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THE SWAN CATCHMENT COUNCIL MARINE AND COASTAL NATURAL RESOURCE INVENTORY

A Report to the Swan Catchment Council

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THE MARINE AND COASTAL NATURAL RESOURCE INVENTORY

1 PROJECT BRIEF

This project has arisen from a request by the Swan Catchment Council (SCC) to compile a database of marine and coastal information from the SCC region. This region encompasses the metropolitan area and extends north to Two Rocks and south to Singleton Beach. The project aims were:

- To improve the SCC region's ability to access coastal and marine information readily for mapping and management purposes;
- To provide up to date information about environmental condition for the Strategy planning process;
- To assess the adequacy of existing scientific information for management purposes; and,
- To Identify gaps in the current information/research available.

The project was conducted in three phases. The first two phases involved searching library catalogues and databases and compiling a database of literature. The third phase involved reviewing the literature and attempting to identify gaps in knowledge. The project was conducted over a 6 week period. Approximately 900 references were located which have been collated in an Endnote library. As stated in the project submission, an exhaustive critical review of all literature pertaining to coastal and marine environments of the Swan region was not possible within the budget and timeframe, given the number of articles and the scope of the project. The research topics as outlined in the project brief (Section 5.1) were classified under Environmental Condition and Threatening Processes. Following discussion with the Marine and Coastal NRM coordinator gaps in the knowledge were identified for many but not all research topics. However, any available information is contained in the Endnote library.

Gaps that were identified are based only on the literature that was located in the literature search. Some of the issues identified are possibly being dealt with by respective Government Departments and some literature may not have been readily accessible and therefore did not turn up in the searches (see Appendix 1 - list of searches). If gaps have been identified that are already being dealt with, this might highlight that the work is in progress or that information has not been made available to the wider community. Further critical evaluation, of the potential impacts of various developments would be included in the Environmental Protection Authority (EPA) Reports and Recommendations which exist on all activities that might impact the environment. For each Public Environmental Review (PER), Consultative Environmental Review (CER) or Environmental Review and Monitoring Programme (ERMP) there will be a corresponding EPA Report and Recommendations. This would likely identify deficiencies in the knowledge of the particular activity or potential impacts.

2 CONTENTS OF THE INVENTORY

2.1 Searches

Searches were made at the University of Western Australia, Murdoch University, Edith Cowan University, Curtin University, and the Library Information Service of Western Australia. Unfortunately the Edith Cowan University catalogue was often unavailable and could not always be searched. Many websites were also searched including government departments, local councils and consulting firms. Full details of all sources searched are provided in Appendix 1. Information of relevance to SCC region was added to the Endnote library in addition to other literature with a broader context but local application i.e. lobster fishing and ecology. Where literature included the term southwestern Australian waters, and had relevant subject matter, it was also included.

Search terms included: the research topics as defined in section 5.1 of the project brief, the names of authors including prominent local researchers, locations (e.g. Perth, Western Australia, various Islands, Marine Parks and various developments). Effort was put into locating local theses.

2.2 Databases of information and datasets

A number of databases were located that contain datasets of relevance to this project. These are outlined in Table 1 with information on the contents of the database, access requirements and whether the data is spatial or non-spatial. These databases are discussed in more detail under the research topic headings in this report.

3 HOW TO USE THE ENDNOTE LIBRARY

When the Endnote library is opened a main page appears with a list of all references. This summarises the details of all the references under the author, year and title. The library can be sorted by selecting column headings. There is a column "PDF or Link" which signifies the existence of a PDF document or a link to a website containing the document. The notes column shows the location of articles within the libraries that they were located. When a particular reference is selected from the main Endnote window, another window will open with all the details of that reference. From the initial page users can search all references in the Endnote library under any combination of terms. User help and frequently asked questions (FAQs) for Endnote can be found at http://www.endnote.com/ . Acronyms have been used for some of the authors but the full names will be detailed in the reference under "Institution".

3.1 PDF documents and Links

To use links, open the reference and use the URL. If you are online you will be automatically directed to the website. PDF articles that were downloaded have been placed in a folder on the enclosed compact disc. The PDF articles are listed under the author name, the year of publication and the first couple of words in the title. These should be installed on a hard disk and can then be directly linked to the references in Endnote. Once this is done you will be able to seamlessly open the PDF documents from Endnote, rather than go to the folder and open the file. Most of the PDF articles can be searched. When in Adobe reader, use the find function to locate key words within the articles. Some of the older articles are in an image format and cannot be searched and this will be evident when you attempt a search. The URLs were current at the time of writing but may become obsolete or be moved by website administrators.

