Carpentaria and Torres Strait were thus subjected to erosion and sedimentation by rivers and wind on several occasions during the past 150,000 years. Basins perched on the continental shelf in Bass Strait, the Gulf of Carpentaria and Bonaparte Gulf are considered to have been the sites of large fresh to brackish water lakes and lagoons during these periods of emergence (Blom and Alsop, 1988; Jones and Torgersen, 1988; Chivas et al., 2001).

2.2 *Sedimentological Environment*

As on all continental shelves, the nature and distribution of sediments around Australia is determined by a range of past and contemporary influences, including climate and sea level change, past and present shelf energy regimes, sediment supply, morphology, biology and chemistry. These factors are often interconnected in terms of their effect on shelf sediments, and significant effort has been directed towards understanding different processes and their sedimentological expression.

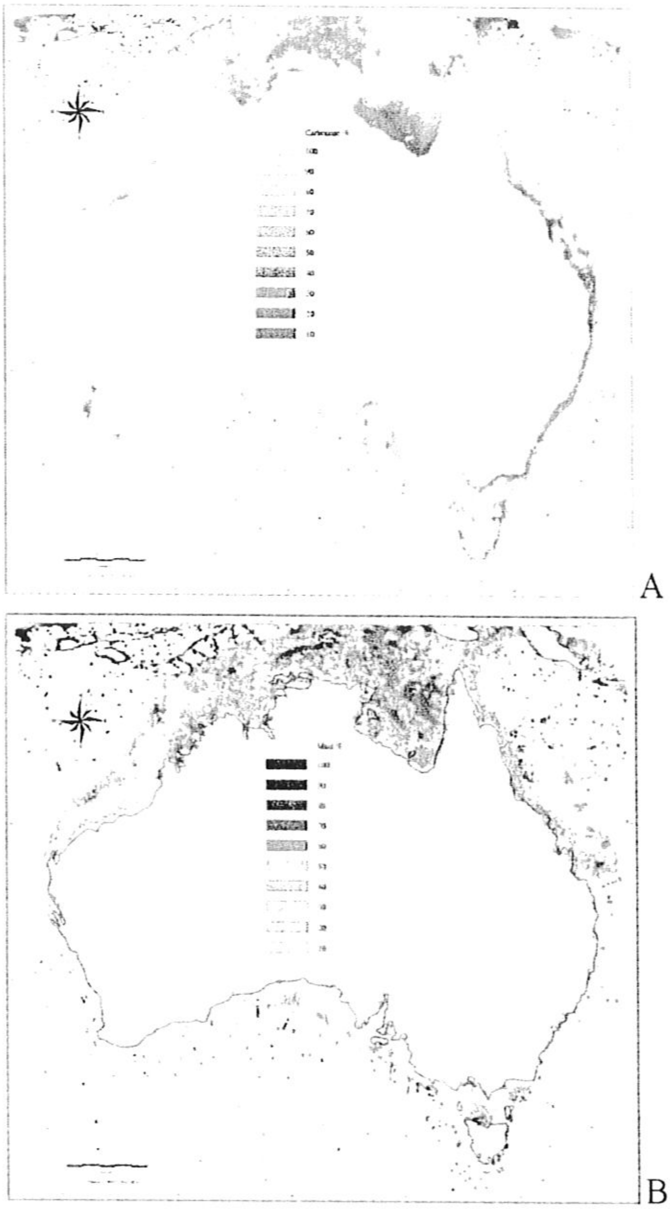

Figure 35.2 Maps of (A) calcium carbonate content and (B) mud content for surficial sediments on the Australian continental shelf (water depth less than 500m), based on data extracted from the AUSEABED database (Jenkins, 1997).

One of the most important parameters characterizing shelf surficial sediment composition and type is the percentage of calcium carbonate content. Australia is distinguished from other continents by comparatively high carbonate content over most of its shelf, exceeding 80% over large parts of the southwest, west and northwest (Fig. 2). These distributions are largely explained by the small riverine sediment loads around most of the continent, supplying less than 150 million tonnes per annum to the entire coastline. Significant regions of non-carbonate sediments of terrigenous origin are only found in the southern Gulf of Carpentaria (Jones 1987), southern Great Barrier Reef (Maxwell, 1968), and southeastern Australian inner shelf.

Another key parameter characterizing shelf sediments is the mud content. On the Australian shelf, enhanced mud content can be attributed to fluvial inputs in a few regions, such the northern Great Barrier Reef (Belperio and Searle, 1988) and eastern Australia (Short, 1979). However, significant mud content is found more commonly in the tide-dominated regions of the north (Jones, 1987), southern Great Barrier Reef (Maxwell, 1968), and Bass Strait (Fig. 2). It has been proposed that continuous reworking of soft calcareous sediment by tidal currents causes grains to fracture and gradually disintegrate, thus generating silt-sized carbonate detritus (Harris, 1994). In this way, carbonate mud is generated and deposited on tide-dominated parts of the shelf, whilst the mean carbonate content of the shelf deposits remains relatively constant (Fig. 2). The lower mud content associated with wave-dominated regions can be attributed to the lower energy available to transport carbonate sand as bedload and the winnowing of fine particles and their export to deeper waters.

2.3 *Physical Environment*

The Australian continent spans a number of climatic zones, ranging from wet tropics in the northeast and dry tropics in the northwest to temperate conditions in the south. The large-scale wind patterns show significant seasonal variability (Fig. 3). They are influenced by the tropical monsoon in the north, where persistent southeasterly trade winds are replaced by northwesterlies during summer. The trade winds extend over the subtropics and are then replaced by the westerly Roaring Forties, which reach southern Australia during winter and spring.

Oceanic temperatures, salinities, and current patterns also exhibit strong seasonality and major contrasts between tropical and temperate systems (see review by Church and Craig, 1998; Ridgway et al., 2002). Currents throughout the shallow tropical shelf seas from North West Cape to the southern Great Barrier Reef on the east coast are dominated by mainly semidiurnal tidal flows. The peak tidal range occurs at King Sound (>10 m), with strong tidal currents also common at bathymetric constrictions such as Torres Strait and parts of the Great Barrier Reef. An M_2 amphidrome off the southwest of the continent results in diurnal tides locally, with semidiurnal and mixed tides in other subtropical and temperate regions. With the exception of semi-enclosed regions, such as Bass Strait and the South Australian Gulfs, tidal elevations and currents are relatively small compared to those in the tropical regions.

Wind-driven circulation is significant over much of shelf and is known to generate coastal-trapped ways around much of the coastline (e.g., Church et al., 1986). With the possible exception of southwestern Australia, significant wind-driven upwelling events tend to be infrequent and localized (Schahinger, 1987; Gersbach et al., 1999; Pearce and Pattiaratchi, 1999). On the other hand, stronger winds (Fig. 3) and surface cooling during the winter months often results in complete vertical mixing of shallow seas such as the Gulf of Carpentaria and Bass Strait.

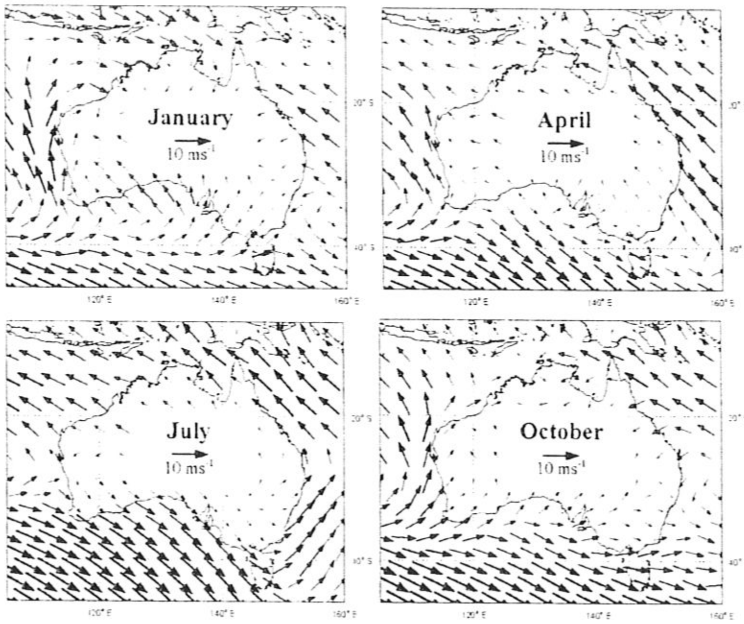

Figure 35.3 Large-scale seasonal wind patterns illustrated using wind vectors at 10 m from the NCEP-NCAR Reanalysis product (Kalnay et al.1996).

Regional current systems have a major impact on Australia's shelf and slope seas, particularly off the east and west coast (Fig. 4). The major western boundary current in the South Pacific is the East Australian Current. This system is fed from the east by a complex pattern of flows forming the South Equatorial Current (Ridgway, 2003), which split into northward and southward branches following the continental slope offshore of the Great Barrier Reef (Brinkman et al., 2001). To the south, the East Australian Current develops as a series of intense anticyclonic eddies, carrying warm low-nutrient water southward (Figs. 5 and 6). It usually separates from the upper slope at around 33°S to form the southern boundary of the South Pacific subtropical gyre. East Australian Current eddies extend down the east coast of Tasmania during summer, but retreat to the north as the system weakens during winter (Fig. 4). Variability in the East Australian Current is believed to be closely related to upwelling events observed along the east coast.

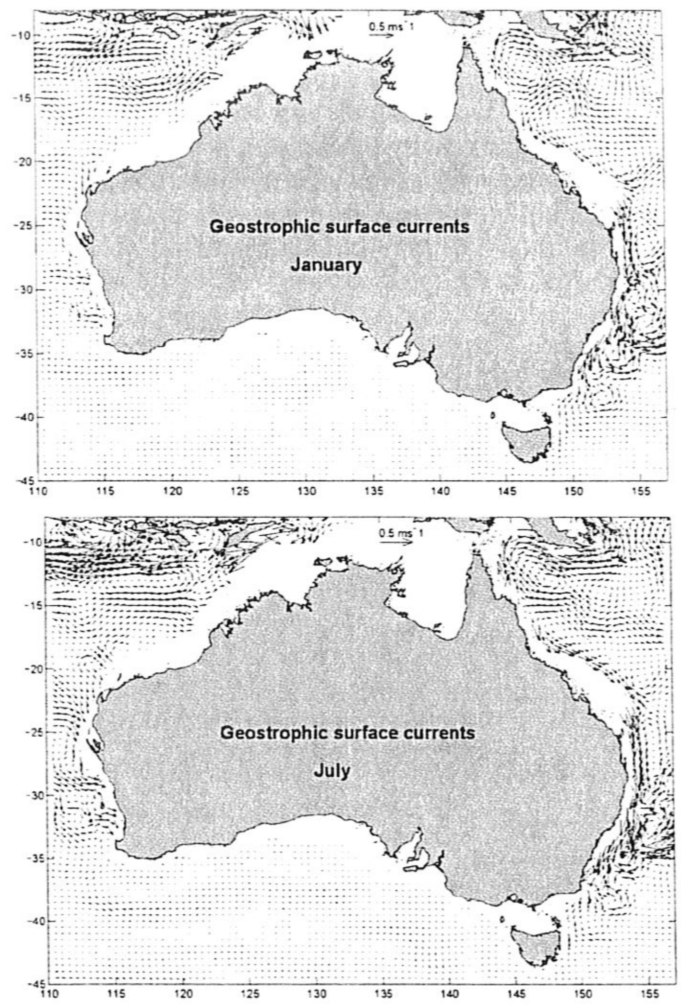

Figure 35.4 Geostrophic surface currents for summer (January – upper) and winter (July – lower) relative to a reference depth of 2000 m. These estimates were made from dynamics height fields based on the CSIRO Atlas of Region Seas (CARS) temperature and salinity fields (Fig. 5) for waters deeper than 200 m.

On the west coast, the poleward flowing Leeuwin Current intensifies along the upper continental slope (Fig. 4) and carries warm, low-salinity water southward (Fig. 5; Godfrey and Ridgway, 1985). It opposes the prevailing southerly winds (Fig. 3) and effectively prevents the formation of a major upwelling system like those observed off the west coasts of other continents. The system is weak during summer, allowing northward flow to develop over the shelf including localized upwelling associated with the Capes Current in the south (Pearce and Pattiaratchi, 1999). The Leeuwin Current then develops rapidly in autumn (Fig. 4), eventually wrapping around the southwest corner of the continent and continuing eastward across the Great Australian Bight to form what is arguably the longest continual coastal current in the world (Ridgway and Condie, 2004).

Another major current system coincides with the Subtropical Front, south of Australia (e.g. Rintoul and Trull, 2001). This feature separates the high nutrient waters of the Subantarctic Zone from more depleted subtropical waters (Fig. 6). It is also evident in the mixed layer depth distribution, but tends to be smeared out in the seasonal temperature and salinity fields due to variability in the location of the frontal zone (Fig. 5). During most of the year the Subtropical Front is south of the Australian continent, but tends to encroach onto the Tasmanian continental slope during the winter months.

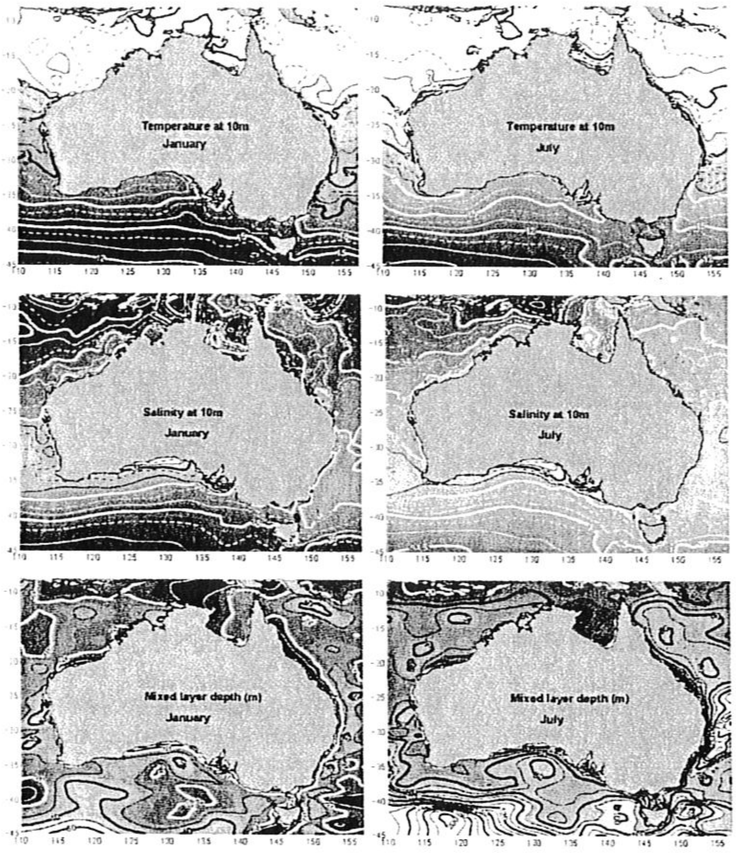

Figure 35.5 Temperature in °C (upper) and salinity in PSU (middle) at a depth of 10 m from the CSIRO Atlas of Regional Seas (CARS, Dunn and Ridgway 2002, Ridgway and Dunn 2002), and an associated estimate of mixed layer depth in metres (lower, Condie and Dunn 2004). Fields are for summer (January – left) and winter (July – right). The base of the mixed layer is defined as the depth where the temperature falls more than 0.04° below the value at 10 m depth or the salinity rises more than 0.03 PSU above the value at 10 m depth.

2.4 *Chemical Environment*

Australia's shelf seas tend to be strongly oligotrophic (Rochford, 1984; Condie and Dunn, 2004). Relatively arid conditions across most of the continent restrict the input of nutrients from riverine sources. As in most tropical systems, nutrients in the surface waters around northern Australia are rapidly consumed and recycled, so that the only significant replenishment is from below the mixed layer. In subtropical waters, both the East Australian Current and Leeuwin Current tend to envelope the continent in low nutrient subtropical water (nitrate < 0.5 μM, Fig. 6). The influence of these systems is seasonal in the southeast, where nitrate and phosphate are moderately enhanced during winter by the withdrawal of the East Australian Current and northward migration of the Subtropical Front (Rochford, 1984).

Figure 35.6 Nitrate (upper), phosphate (middle), and silicate (lower) at a depth of 10 m from the CSIRO Atlas of Regional Seas (CARS, Condie and Dunn 2004). Fields are for summer (January – left) and winter (July – right) and are in micromolar units (μM).