3.2 Location of articles

The locations of documents have been abbreviated in Endnote (e.g. UWA, MU, ECU, CU, LISWA) and include the library within each campus (e.g. BIOL, GEOL etc) (Table 2). Some articles are also labelled CALM MCB. These could not be located in any of the libraries but can be accessed by contacting the Department of Conservation and Land Management, Marine Conservation Branch. Other articles may be obtained through the relevant consulting firms and suggestions have been made on whom to contact, but these articles may be regarded as confidential. In some cases locations could not be found and suggestions have been made on the likely locations. Articles that cannot be located in Western Australia could be located through inter-library loans with libraries in other states or overseas. Users should visit the library websites (see Appendix 1) to check if documents are on loan. If visiting libraries at government departments, telephone first to ensure they are attended and will allow you access.

The Department of Environment (DOE) was previously known as the Department of Environmental Protection (DEP), the Department of Conservation and Environment (DCE) and the Environmental

Protection Authority (EPA). All documents by the DEP, DCE and EPA will be in the DOE library. The Department of Fisheries were previously known as Fisheries WA. Documents by the Department of Fisheries should be located in the library at the WA Marine Research Laboratories library, Department of Fisheries. Library locations will sometimes differ for the same journal as not all libraries hold the entire set. Maps to the various libraries at the University of Western Australia can be found at http://www.library.uwa.edu.au/maps/campus.html

The Endnote library should be periodically updated to stay current with new research and management in the SCC region. The Web of Science and Current Contents databases operate through the ISI interface and can export references directly to Endnote. These databases can be accessed at the University of Western Australia, Murdoch University, Edith Cowan University and Curtin University.

Many journals are now available electronically and users can download PDF documents to their computer or to a floppy disk. This can be done remotely if the user is registered with the University and has online access rights. Access is available to non-registered users if they access the databases from computers within the library. If a user requires an electronic journal article they can access it by searching the journal name in the library catalogue and then browsing the journal online for the article. If an article is marked electronic, in the Endnote library, this indicates that volume is electronic, not necessarily the whole journal. Older articles are often only available as hard copies.

Table 1: Databases of information.

Database	Contents	Spatial	Managed by	Access	Restrictions
Algaebase	Common names, images, literature, links.	Non spatial	European Union	http://www.algaebase.org/	None
Faunabase and Faunalist	Amphibians, birds, mammals, reptiles and fishes. Common names, image gallery, taxonomic tree, family list, species search and area search.	Distributions and locations of type specimens	WA Museum	http://www.museum.wa.gov.au/faunabase/prod/index.htm	None
Fishbase	Distributions, biology, diet, maturity	Distribution maps	World Fish Center	http://www.fishbase.org/search.cfm	None
Florabase	Plant names, flora descriptions, interactive identification, distribution maps, botanical library	Distribution maps	Department of Conservation and Land Management	http://www.calm.wa.gov.au/florabase/index.html	None
Hydstra	Continuous water levels, surface water, rivers, in situ conductivity and total dissolved solids, nutrient loads	Spatial, georeferenced	Water and Rivers Commission / Department of Environment	telephone information officer (9278 0580) or email: waterinfor@environment.wa.gov.au	None
Seabase	Water quality data for Cockburn Sound, Perth Long-term Ocean Outlet Monitoring (PLOOM) and the Perth Coastal Waters Study.	Spatial, georeferenced	DAL Science and Engineering on behalf of Water Corporation	Contact DAL Science and Engineering 9389 9669. Access will be provided on a case by case basis. Authorised users will be issued with a PIN code that will allow online access.	Authorised use only
Statewide ground truthing sites	Information on habitat and biological assemblages and/or substrate. Wildlife distributions in the Perth region (work in progress)	Recent information spatially tagged. Older information in blocks of 5 x 5 nautical miles	Department of Conservation and Land Management, Marine Conservation Branch	Email Dr Chris Simpson with specific request (chriss@calm.wa.gov.au)	None
Western Australian Land Information System (WALIS)	Natural environment, planning and land use, tourism and recreation.	Spatial, georeferenced	Western Australian Land Information System	http://www.walis.wa.gov.au/cgi-bin/index.cgi?offset=117	None
Water Information Database (WIN)	Mainly surface and groundwater, some marine information with aim to increase marine focus. Water quality, rivers, estuaries, bores, water chemistry, and phytoplankton.	Spatial, georeferenced	Water and Rivers Commission / Department of Environment	www.wrc.wa.gov.au/waterinf/wric/wric.asp or telephone information officer (9278 0580) or email: waterinfor@environment.wa.gov.au	None