Wind-driven upwelling events around Australia, such as occur on the Bonney Coast and Cape Leeuwin areas, tend to be infrequent and localized (Lewis, 1981). Any enhancement in nutrient levels is therefore short-lived and often restricted to subsurface waters, leaving little evidence of upwelling activities in the seasonal fields (Figs. 5 and 6). However, wintertime mixing associated with stronger winds (Fig. 3) and surface cooling in shallow seas, such as the Gulf of Carpentaria and Bass Strait, tend to produce a longer-term enhancement in near-surface nutrient levels (Gibbs et al., 1986).

While eutrophication and other significant chemical contamination have been documented in a number of estuaries and embayments around Australia, there is little evidence of major impacts on the continental shelf. Areas of potential concern include oil, produced formation water, and drilling fluids from oil and gas production on the North West Shelf (Furnas and Mitchell, 1999; Holdway and Heggie, 2000), deep-water sewage outfalls off Sydney (Gray, 1996b; Middleton et al, 1997), and the exposure of the Great Barrier Reef Lagoon to riverine inputs of nutrients and contaminants such as organochlorine compounds, hydrocarbons, and heavy metals (Haynes and Johnson, 2000; Haynes and Michalek-Wagner, 2000).

2.5 *Biological Characteristics*

Information on biological characteristics tends to be concentrated in localized regions with particular conservation or fisheries significance. In the past, significant effort was directed at national collations of species level phytoplankton information (Jeffrey and Hallegraeff, 1990) and zooplankton biomasses (Tranter, 1962). However, more recently collected data, including species distributions, biomass and productivity measurements, and satellite ocean-color data, are still to be incorporated into these descriptions. Other biological distributions have been summarized at various spatial scales in terms of bioregionalisations, which were derived using a diverse range of data inputs and expert opinion.

The phytoplankton biogeography around Australia was described by Jeffrey and Hallegraeff (1990). While nanoplankton species (2–20 μm) are remarkably similar around the continent, significant regional differences are evident in diatom and dinoflagellate communities (30–100 μm) (Fig. 7). Australia's tropical shelf seas contain diatoms, dinoflagellates, and cyanobacteria (*trichodesmium*), but with a high proportion of nanoplankton (70–95% of total chlorophyll). The west and southwest coast and much of the east coast include diatoms, cyanobacteria, and a great diversity of dinoflagellates. Cell concentrations are particularly low off the northeast (Coral Sea), where nanoplankton and picoplankton form a high percentage of total chlorophyll (70–95%). The southeastern region around Tasmania includes a wide variety of diatoms and dinoflagellates, with nanoplankton contributing 50–80% of chlorophyll, except during diatom blooms when this range falls to 10–40%. During summer the southeastern plankton community contracts to the south along the NSW coast to be replaced by Coral Sea species carried by the East Australia Current. Detailed species level information for the three regions can be found in Jeffrey and Hallegraeff (1990) and the earlier compilations of Wood (1954), Crosby and Wood (1958), and Revelante et al. (1982).

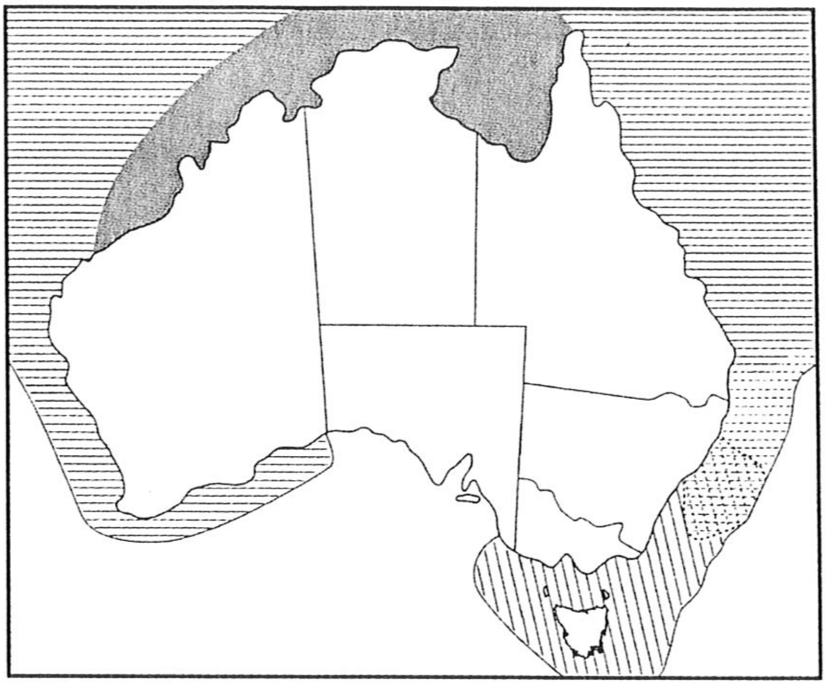

Figure 35.7 Regionalisation based on phytoplankton community distributions around the Australian continent (adapted from Jeffrey and Hallegraeff 1990). The three distinct communities reside in the tropical northern Australian shelf seas including part of the North West Shelf (solid grey); the Eastern Indian Ocean and Coral Sea regions (horizontal hatching); and the southeast (diagonal hatching). During summer the southeastern community contracts to the south to be replaced by Coral Sea species (indicated by dashed lines).

Attempts to calibrate satellite ocean-color in Australia's shelf waters have only commenced recently and reliable algorithms are not yet available. This is particularly problematic in the turbid waters off northern Australia, where large suspended sediment concentrations introduce a significant non-biological contribution to the ocean color signal. Under these circumstances the absolute chlorophyll levels are not always reliable, although the temporal and spatial trends are still informative. Seasonal chlorophyll estimates over the shelf typically fall within the range of 0.3 to 0.9 mg m^{-3}, with peak values usually occurring in the cooler months (Fig. 8). For example, the afore' mentioned wintertime mixing and entrainment of nutrients in the Gulf of Carpentaria and Bass Strait, correspond to almost a doubling in estimated chlorophyll levels according to both ocean color and in situ estimates (Fig. 8 and Table 1). The main exception to winter chlorophyll enhancement is around southern Tasmania, where shallow summer mixed layers (~ 30 m, Fig. 5) and moderately enhanced nutrient levels (nitrate ~ 1 μM, Fig. 6) appear to support quite high chlorophyll concentrations extending offshore to the east (> 0.5 mg m^{-3}, Fig. 8). While localized upwelling events are clearly visible on individual ocean-color images, they have little impact on the seasonal fields due to their intermittent nature. Measurements of primary production are extremely sparse around the Australian shelf, but published rates range up to 3 g C m^{-2} d^{-1} in both tropical and temperate waters (Table 1).