Table 2: Library acronyms and locations

Acronym	Location	Library acronym	Library
UWA	University of Western Australia, Stirling Highway Nedlands	BIOL	Biology
	University of Western Australia, Stirling Highway Nedlands	GEOL	Geology
	University of Western Australia, Stirling Highway Nedlands	HSS	Humanities Social Sciences
	University of Western Australia, Stirling Highway Nedlands	SCHOLARS	Reid
ECU	Edith Cowan University, 100 Joondalup Drive, Joondalup	JO	Joondalup
	Edith Cowan University, 2 Bradford St, Mount Lawley	ML	Mount Lawley
	Edith Cowan University, Pearson St, Churchlands	CH	Churchlands
MU	Murdoch University, South St Murdoch		
CU	Curtin University, Kent St, Bentley		TL Robertson
LISWA	Library Information Services of WA, State Library of Western Australia, Perth Cultural Centre, Francis St, Perth		Alexander Library
CSIRO	Underwood Avenue Floreat		
DOE	Department of Environment Library, Westralia Square, 141 St Georges Tce		
Fisheries	Department of Fisheries, West Coast Drive, Waterman		WA Marine Research Laboratories
Water Corporation	John Tonkin Water Centre, 629 Newcastle Street, Leederville.		

ENVIRONMENTAL CONDITION

1 SEAGRASS HABITATS

"Seagrass" occurs as a term in 20% of references in the database. This reflects the high level of attention seagrasses have received in the SCC region, their role in providing habitat and their vulnerability to human-induced impacts.

1.1 Seagrass loss due to nutrient inputs

Seagrasses have been the subject of extensive research in Western Australia. This commenced in the 1970s (Cambridge, 1975; 1979) with a focus on the effects of nutrients on seagrass growth and cover in Cockburn Sound (Silberstein, 1980; Cambridge and McComb, 1984; Silberstein, 1985; Cambridge et al., 1986; Hillman, 1986; Silberstein et al., 1986). Seagrasses were being impacted by excessive growth of epiphytic algae and phytoplankton caused by industrial nutrient inputs. This limited the light available for seagrass growth. Between 1954 and 1978 seagrass cover in Cockburn Sound was reduced from 4200 to 900 ha (Cambridge and McComb, 1984). Consequent changes in industry practices reduced the nutrient input to the Sound.

1.2 Seagrass loss due to moorings

Seagrasses may be impacted by boat moorings. Older style moorings caused circular scouring of seagrasses (Walker et al., 1989; Hastings et al., 1995) with overall loss estimated to be 5.4 ha in the Rottnest Island, Warnbro Sound and Cockburn Sound regions of Western Australia. The Rottnest Island Authority have introduced moorings with bottom apparatus that cannot move and do not scour the seafloor (Rottnest Island Authority, 2003). Gordon (1986) contains information on mooring damage in Mangles Bay, Cockburn Sound.

1.3 Seagrass loss due to dredging

Cockburn Cement have been dredging shellsands on Success Bank, Parmelia Bank and Owen Anchorage since 1972 (Environmental Protection Authority, 2001). When dredging takes place over seagrass meadows, the seagrasses and associated habitats are lost. Renewal of the dredging licence has been subject to public debate over the potential effects of this activity. This spawned a major investigation in 1996 into the ecological significance of seagrasses. Studies were conducted on many aspects of seagrass communities to assess the impact of shellsand dredging and the potential of rehabilitation and replanting seagrasses. Particular areas of investigation were; calcium carbonate and nitrogen turnover; primary production; socio-economic uses and values; invertebrate assemblages; fish assemblages; and rehabilitation techniques (Hyndes et al., 1998; Kendrick et al., 1998; Lavery et al., 1998; Paling et al., 1998; Annandale, 1999; Brearley and Wells, 2000). The Environmental Protection Authority evaluated the findings of these studies and issued a licence renewal for long-term shellsand dredging (Environmental Protection Authority, 2001). The studies were summarised in the Cockburn Cement Environmental Review and Management Programme (Cockburn Cement, 2000).

1.4 Algal epiphytes on seagrasses

Algal epiphytes often colonise the leaves of seagrasses. Perfectly healthy seagrass communities include assemblages of epiphytic algae often with a diversity of species and growth forms. Epiphytes may proliferate when subject to nutrient enrichment which can then reduce the photosynthetically

active radiation (PAR) reaching the leaves of seagrasses. Seagrass epiphytes were studied in Cockburn Sound in relation to nutrient enrichment (Cambridge and McComb, 1984; Cambridge et al., 1986; Silberstein et al., 1986) and as part of the Cockburn Cement Shellsand dredging project (Kendrick et al., 1998; Lavery et al., 1998).