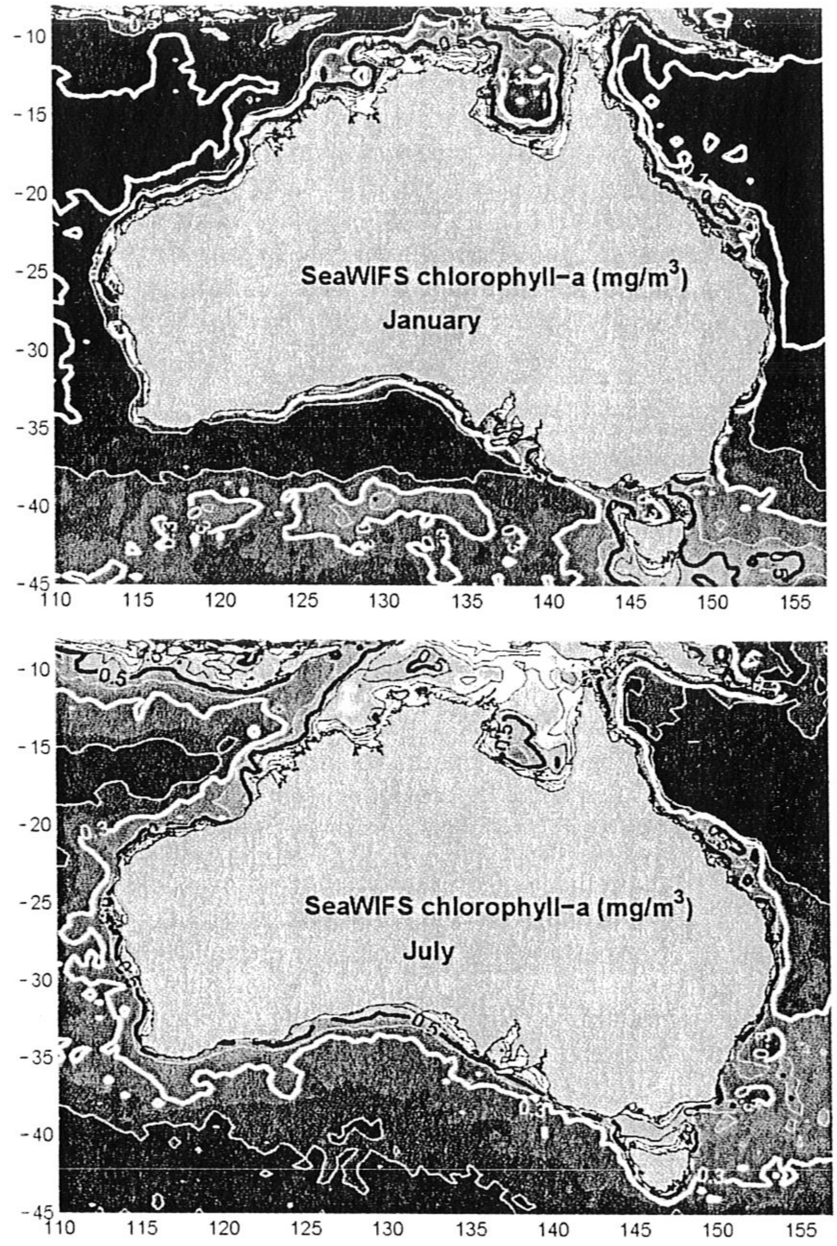

Figure 35.8 Surface chlorophyll concentration (mg m^{-3}) for summer (January – upper) and winter (July – lower) based on SeaWiFS data. These fields are seasonal composites derived using the spatial and temporal mapping methods adopted for the CSIRO Atlas of Region Seas (CARS).

TABLE 1

Estimated chlorophyll concentration and light saturated primary production of phytoplankton in Australian shelf waters. This is an updated version of a table presented by Jeffrey and Hallegraeff (1990), but restricted to shelf waters.

Area	Chlorophyll (mg m^{-3})	Productivity (g C m^{-2} d^{-1})	Season	Reference
Central Great Barrier Reef	0.3 – 1.0	0.55 ± 0.23	Summer	Furnas and Mitchell 1987
(mid-shelf)	0.2 – 0.5	0.39 ± 0.18	Winter	Furnas and Mitchell 1987
Central Great Barrier Reef	0.2 – 0.5	0.41 ± 0.17	Summer	Furnas and Mitchell 1987
(shelf-break)	0.3 – 0.5	0.39 ± 0.25	Winter	Furnas and Mitchell 1987
Bass Strait and Tasmanian east coast	1.5 – 2.4	1.3 – 2.9	Spring	Harris et al. 1987
Tasmanian west coast		0.3 – 0.5	Winter	Harris et al. 1987
Great Australian Bight	0.1 – 0.4	0.44	Summer	Motoda et al. 1978
Exmouth Gulf	0.2 – 0.4	0.15 – 0.25	Spring	Ayukai and Miller 1998
North West Shelf (Barrow-Monte Bello Is.)	0.25 – 0.26	0.45 – 2.5	Spring	Furnas and Mitchell 1999
Gulf of Carpentaria -	1 – 2	1.43 ± 0.40	Summer	Rothlisberg et al. 1994
coastal	0.29 ± 0.02	0.95 ± 0.32	Summer	Burford and Rothlisberg 1999
	0.24 ± 0.03	0.75 ± 0.38	Winter	Burford and Rothlisberg 1999
Gulf of Carpentaria -	0.1– 1.6	3.2	Summer	Motoda et al. 1978
central	0.1– 0.2	0.66 ± 0.11	Summer	Rothlisberg et al. 1994
	0.34 ± 0.02	0.96 ± 0.13	Summer	Burford and Rothlisberg 1999
	0.66 ± 0.03	0.56 ± 0.35	Winter	Burford and Rothlisberg 1999

Information on secondary production of zooplankton and higher trophic levels is extremely patchy over the Australian shelf. Tranter (1962) collated zooplankton data from around Australia and reported that biomass levels on the shelf varied from 82 to 213 mg m^{-3} with an average of around 100 mg m^{-3}, which is relatively low compared to many other parts of the world. While significant quantities of new data have been gathered within the intervening 40 years, there has been surprisingly little progress in updating Tranter's analysis or expanding its scope to include more species level information.

Higher trophic levels have been studied mainly in a fisheries context. The most extensive datasets have been collected for the large multi-species fishery operating in southeastern Australia, where dietary data from commercial species has allowed food-webs to be constructed and trophic exchanges to be quantified (Young et al., 1997; Bulman et al., 2001). The focus for seabed habitat studies has followed similar trends, motivated largely by concerns about the impacts of trawling (e.g., Bax et al., 1999; Bax and Williams, 2001). However, substantial effort has also been devoted to maximizing the use of limited habitat data so as to develop preliminary characterizations of the distributions of ecosystems in Australian waters at a range of spatial scales (Fig. 9, Interim Marine and Coastal Regionalisation for Australia Technical Group, 1998; The Marine Science and Technology Plan Working Group, 1999).

TABLE 2:

Studies categorized according to province and dynamical process.

	Great Barrier Reef	East Coast	Southeast Coast	South-west & Great Australian Bight	West Coast	North West Shelf	Northern Australian Seas
Transport of nutrients and sediments from nearshore	Birkeland 1982, Alongi 1990, Mitchell et al. 1997, Larcombe & Woolfe 1999, Orpin et al. 1999, Lambeck & Woolfe 2000, Woolfe et al. 2000, Cappo & Kelly 2001, Lourey et al. 2001, Brunskill et al. 2002, Neil et al. 2002						Wolanski et al. 1999, Hemer et al. 2003
Transport of nutrients from offshore	Wolanski et al. 1988, Furnas and Mitchell 1996	Newell 1966		Lewis 1981, Schahinger 1987		Holloway et al. 1985	Harris 1989, 1991
Primary productivity and plankton blooms	Revelante et al. 1982, Revelante & Gilmartin 1982, Furnas and Mitchell 1986, Furnas and Mitchell 1987	Tranter et al. 1986, Hallegraeff & Reid 1986, Hallegraeff & Jeffrey 1993, Gibbs 2000	Harris et al. 1987, Clementson et al. 1989, Gibbs et al. 1986, 1991, Bax et al. 2001	Motoda et al. 1978	Kimmerer et al. 1985	Tranter & Leech 1987, Ayukai & Miller 1998, Furnas & Mitchell 1999	Motoda et al. 1978, Rothlisberg et al. 1994, Burford et al. 1995, Burford & Rothlisberg 1999
Larval transport and recruitment	Alldredge & Hamner 1980, Doherty et al. 1985, Sammarco & Andrews 1988, 1989, Doherty et al. 1988, Dight et al. 1990a,b, James et al. 1990, Black et al. 1991, Keesing & Halford 1992, James & Scandol 1992, Scandol and James 1992, Brodie 1992, Oliver et al. 1992, Black et al. 1995, Jones et al. 1999	Rothlisberg et al. 1995, Gray 1996, Smith 2000	Harris et al. 1988, Gunn et al. 1989, Bruce et al. 2001a,b,c	Fletcher et al. 1994, Maxwell & Cresswell 1981	Simpson 1991, Caputi & Brown 1993, Hutchins & Pearce 1994, Caputi et al. 1996, Lenanton et al. 1996, Caputi et al. 2001, Griffin et al. 2001	Condie et al. 2003	Rothlisberg et al. 1983, Rothlisberg et al. 1996, Condie et al. 1999

TABLE 2 (*continued*)

Biophysical distributions	Williams & Hatcher 1983, Doherty 1987, Done 1992, Moltschaniwskyj & Doherty 1995, Newman et al. 1997.	Gray 1996a, Dempster et al. 1997, Smith et al. 1999, Smith & Suthers 1999, Gray & Miskiewicz 2000, Smith 2000, Young et al. 2001	Harris et al. 1988, Jordan et al. 1995, Bax & Williams 2001, Williams and Bax 2001	Bone & James 1996, Griffin et al. 1997, Li & McGowran 1998, James et al. 2001	Collins et al. 1996, James et al. 1999	McLoughlin & Young 1985, Penn & Caputi 1986, Wilson et al. 2003	Somers 1987, 1994, Wolanski & Ridd 1990

3. Regional and National Interdisciplinary Studies

The Large Marine Ecosystems (LMEs, Fig. 9) represent major marine provinces based on physical characteristics, such as the geomorphology, sediment distributions, and physical and chemical oceanography (as described above), with further refinements based on selected biological data such as fish distributions (The Marine Science and Technology Plan Working Group, 1999). Studies with a significant focus on interactions between the physical, chemical, biological, or sedimentological components of the Australian shelf system will now be described by considering each of these provinces in turn. An attempt has also been made in Table 2 to categorize these studies in terms of the dynamical processes under investigation.

3.1 Great Barrier Reef

The Great Barrier Reef system is made up of almost 3000 individual coral reefs extending 2600 km along Australia's east coast from the Tropic of Capricorn in the south to the coast of Papua New Guinea in the north (Fig. 9). The region is exposed to southeast trade winds throughout most of the year and there is a relatively high incidence of tropical cyclones impacting the reefs (Done, 1992). The reefs cover about 5% of the shelf, while the remainder is characterised by inter-reef sediments, ranging from nearshore terrigenous material to outer shelf carbonate facies (Woolfe et al., 2000). This offshore zonation is also reflected in the long-term carbon burial rates, which consist almost entirely of organic carbon on the inner shelf and carbonate on the mid- and outer-shelf (Brunskill et al., 2002). It also appears to have a marked influence the distributions of various fish communities (Williams and Hatcher, 1983; Doherty, 1987; Moltschaniwskyj and Doherty, 1995; Newman et al., 1997).

Riverine inputs of terrigenous sediment are supplied to the Great Barrier Reef shelf at an annual rate of about 10 tonnes per metre of coastline (Belperio and Searle, 1988). They have high mud content, which is reflected in the nearshore facies (Fig. 2). One exception is the southern Capricorn Channel, where tidal current processes contribute to the production of carbonate mud as described previously (Harris, 1994). High carbonate facies are restricted to areas of reef growth and adjoining areas where reef derived sediments are dispersed by waves and currents. In the high tidal energy zone of the southern Great Barrier Reef, the area of carbonate dispersal is up to 20km distant from the nearest reef, whereas further north it rarely extends more than 2km beyond reef margins (Maxwell, 1968).

There is significant potential for riverine inputs of terrigenous sediment, carbon, nutrients, and other contaminants to impact biota within the Great Barrier Reef lagoon (Isdale, 1984; Haynes and Johnson, 2000; Wolanski, 2001; Cappo and Kelley, 2001; Suzuki et al., 2001). While sediment loads have been increased approximately four-fold by changes in land use (Neil et al., 2002), the impact on coral communities located over the mid- and outer-shelf is still unclear. For example, Larcombe and Woolfe (1999) argue that sediment accumulation and turbidity are limited by wave and current dynamics rather than sediment supply. Sediments, resuspended mainly by wave action on the inner-shelf, migrate northward with the wind-driven currents and may be carried offshore in the lower water column by downwelling flows (Orpin et al., 1999; Lambeck and Woolfe, 2000).

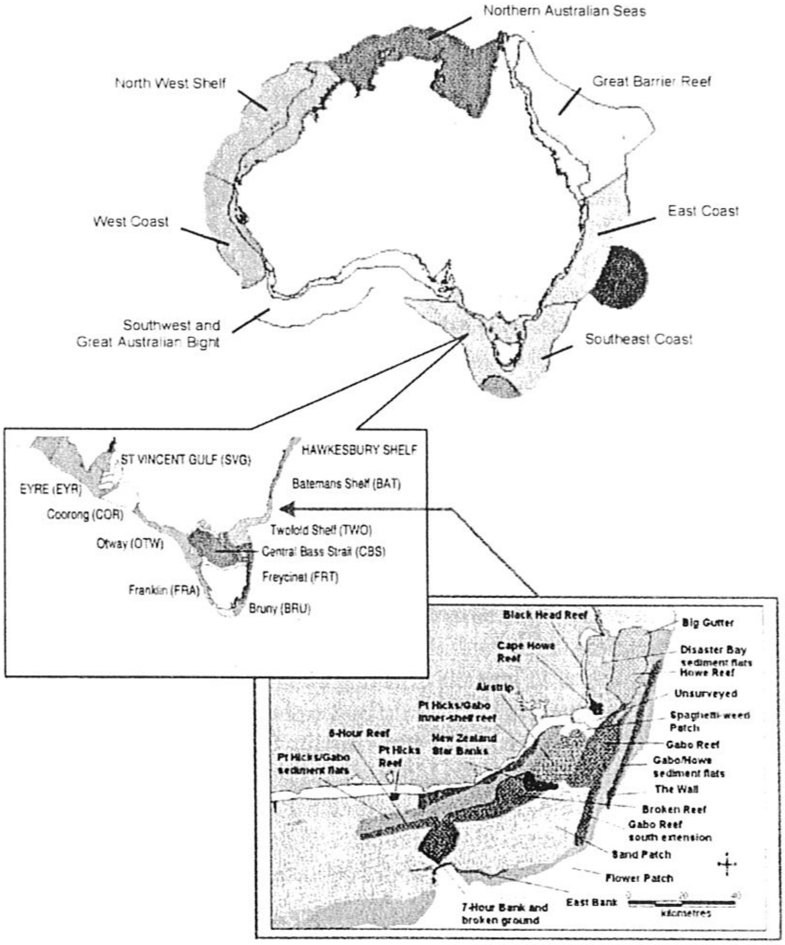

Figure 35.9 A Large Marine Ecosystem (LME) regionalisation for the seas surrounding the Australian continent (upper, The Marine Science and Technology Plan Working Group 1999); the southeast sector of a meso-scale regionalisation referred to as the Interim Marine and Coastal Regionalisation of Australia (IMCRA) for the continental shelf (center left, Interim Marine and Coastal Regionalisation for Australia Technical Group 1998); and a still smaller scale mapping of seabed habitats over part of the south-eastern continental shelf (lower right, adapted from Bax and Williams 2001).

Riverine nutrient inputs are highly variable with strong peaks during floods induced by tropical cyclones (Birkeland, 1982; Mitchell et al., 1997; Cappo and Kelley, 2001). Significant inputs have also been associated with tidal exchange of detritus from coastal mangroves (Alongi, 1990) and regeneration in bottom sediments (Lourey et al., 2001). However, riverine inputs are largely responsible for the seasonality in phytoplankton, particularly the inner-shelf diatom community, which peaks during periods of high rainfall (Revelante et al., 1982; Revelante and Gilmartin, 1982). Nutrient supply to the outer reef from offshore has been documented through summer upwelling events (Furnas and Mitchell, 1986; 1996) and exchanges associated with internal tides (Thompson and Golding, 1981). Wolanski et al. (1988) estimated that the tidal mechanism could easily provide the entire nitrogen requirements of the *Halimeda* banks found inside the outer ribbon reef. However, the waters are much more oligotrophic than those on the inner-shelf, so that dinoflagellates appear to out compete diatoms for available nutrients (Revelante et al., 1982) and when upwelling is absent nanoplankton and picoplankton form most of the biomass (Furnas and Mitchell, 1986). Consequently, total phytoplankton productivity is relatively low and there is little evidence of a regular seasonal cycle (Furnas and Mitchell, 1987; Table 1).

There have been a large number of larval transport studies in the Great Barrier Reef region, applied to recruitment of coral larvae and coral fish larvae, and aggregations of other zooplankton (Doherty et al., 1985; Doherty and Williams, 1988; Williams and English, 1992). These have focused on either retention of larvae around individual reefs (Jones et al., 1999; Carleton et al., 2001), or inter-reef exchange (Dight et al., 1990a,b). Retention or aggregation of larvae adjacent to reefs and coastal features have been associated in this region with physical features such as wake eddies (Alldredge and Hamner, 1980; Sammarco and Andrews, 1988; 1989), tidal fronts, and Langmuir cells (Kingsford, 1990; Kingsford et al., 1991). Even with very modest vertical migratory behavior, larvae can be trapped in small-scale features for extended periods. This may increase food availability and increase the chance of recruitment back to the spawning reef. However, the small length scales of these features and patchiness of larval distributions provides a major challenge for dispersion models (Black et al., 1991; Oliver et al., 1992).

Outbreaks of the coral-eating crown-of-thorns starfish (*Acanthaster planci*) have had major ecological impacts on the Great Barrier Reef, with recovery time-scales of 20 years or more (Johnson, 1992). Understanding of the outbreaks has focused on the chain of reproduction, dispersal, and recruitment. While elevated nutrient levels may enhance larvae survival (Birkland, 1982; Brodie, 1992), physical factors appear to be more important (Keesing and Halford, 1992) with outbreaks favored by weak residual currents and high local retention of larvae (Black et al., 1995). Models of circulation and larval dispersion suggest that once initiated, outbreaks propagate as a wave of secondary outbreaks (Dight et al., 1990a,b; James and Scandol, 1992; Scandol and James, 1992). The spatial extent of the outbreak is restricted by larval behavior and the time-scales over which they are competent to settle (Johnson, 1992).