Epiphyte assemblages have been studied in some detail on various seagrass species in Perth coastal waters including *Amphibolis griffithii*, *A. antarctica*, *Posidonia australis*, *P. sinuosa* and *P. coriacea* (Borowitzka et al., 1990; Kendrick and Burt, 1997; Van Elven, 1998; Trautman and Borowitzka, 1999; Vanderklift and Lavery, 2000; Lavery and Vanderklift, 2002). Methods have also been developed to monitor epiphyte growth on artificial substrates including artificial seagrasses and perspex plates (Horner, 1987; Lethbridge et al., 1988; Kinhill Engineers Pty Ltd, 1997; DALSE, 2003) which can be a useful method for monitoring the effects of increased nutrients.

The Department of Environment and the Department of Defence monitor epiphyte biomass on seagrasses along the metropolitan coast on Success Bank, in Cockburn Sound, Warnbro Sound and Shoalwater Bay (Lavery and Westera, 2003a; b).

The currently available information on epiphyte growth, epiphyte assemblage structure and the role of epiphytes as indicators of nutrient enrichment, would be useful for future monitoring of nutrient related impacts in the marine environment. However the response of epiphytes to nutrients may be influenced by season and local hydrodynamics. Thus, baseline work and ongoing monitoring would likely be needed to assess nutrient related impacts such as stormwater runoff, or disposal of sewage and industrial effluent.

1.5 Invertebrates associated with seagrass communities

Jernakoff and Nielsen (1998) examined relationships between epifaunal invertebrates (amphipods, molluscs and polychaetes) and epiphytes on seagrasses. Brearley (1995; 1996) examined the biology of isopods on seagrasses and Brearley and Wells (2000) compared invertebrate assemblages in different seagrass habitats on Success Bank.

1.6 Seagrass mapping

Seagrasses have been mapped at different resolutions as part of various surveys and projects. Kendrick et al (2002) evaluated changes in seagrass cover in Cockburn Sound between 1967 and 1999, and produced a baseline for further monitoring and management of seagrasses in Cockburn Sound. Hillman (1986) documented the dieback of seagrasses in Cockburn Sound with detailed maps of seagrass cover in 1977 and 1985 and losses in seagrass cover over time. DAL (2000) mapped seagrass in Cockburn Sound and Owen Anchorage and this report may be available on request. The Perth Coastal Waters Study (Lord and Hillman, 1995) includes habitat maps with seagrass cover that were derived from GEOSCAN imagery. These cover significant areas surrounding ocean outfalls at Ocean Reef, Swanbourne and Cape Peron, but they have no taxonomic resolution. DALSE (2002) mapped benthic habitats of Cockburn Sound which would provide a baseline for future assessment. Gordon (1986) mapped benthic habitats including seagrasses in the Shoalwater Bay to Warnbro Sound region

Habitat maps of the region surrounding the Ocean Reef Wastewater outlet were produced in 1991 and 1994 (Kinhill Pty Ltd, 1991; Bowman Bishaw Gorham, 1994). Similar areas were investigated in the PLOOM study (DALSE, 2003) but information was not compiled as a map in the PLOOM Report. There appears to be a lack of habitat maps for the SCC region north of Fremantle

The WALIS database (WALIS, 2004) has links to the Australian Natural Resources Atlas. This has information about seagrass distribution that is not correct. The WALIS database is a useful tool but needs updating with regard to seagrass distribution in the SCC region.

Current seagrass maps should be sufficient for large scale monitoring of seagrass cover in the region from Fremantle to the southern end of Cockburn Sound including Success Bank, Parmelia Bank and Owen Anchorage. Areas to the north of Fremantle may require finer scale seagrass mapping that includes species types.

1.7 Seagrass monitoring

The Department of Environment and the Department of Defence conduct annual monitoring of seagrass meadows at 13 sites from Stragglers Rocks to Warnbro Sound (Lavery and Westera, 2003a; b). A range of variables are measured including shoot density, productivity, biomass, shoot heights and epiphyte load. The depth of seagrass growth is also measured at three sites in Cockburn Sound and one site in Warnbro Sound. These data are reported to the Cockburn Sound Management Council for incorporation into the Cockburn Sound Environmental Protection Policy (Environmental Protection Authority, 2003). The Cockburn Sound Management Council issue annual "report cards" on the status of seagrasses in Cockburn Sound (Cockburn Sound Management Council, 2004a). Seagrass monitoring was also conducted for the Jervoise Bay, Southern Harbour Construction (Tunbridge, 2002).