3.2 *East Coast*

The east coast province extends from south of the Great Barrier Reef to the southeastern corner of mainland Australia (Fig. 9). The shelf is relatively narrow (< 50 km) and sediments range from clean quartzose sand with low carbonate and mud contents on the inner shelf, to calcareous gravelly sands with high carbonate content on the outer shelf (Short, 1979; Jones and Davies, 1979; Fig. 2). The carbonate material is derived from bryozoans and red algae occurring as rhodoliths off Fraser Island and commonly form cemented hardgrounds (Harris et al., 1994).

The presence of shallow water fossil species is also suggestive of a relict origin (e.g. Roy and Thom, 1981).

The east coast is the strip of shelf most strongly influenced by the East Australian Current and its energetic eddy field. Newell (1966) was the first to propose that nutrient enrichment observed in this area is caused by upwelling of slope water, and subsequent studies have identified a range of current, wind, and topographic interactions that may drive the upwelling (Boland, 1979; Tranter et al., 1986; McClean-Padman and Padman, 1991; Condie, 1995; Gibbs et al., 1997, 1998, 2000; Marchesiello et al., 2000; Oke and Middleton, 2000, 2001). These flows also influence the transport of primary treated sewage plumes from offshore outfalls near Sydney. Salinity fronts associated with these plumes appear to attract large numbers of juvenile fish, although any consequences for contamination of the local food web are still unclear (Gray, 1996b; Middleton et al., 1997).

Results from a long-term monitoring station off Sydney (100 m isobath) have identified variability in the plankton community associated with the East Australian Current (Hallegraeff and Reid, 1986), as well as short-term succession of diatoms and dinoflagellates in spring and summer (Grant and Kerr, 1970), and more persistent groups such as the nanoplankton (Hallegraeff, 1981). Subsequent observations confirm that the phytoplankton response extends over most of the east coast region (Tranter et al., 1986; Hallegraeff and Jeffrey, 1993; Gibbs, 2000) and pelagic species such as yellowfin tuna appear to aggregate in response (Young et al., 2001). While the modeling studies mentioned above have successfully simulated a number of physical upwelling events, plankton responses and other biogeochemical processes are yet to be explicitly represented in these models.

The cross-shelf circulation on the east coast appears to have a significant influence on the vertical distribution of larval fish. One consequence is that there is no simple correlation between species distributions and water masses (Miskiewicz et al., 1996; Dempster et al., 1997; Gray and Miskiewicz, 2000). However, consideration of offshore transport during upwelling favorable winds has allowed larval distributions to be tracked over timescales of days to weeks (Smith et al., 1999; Smith and Suthers, 1999; Smith, 2000). For other species living in such a dynamic environment, larval behavior may be the dominant influence (Gray, 1996a,b). For example, the vertical migratory behavior of prawn larvae has been shown to assist recruitment to east coast estuaries through tidal advection processes (Rothlisberg et al., 1995).

3.3 Southeast Coast

The southeast coast region encompasses all the waters surrounding the island of Tasmania, including Bass Strait (Fig. 9). The area covers a temperate, carbonate-shelf environment, where the lack of large rivers results in a characteristically low level of terrigenous material being deposited (Rao, 1986; Blom and Alsop, 1988; Lavering, 1994; Harris, 1994). Sediments are reworked and dispersed by tidal and ocean currents and storm waves, with sediment grain sizes and composition often being closely related to the controlling physical processes (Malikides et al., 1988, 1989; Harris, 1994). Fine sediments (muds and silty sands) occur only in pockets along the east coast of Tasmania and in the central Bass Strait where carbonate content is also very high (Fig. 2). A notable plume of terrigenous (low-carbonate) sediments, located off the west coast of Tasmania, probably reflects the influx of fluvial sediments from Macquarie Harbour.

Winter cooling of the shallow waters of Bass Strait generates a strong frontal region where they meet the warmer waters of the Tasman Sea. This feature feeds into the Bass Strait Cascade, which carries nutrient rich water north along the mainland east coast and supports enhanced phytoplankton and zooplankton levels (Gibbs et al., 1986, 1991; Bax et al., 2001). Further south, the Tasmanian shelf is influenced by the Subtropical Front separating the low nutrient subtropical waters of the East Australian Current from more productive subantarctic waters. Long-term monitoring off eastern Tasmania (~ 40 years) reveals high interannual variability in the timing and duration of the spring phytoplankton bloom (Harris et al., 1987; Clementson et al., 1989, Table 1). This variability is driven by a combination of seasonal and episodic events related to ENSO and the location of the westerly wind belt, which influence environmental factors such as the positioning of East Australian Current eddies and local mixed layer depths. It also appears to have a significant influence on spawning times and recruitment levels in local fisheries (Harris et al., 1988; Jordan et al., 1995).

The shelf-break current system known as the Zeehan Current travels anti-clockwise around western and southern Tasmania (Baines et al., 1983). Studies using aged larval data suggest that the recruitment of finfish spawning over the Tasmanian slope may be strongly influenced by advection patterns within this system (Gunn et al., 1989; Bruce et al., 2001b,c). This conclusion has been further supported by recent modeling of dispersion patterns in the southeast region suggesting that larvae sampled off the southeast mainland were spawned off eastern Bass Strait slope, rather than the known spawning grounds off the west coast of Tasmania (Bruce et al. 2001a).

3.4 *The Southwest and Great Australian Bight*

This region extends from the southwest corner of mainland Australia eastward across the Great Australian Bight to the gulfs of South Australia. It comprises the largest cool-water carbonate province in the modern world (James et al., 2001). The facies are characterised by abundant bryozoans and are contrasted from tropical carbonates by the lack of corals and Halimeda (Bone and James, 1993). In the Great Australian Bight biogenic sediment production is balanced by surface-wave erosion processes to yield zero net sedimentation (James et al., 1994). Sediments found in less than 100 m water-depth contain mainly coarse-grained sand and gravel consistent with wave reworking and slow accumulation rates (James et al., 2001). Sediment facies exhibit contrasts in upwelling, downwelling and sedimentation patterns between the central Bight (Eyre shelf) and adjacent shelves to the west (Baxter shelf) and east (Ceduna shelf), where periodic upwelling occurs (James et al., 2001). These gradations are also reflected in the distributions of planktonic foraminifera (Li and McGowran, 1998). The inner Baxter shelf experiences warm (22°C) oceanic conditions due to the southern arm of the Leeuwin Current, which supports luxuriant algal growth and the deposition of abundant rhodoliths, while sediments on the middle shelf and upper slope are dominated by molluscs and bryozoans.

Seasonal variations in the southern arm of the Leeuwin Current also impact the dispersion of eggs and larvae along the southwest coast from both small pelagics such as pilchards (Fletcher et al. 1994) and more tropical species (Maxwell and Cresswell, 1981). Because the Leeuwin Current is low in nutrients and there are few terrestrial inputs, productivity tends to be low over most of the Great Australian Bight (Motoda et al. 1978, Table 1). However, seasonal winds off Kangaroo Island can lead to episodic upwelling of higher nutrient slope water (Lewis 1981, Schahinger 1987) and localized phytoplankton blooms. Griffin et al. (1997) considered the potential role of these processes in initiating a mass mortality of adult pilchards in 1995, but concluded that environmental conditions were not abnormal for the region at the time of the outbreak.

3.5 West Coast

The west coast shelf is relatively broad in the north where the main feature is Shark Bay, then gradually narrows to the south (Fig. 1). Sediments deposited on the shelf along the southwest margin of Western Australia reflect the transition from sub-tropical to temperate climate regime that characterizes this region. West-coast rivers carry little sediment and most of this is trapped in estuaries. Thus terrigenous sediment is typically a minor constituent in shelf deposits, which are mostly algal remains, shell fragments, foraminifera, and bryozoa. The southern Rottnest Shelf sediments consist of mobile medium-to-coarse sands, transitioning to finer silts and clays beyond the 90 m isobath (Collins, 1988). In contrast, the northern Rottnest shelf is characterised by luxuriant seagrasses growing on coralline-encrusted hardgrounds (James et al., 1999). The Houtman Abrolhos reef platforms support widespread coral growth with surrounding sediments dominated by bryozoans and coralline red algae (Collins et al., 1996).