The results of Lavery et al (2003a) indicate that there were no significant regional-wide changes in the status of seagrass meadows at the sites surveyed between 1998 and 2003. However, they add that trends in data should be treated with caution, as they do not account for seasonal or shorter timescales. There were some areas of concern that were to be noted in future surveys. Seagrass aboveground biomass had decreased at Garden Island 7m and Fish Rocks. They also state that seagrasses at Mangles Bay (in southern Cockburn Sound) remain highly stressed and biomass in 2003 was significantly lower than in 1998 when the survey commenced. This may be due to nutrient inputs from nearby Lake Richmond (Natural Resource Management Office, 2003) or the adjacent causeway affecting circulation and coastal processes (Cockburn Sound Management Council, 2004c). These issues are being investigated by the Cockburn Sound Management Council.

Kirkman (2000) described temporal changes in seagrasses along two transects in the Marmion Marine Park and results could be inferred to similar areas for long term monitoring.

1.8 The condition of seagrass habitats and gaps in the knowledge

Current information suggests that seagrasses are not in decline on a regional scale. However, seagrasses may have been impacted in Mangles Bay and may suffer as a consequence of coastal development (e.g. Jervoise Bay Southern Harbour). Long term monitoring is in place at a number of locations between Fremantle and Warnbro Sound (Lavery and Westera, 2003a; b). This is conducted in January each year and therefore does not account for seasonal changes in seagrass characteristics. Lavery et al (2003a) acknowledge that results would indicate whether dramatic shifts have occurred in features of seagrass meadows over time, which may warrant more intensive investigation but may not account for patchiness in time and space within seasons. There does not appear to be any long-term monitoring of seagrasses in the SCC region north of Fremantle except for areas within the PLOOM study. Similarly, habitat maps of the SCC region north of Fremantle are coarse and based on GEOSCAN imagery from 1995 (Lord and Hillman, 1995).

2 REEF SYSTEMS

There are many biological components of reef systems in the SCC region. These reefs are predominantly limestone and are colonised by a diversity of algae and invertebrates. The structure of reef communities is influenced by wave exposure, depth and light. The CSIRO are currently investigating spatial and temporal trends in benthic reef communities of the temperate west coast of Western Australia (SRFME, 2004). This includes sites in the Marmion Marine Park and at Ocean Reef.

2.1 Algae

Marine macroalgae are the dominant benthic organisms on most temperate reefs in the SCC region. *Ecklonia radiata*, the most common macroalga, colonises reef and forms a canopy over an assemblage of smaller algal species. *Ecklonia* provides a structural habitat and shelter for fish and invertebrates, many of which are herbivorous and feed on the algal understorey. We are fortunate in Western Australia to have a number of phycologists that have conducted taxonomic and ecological studies on algae and algal epiphytes in temperate waters.

There are some excellent texts and keys for identification of algae in the SCC region. This includes local resources (Huisman and Walker, 1990; Huisman, 2000) and books with broader relevance that encompass our temperate coastal waters (Womersley, 1984; 1987; 1994; 1996a; b; 2003). Early work on algal distribution was conducted at Cockburn Sound and Rottnest (Smith, 1952).

Algaebase is a database maintained by the European Union (European Union and Irish Higher Education Authority, 2004). It contains information the biology of particular algal species, including those in the SCC study area, and links to other information and websites. Algaebase does not provide distribution maps.

2.2 Sponges

Sponges form part of the diverse benthic assemblages on reef habitats in Perth coastal waters. They co-exist with algae and invertebrates and often colonise the upper faces and ledges of reefs where light limitation prevents algal growth. The ecology and biology of sponges has been investigated in some areas of the SCC region. This includes studies on the reproductive capacity of demosponges (Fromont, 1999), sponge communities of the Marmion Marine Park (Bancroft, 1993), the filtering capacity of sponges in Cockburn Sound (Lemmens et al., 1996), the effect of sewage effluent on sponge communities (McQuillan, undated) and the use of sponges to trace the dispersal of sewage effluent (Gartner et al., 2002).

2.3 Cnidarians (Corals, anemones, hydras)

Coral colonies are not dominant in temperate waters due to water temperatures that are generally lower than 18°C. However, some corals exist on the coast of Rottnest Island as the Leeuwin Current provides warmer water at certain times of the year and is a source of coral propagules. Some large coral colonies exist on the eastern banks of Cockburn Sound (pers. ob.). Particular studies of corals in the SCC region are listed below.

- *Acropora* corals at Rottnest (Marsh, 1992)
- *Pocillopora damicornis* at Rottnest Island (Wells et al., 1993; Rottnest Island Authority, 2003)
- spawning and reproduction of *Pocillopora* at Rottnest Island (Stoddart and Black, 1985; Ward, 1992)
- catalogue of cnidarian specimens from the south-west of Western Australia (Griffith and Fromont, 1998)

- Hermatypic corals of Western Australia including Rottnest Island (Veron and Marsh, 1988)
- the effect of mechanical damage on *Pocillopora* at Rottnest (Ward, 1995)
- a new species of soft coral at Rottnest (Alderslade and Baxter, 1987)
- filtering capacity of hydroids in Cockburn Sound (Lemmens et al., 1996)
- the benthic fauna of Cockburn Sound (Wilson, 1978)

2.4 Echinoderms (urchins, stars, holothurians)

Echinoderms include the sea urchins, sea stars, and sea cucumbers. These are often common on reefs in the SCC region. A useful guide on the distribution of echinoderms and other invertebrates is Edgar (1997). Urchins are herbivores and severe grazing by urchins has reduced the cover of seagrasses in some areas in the SCC region. Cambridge (1986) recorded severe grazing by urchins at a number of locations in Cockburn Sound and Warnbro Sound. Bancroft (1992) documented the loss of a 3 ha area of shallow *Posidonia sinuosa* meadows, north of Sulphur Bay, Garden Island, which disappeared as a result of an invasion by the urchins *Heliocidaris erythrogramma* and *Temnopleuris michaelsenii*. Particular studies of echinoderm biology and distribution in the SCC region are listed below.

- *Echinometra mathaei* at Rottnest Island (Pearse and Phillips, 1968)
- the marine fauna of Cockburn Sound including echinoderms, gastropods and bivalves (Wilson, 1978)
- population genetics of *Echinometra mathaei* (Watts et al., 1990)
- echinoderm fauna of Rottnest Island (Marsh and Pawson, 1993)
- catalogue of species at the WA Museum (Marsh et al., 1999)
- distribution of echinoderms (O'Hara and Poore, 2000)
- mollusc and echinoderm assemblages on intertidal beachrock platforms (Moore and Ottaway, 1987)
- the functional role of the sea urchin Echinometra mathaei in community organization on intertidal rock platforms at Rottnest Island (Prince, 1992)
- the influence of urchin grazing on community structure of algae (Prince, 1995)
- grazing and interactions between urchins and macroalgae (Vanderklift, 2002)

Urchins are well catalogued but more needs to be known about their ecological role including grazing effects (but see Vanderklift 2002) and about predator prey-relations in reef and seagrass systems (i.e. urchins as prey). Urchins are a favoured food source of fishes due to their high proportion of gonad material that is rich in protein. They have been shown to increase in areas where their predators (such as fish) are reduced and they may influence algal and seagrass communities through heavy grazing.

2.5 Molluscs

Molluscs include the seashells (gastropods, bivalves etc), limpets, and cephalopods (octopus, squid and cuttlefish). The distribution and taxonomy of molluscs has been well documented by Wells et al (1980; 1985; 1987; 1988; 1989; 1993; 1996; 1997; 2000). Some studies of relevance to the SCC region are listed below.

- the marine fauna of Cockburn Sound including echinoderms, gastropods and bivalves (Wilson, 1978)
- survey of soft-bottom molluscs of Cockburn Sound (Wells and Threlfall, 1980)
- exploitation of molluscs by aboriginals (may provide an historic perspective) (Dortch et al., 1984)
- Rottnest Island survey and the influence of the Leeuwin current (Wells, 1985)
- *Littorina* on rocky shores (Black et al., 1988)

- diversity and distribution of subtidal macromolluscs around Rottnest Island (Glover and Taylor, 1999)
- shallow water marine gastropods endemic to Western Australia, distribution and separation into temperate, tropical and endemic species (Wells, 1996)
- limpets that grow on abalone (Wells and Keesing, 1988)
- survey of mollusc assemblages in the Marmion Marine Park (Moore and Ottaway, 1987)

Abalone are molluscs that inhabits limestone reefs in the SCC region. The most common species, *Haliotis roei,* is highly sought after by fishers. Articles relating to abalone include:

- growth of *H. roei*, differences between intertidal and subtidal areas (Keesing and Wells, 1989)
- *H. roei* spawning and feeding (Wells and Keesing, 1989)
- *H. roei* grazing experiment and interactions with other grazers (Scheibling, 1994)
- study of *H. roei* recruitment (Wells and Keesing, 1997)
- genetic study of *H. roei* population structure (Hancock, 2000)

2.6 Invertebrates assemblages

Information on invertebrate assemblages is contained in most marine management plans and the larger collaborative studies that have been conducted on water quality and shellsand dredging. These are listed below. The CSIRO are currently investigating the abundance and distribution of macroinvertebrates on reef habitats in the Marmion Marine Park and the Two Rocks region (SRFME, 2003; 2004).