Adjacent to Shark Bay, the Dirk-Hartog shelf exhibits mostly relict sediment of sorted planktonic foraminiferal sands under strong bottom currents, or spiculitic mud. James et al. (1999) suggested that relict sediments are due to arrested carbonate sedimentation caused by downwelling and episodic outflows of saline waters from Shark-bay onto the outer shelf and upper slope. Within Shark Bay the plankton community is dominated by diatoms and small copepods (Kimmerer et al., 1985), and algae trap and bind sediment in columnar structures referred to as stromatolites (Logan et al., 1964; Playford, 1979). These structures develop preferentially in the hypersaline parts of Shark Bay, where grazing pressure by metazoans such as gastropods is low. Here extreme nutrient limitation also favors a plankton community consisting mostly of dinoflagellates and demersal forms of zooplankton (Kimmerer et al., 1985).

Biophysical studies along Australia's west coast have focused on the role of the Leeuwin Current on larval advection and recruitment of finfish and invertebrates such as the western rock lobster (Caputi et al., 1996). For example, the main spawning of tailor on the inner shelf coincides with the presence of wind-driven northward coastal currents capable of transporting eggs and larvae towards coastal nursery areas (Lenanton et al., 1996). Rock lobsters have a much longer planktonic larval phase (9–11 months) and the correlation between Leeuwin Current strength and settlement is well established (Pearce and Phillips, 1988; Caputi and Brown, 1993; Caputi et al., 2001). However, sophisticated models of larval movements have not been able to explain the observed interannual variability in settlement (Griffin et al., 2001).

The Leeuwin is also responsible for the recruitment of tropical reef fishes as far south as Rottnest Island off Perth (Hutchins and Pearce, 1994), and influences the recruitment of other species such as scallop and pilchards (Caputi et al., 1996), and possibly corals (Simpson, 1991; Simpson et al., 1993). The presence of this poleward flow also suppresses upwelling along the west coast and the resulting low primary productivity levels appear to strongly limit fish densities (Williams et al., 2001).

3.6 *North West Shelf*

Australia's North West Shelf encompasses the tropical waters from Northwest Cape northeast almost to Joseph Bonaparte Gulf. It is characterised by large tidal ranges, including internal tides along the outer shelf, and a high incidence of tropical cyclones (Lough, 1998). Each of these processes contributes to the movement of sediments across the North West Shelf (Ribbe and Holloway, 2001). The composition of the sediments is predominantly calcareous sands and gravels derived from relict skeletal debris (Jones, 1973; McLoughlin and Young, 1985). Calcareous pellets (pisoliths) and oolites comprise more than 50% of the sediments over much of the middle and outer shelf (Jones, 1973), indicating that most of the shelf is currently starved of sediments. Finer silts and clays appear to be restricted to coastal environments, such as Exmouth Gulf (Brunskill et al., 2001), where water column turbidity is also high.

With minimal terrestrial inputs (Lough, 1998; Burns et al., 2003), nutrients are supplied to the shelf through a combination of barotropic and internal tidal motions, summertime wind-driven upwelling, and episodic cyclone events (Holloway et al., 1985). Because upwelling does not extend to the surface, nutrient levels in surface waters remain very low. As a consequence, phytoplankton biomass is also low, although rapid recycling of nutrients supports high primary productivity rates (Table 1, Furnas and Mitchell, 1999; Burns et al., 2003) and higher than average zooplankton abundance (Tranter, 1962; Wilson et al., 2003). While the biomass levels are similar in Exmouth Gulf, lower primary productivity and high grazing pressure have been reported in this system (Table 1, Ayukai and Miller, 1998). Over the mid- and outer-shelf phytoplankton biomass tends to be concentrated below the thermocline or in the bottom mixed layer, where benthic production is also high (Tranter and Leech, 1987).

Recent modeling studies indicate that primary production is closely coupled to the spring-neap tidal cycle, with only relative weak seasonal variability (NWSJEMS). However, El Nino conditions also affect the region by lowering the incidence of tropical cyclones, weakening the Indonesian Throughflow, and allowing increased upwelling. Recent studies suggest these conditions support higher chlorophyll and zooplankton abundance on the shelf (Wilson et al., 2003). A relationship has also been demonstrated between tropical cyclone incidence and recruit survival for tiger prawns in Exmouth Gulf (Penn and Caputi, 1986). The influences of seasonal and interannual variability on larval dispersion are only now being studied for coral spawning events, commercial pearl oysters, and other applications (Condie et al., 2003).

3.7 Northern Australian Seas

The tropical coastal waters of northern Australia are characterised by broad shallow shelf seas, such as the Timor Sea (Sahul Shelf), the Arafura Sea, the Gulf of Carpentaria, and Torres Strait. Currents in the Timor Sea are influenced by the eastern arm of the Indonesian Throughflow (Godfrey, 1996), as well as seasonal winds driving currents to the northeast during the summer monsoon and to the southwest during winter (Cresswell, 1993). However, most of the shelf is dominated by tidal motions, which are particularly strong in Joseph Bonaparte Gulf and Torres Strait.

The surficial sediment composition varies significantly across the region. On the Sahul Shelf grain size is negatively correlated with calcium carbonate content (Fig. 2), with coarse-grained carbonate sediments contrasting with fine-grained terrigenous mud (Van Andel and Veevers, 1967). This relationship breaks down in Joseph Bonaparte Gulf where sediments are enriched with quartzose terrigenous sand deposited as ebb tidal deltas (Lees, 1992). On the Arafura Shelf carbonate content diminishes toward the coast as fluvial inputs become more significant (Fig. 2).

In the Gulf of Carpentaria, bottom sediments and suspended sediments generally trend parallel with the coastline (Jones, 1987; Wolanski and Ridd, 1990). They include sandy near-shore facies characterised by relatively high sedimentation rates and mud-sand mixtures in deeper areas characterised by low sedimentation rates. These patterns have been shown to influence the distribution of commercial prawns, with some species preferring muddy sediments and others sandy sediments (Somers, 1987, 1994). Tidal sand banks and subtidal dunes can also be found around the major island groups. The latter have been shown to reverse their orientation in Torres Strait in response to seasonal reversals in wind direction (Harris, 1988, 1991). Sedimentation rates in northern Torres Strait may also be enhanced by inputs from the Fly River, with potential impacts on coral and seagrass communities (Wolanski et al., 1999; Hemer et al., 2003).

Turbidity tends to be high in the northern seas, particularly within the coastal zone (0 – 20 m), where phytoplankton production has been found to be light limited (Table 1, Rothlisberg et al., 1994; Burford and Rothlisberg, 1999). While nitrate and phosphate levels are relatively low, the availability of silicate allows diatoms to dominate the phytoplankton community with chlorophyll levels peaking over the wet season (Burford et al., 1995). Further offshore thermal stratification develops during summer and surface production becomes nutrient limited. The net effect is limited seasonal variability in chlorophyll without any obvious species succession of diatoms (Burford et al., 1995).

Because of their commercial importance, a number of modelling studies have addressed the advection and recruitment of prawn larvae to mangrove and seagrass nursery beds (Rothlisberg et al., 1983, 1996; Condie et al., 1999). These studies have demonstrated how larvae can move rapidly towards the coastline and estuaries by coinciding periods of pelagic swimming with flood tides, and periods of benthic habitation with ebb tides. However, the results of these models are sensitive to details of the larval behavior, which are yet to be fully quantified.

3.8 *National integration*

Section 2 described various attempts to develop geographically integrated descriptions of the physical, chemical, biological, or sedimentological environment around the Australian continent. A small number of studies have progressed to exploring interdisciplinary links at the national scale. For example, Porter-Smith et al. (2004) have used oceanographic conditions and sediment characteristics from around the entire continental shelf to identify where bottom sediments are likely to be mobilized and by what processes. Their results indicate that sediments are mobile over most of the mid- and inner-shelf, with the North West Shelf, Northern Australia (excluding the southern Gulf of Carpentaria), southern Great Barrier Reef, and parts of Bass Strait dominated by tidally induced resuspension, and the remainder by wave induced resuspension (Fig. 10).