Management plans

- Garden Island Management Plan (Environmental Management Services Pty Ltd, 1993)
- Rottnest Island Management Plan 1985 (Rottnest Island Management Planning Group, 1985)
- Rottnest Island Management Plan 2003-2008 (Rottnest Island Authority, 2003)
- Marmion Marine Park Management Plan (Pobar, 1992)
- Shoalwater Islands Marine Park Management Plan (CALM, 2001)
- Shoalwater Islands Nature Reserve Management Plan (CALM, 1992)
- Carnac Island Nature Reserve Management Plan (Conservation Commission, 2003)

Collaborative studies

- benthic invertebrate survey of Cockburn and Warnbro Sound (Cary et al., 1995)
- invertebrate assemblages on Success Bank in seagrass and sand habitats (Brearley and Wells, 2000)
- Perth Coastal Waters Study (Lord and Hillman, 1995)
- Southern metropolitan Coastal Waters Study (DEP (WA), 1996)
- Perth Long-Term Ocean outlet Monitoring (PLOOM) Study (DALSE, 2003)

2.7 The condition of reef systems and gaps in the knowledge

Algal and invertebrate communities in the SCC region appear to be in good condition and there is a large body of research on the biology and ecological processes of temperate reef communities. One area that requires further investigation is the effect of human activities on linkages between marine organisms. For example, the structure of algal and seagrass communities may change as a result of nutrient enrichment. This was shown in Cockburn Sound and may occur near ocean wastewater outlets. Changes in seagrass and algal communities may affect assemblages of herbivorous fish and invertebrates that graze upon seagrass or algae. Higher order predators such as fish may then be affected, if they prey upon the grazing fish and invertebrates. Conversely, extraction of resources

from the marine environment may affect higher order predators, which then affect organisms below them in the food chain. These food-web linkages may change over many years and are difficult to monitor and measure. However, understanding the longer term effects of our activities is fundamental for the management of natural resources.

Sponges form a significant part of the ecology of reefs in the SCC region however this is not reflected by the amount of research. More work may be needed on the biology and ecological role of sponges in the SCC region.

A number of urchin outbreaks have been recorded in the SCC region, particularly in Cockburn Sound (Cambridge et al., 1986; Bancroft, 1992). A reduction in fish predators has been shown to allow increases in their urchin prey (Shears and Babcock, 2002; Westera, 2003). Pink snapper (*Pagrus auratus*) is a commonly targeted fish in the SCC region and, according to fishers, catches have been declining in Cockburn Sound (Sumner and Williamson, 1999). Pink snapper have also been shown to prey on urchins (Babcock et al., 1999a). There may be relationships between reductions in predatory fish populations in the SCC region and urchin abundances. This is speculative and would require a survey, dietary analyses and experimentation to test.

3 MARINE WATER QUALITY

Marine water quality data often includes measurements of temperature, salinity, phytoplankton, nutrients, pesticides, metals and biological contaminants such as *E. coli* and salmonella. There appear to be two main databases that contain this information (see Table 2).

Seabase is a database that is maintained by DAL Science and Engineering for the Water Corporation. It contains the majority of water quality data for Cockburn Sound and the Perth Long-term Ocean Outlet Monitoring (PLOOM) study. Access to this database is restricted to authorised users. Access may be gained by contacting DAL Science and Engineering Pty. Ltd.

The Water Information Database (WIN) is curated by the Water and Rivers Commission, which is now part of the Department of Environment. This database holds approximately 11.5 million readings from 2.5 million samples. It includes water quality data from rivers, estuaries, groundwater and surface water. There is currently a small amount of marine information generally related to Cockburn Sound with an aim to include more marine data. The database can be accessed online (see URL in the Endnote library), by email request (waterinfo@environment.wa.gov.au), or by phoning the information officer (9278 0580).

A very useful document is the Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC, 2000a; b). This outlines how to conduct baseline and ongoing water quality studies including design, analysis, sampling programs, reporting and interpretation.

The major studies of water quality in Perth coastal waters are: the Perth Coastal Waters Study (Lord and Hillman, 1995); the Southern Metropolitan Coastal Waters Study (EPA (WA), 1996); and the Perth Long-term Ocean Outlet Monitoring Study (Kinhill Pty Ltd, 1998; 1999; Hale et al., 2001). Each of these is based on a collection of reports and studies on various components of marine ecosystems. Users who wish to investigate these studies should search the name of the study within the Endnote library to identify all the relevant reports. These studies contain information relevant to most sections of this report.