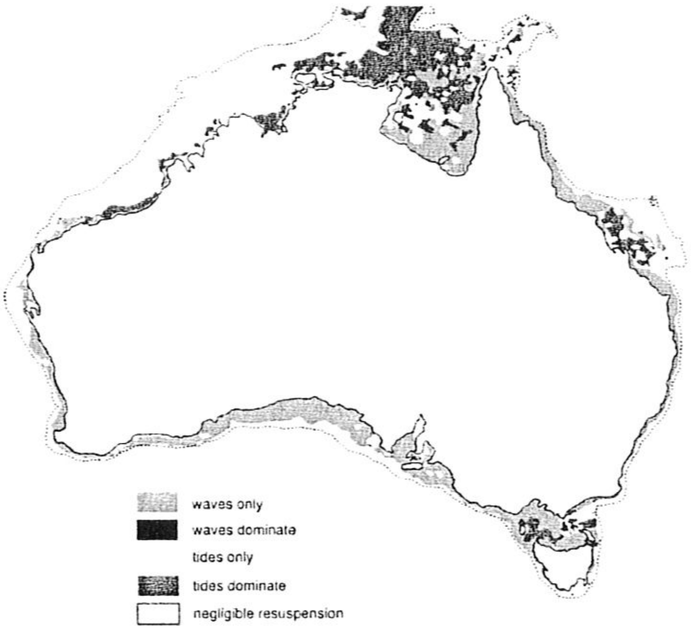

Figure 35.10 Regions of the Australian shelf in which sediment resuspension occurs and whether it is caused by surface waves or tidal currents (adapted from Porter-Smith et al. 2004).

The national biogeographic description used to structure this review (Fig. 9) was developed mainly on the basis of benthic and epibenthic information. However, pelagic descriptions have also been constructed on the basis of seasonal patterns of phytoplankton distributions (Fig. 8) and the physical and chemical conditions limiting primary production (Figs. 5 and 6). While the global biogeographic analysis of Longhurst (1998) does not adequately resolve features on the Australian shelf, finer-scale analyses are consistent with nutrient limitation of surface layer primary productivity over nearly all the shelf (Condie and Dunn, 2004). The main exceptions are the turbid tropical coastal waters of the North West Shelf and Northern Australia, where light limitation is a significant factor.

Approaching the topic of larval advection at a national scale is difficult because of potential dependencies on larval behavior and small-scale circulation features. However, by focusing on the large-scale transport of larvae residing in the upper water column, Condie et al. (2004) have recently developed a national analysis of marine connectivity patterns for advection timescales of days to months. While not replacing the finer-scale larval advection studies needed in complex coastal environments, it provides a generalized description within an easily accessible web-based user-interface (*http://www.per.marine.csiro.au/aus-connie*).

4. Research Directions and Issues

While particular regions or topics have received special attention due to their conservation significance (e.g. nutrient inputs and larval transport on the Great Barrier Reef) or relevance to major fisheries (e.g. larval transport on the West Coast), the number of studies that have focused on interdisciplinary processes in the Australian marine environment is still relatively small (Table 2). However, this situation is changing rapidly as the increasing focus on ecosystem-based management prompts a range of new initiatives. For example, a diverse range of characterization and process studies are progressing on the Great Barrier Reef and providing a basis for the development of a more integrated understanding of the system. While there is significantly less data available for the North West Shelf, highly integrated models have recently been developed for this ecosystem and its interactions with human activities (Section 3.6). Other major ecosystem studies have also been initiated on the west coast, where the focus is on biophysical interactions of the offshore Leeuwin Current system with the shelf and coastal environment, and in the shallow tropical waters of Torres Strait where the focus is on seabed habitats and their response to oceanographic and sedimentary processes. A range of fisheries and ecologically related studies in the Southeast are also beginning to address issues such as the relationship between ocean circulation, primary production, recruitment, and trophic interactions.

4.1 Major information gaps

A comprehensive assessment of information gaps is beyond the scope of this review. However, on such a large continental shelf surrounding a sparsely populated continent, there are clearly large data gaps across all disciplines. Even a seemingly large dataset, such as historic hydrography, is insufficient to characterize the seasonal cycle in many areas of the Australian shelf (Ridgway et al., 2002). Biological distributions are typically very patchy, but for key variables such as primary productivity there are estimates available from only a few localities (Table 1). There are other important ecosystem components that have received almost no attention. For example, studies in other parts of the world suggest that microphytobenthos play a much larger role in nutrient cycling on continental shelves than previously suspected. Information on zooplankton distributions and secondary production is also quite limited and limited progress has been made in collating this data and interpreting it within an ecosystem context. While obtaining the necessary field data to address these issues is major challenge, they represent critical sources of uncertainty in both biogeochemical models and tropic models linking primary production to fisheries production.

4.2 Scale related issues

A recurring issue when considering interdisciplinary interactions in Australian shelf waters (and elsewhere) is that temporal and/or spatial scales are often not directly compatible. This may relate to the scales of the field sampling, model resolution, or the dynamical scales of underlying processes. For example, while it has been clearly established that El Nino cycles effect Australia's marine environment, local ecological impacts of climate variability and change are largely unexplored. Scale mismatches can be particularly problematic where water column and benthic processes are coupled, the latter usually being associated with much smaller length scales. Scales are also important when considering the influence of larval behavior on transport patterns. While most behaviors have limited ability to effect long pelagic phases (e.g. inter-reef exchange), they may be critical during the settlement phase (e.g. retention around reefs). Improved strategies are clearly required for re-scaling information and coupling processes operating at different scales.

4.3 Whole-of-system approaches

This review has described a diverse range of studies exploring specific interdisciplinary links. However, the ultimate goal is to expand this approach into a whole-of-system understanding through the development of conceptual, statistical, or dynamical integrated models. While many of the necessary components for such models are available for intensively studied regions such as the Great Barrier Reef, it has so far only been seriously attempted on the North West Shelf (North West Shelf Joint Environmental Modelling Study, 2002; Condie et al., 2003). The outcomes of this study are centered around coupled ecosystem models incorporating ocean circulation, waves, sediment dynamics, nutrient cycling, primary and secondary production, and higher trophic interactions. This approach has revealed strong interactions between the spring-neap tidal cycle, suspended sediments, primary productivity, and habitat and fish distributions. These ecosystem models have also been dynamically linked to models describing the cumulative impacts of human activities (Fig. 11). This approach is supporting management of the region by allowing a wide range of management strategies to be evaluated in terms of the sometimes-conflicting needs of multiple human uses and the natural ecosystem.

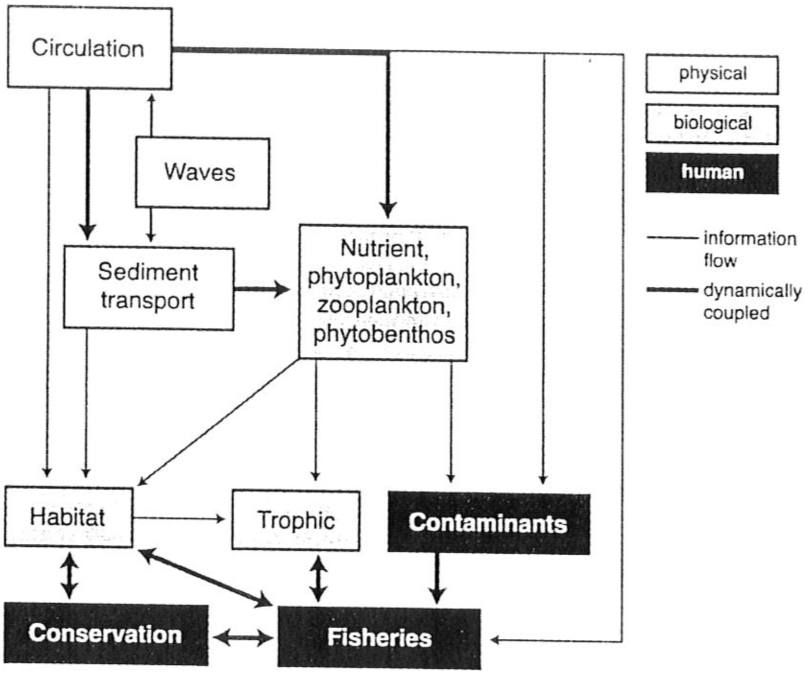

Figure 35.11 Major components of the integrated model applied to the North West Shelf ecosystem and human activities.

The North West Shelf study represents a first attempt at a whole-of-system model for a small part of Australia's continental shelf. It has provided a framework for identifying the processes most critical in addressing particular issues, as well as helping to prioritize needs for further observations (including ongoing monitoring) and improvements in model components and parameterizations. It should also provide a template for regional ecosystem studies in other shelf environments. Focusing interdisciplinary effort on a small number of geographical areas appears to be the most viable strategy for progressing understanding on the Australian continental shelf ecosystem.

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