The Perth Coastal Waters Study (PCWS) was commissioned by the Water Authority of Western Australia (the Water Corporation) to evaluate the effects of wastewater discharge in metropolitan waters and determine the loads of nitrogen in treated wastewaters that could be discharged while maintaining environmental values. A recommendation of the PCWS was to continue monitoring and

this lead to the establishment of the Perth Long-Term Ocean Outlet Monitoring (PLOOM) study. The PLOOM study is discussed further under the section on Stormwater and Wastewater Outfalls. The Southern Metropolitan Coastal Waters Study (SMCWS) was initiated by the EPA to provide information necessary to address problems and facilitate environmental planning and management of waste inputs to Perth's coastal waters. The SMCWS assessed environmental values, developed environmental quality objectives, and reports on water quality measurements, process studies, modelling and baseline studies.

Water quality has been well studied in Cockburn Sound due to past impacts from ocean outlets and industry. The Endnote library contains more than 60 articles on water quality in Cockburn Sound. Users should search the Endnote library for information on particular water quality parameters or areas of interest.

3.1 Water quality: gaps in the knowledge

To critically assess gaps in the knowledge of water quality in the SCC region will require comprehensive critical review of the Perth Coastal Waters Study, the Southern Metropolitan Coastal Waters Study and the Perth Long-term Ocean Outlet Monitoring (PLOOM) Study. Wastewater discharge will increase as the population of Perth increases. The PLOOM study is essential to understanding the potential of impacts of wastewater discharge to water quality. Complementary studies might include further investigation of the ecological effects of nutrients and pollutants. Ecological changes might include shifts in species composition of primary producers due to long-term nutrient inputs and consequent effects on herbivorous fishes and invertebrates. These issues are would require rigorous long-term monitoring and experimentation that is possibly beyond the current limits and obligations of the PLOOM study.

4 TERRESTRIAL COASTAL DUNE VEGETATION

The vegetation of coastal dunes has suffered in the SCC region due to modification of habitats by residential and industrial development. However, some significant areas of coastal vegetation remain in the City of Wanneroo, the City of Cockburn and the City of Rockingham. Rippey (1995) provides an excellent description of coastal vegetation species of the Perth region. Seddon (1972) provides a comprehensive description of coastal vegetation formations and dune complexes including Garden, Carnac and Rottnest Islands. Other relevant literature contained in the Endnote library includes:

- vegetation of the central south coast (Newbey, 1979)
- floristic survey of northern sandplains between Perth and Geraldton (Griffin, 1994)
- Woodman Point Management Plan, provides a comprehensive description of coastal vegetation, diseases of vegetation and a habitat map of vegetation complexes in the Woodman Point Reserve, also includes reference list of other literature on coastal processes (Conservation Commission, 2002)
- honey fungus *Armillaria luteobubalina* (Shearer et al., 1997; Rottnest Island Authority, 2003)

4.1 Local Government Initiatives

The City of Stirling produced a Coastal Report in 1984 (City of Stirling, 1984). This was reviewed in 1996 to form the City of Stirling Coastal Management Strategy (City of Stirling, 1984). They are developing a site specific detailed management plan for each beach location and are working with the University of Western Australia and Coastcare to survey the Trigg Beach to Watermans area. Other initiatives include:

- Local Environmental Strategy for the City of Wanneroo, includes plan to compile vegetation maps (City of Wanneroo, 2004)
- Hillarys park foreshore management plan (City of Wanneroo, 1990)
- Whitfords Beach foreshore management plan (City of Wanneroo, 1991)
- Trigg Beach masterplan (City of Stirling, 2004)
- report on coastal management and development in the City of Stirling (City of Stirling, 1984)
- Coastal planning study, Burns Beach to Jindalee (Hames Sharley Australia, 1992a; b)
- South Cottesloe foreshore management plan and North Cottesloe foreshore vegetation plan (Town of Cottesloe, 1998; 2004)
- Coastal management plan and Coogee structure plan (City of Cockburn, 2004a; b)

5 ISLAND ECOLOGY

Some of the topics within "island ecology" are encompassed by other broader headings. For example "marine birds and mammals" may include broader references that include but are not limited to islands. Only references that were specific to particular islands have been listed in this section. Management plans are of particular relevance and generally include information on birds, reptiles, mammals, vegetation, habitats, geology and soils. The Endnote database contains PDF documents of some of these management plans. Literature on other aspects of island ecology has been listed below.

- Garden Island Management Plan (Environmental Management Services Pty Ltd, 1993)
- Rottnest Island Management Plan 1985 (Rottnest Island Management Planning Group, 1985)
- Rottnest Island Management Plan 2003-2008 (Rottnest Island Authority, 2003)
- Marmion Marine Park Management Plan (Pobar, 1992)
- Shoalwater Islands Marine Park Management Plan (CALM, 2001)
- Shoalwater Islands Nature Reserve Management Plan (CALM, 1992)
- Carnac Island Nature Reserve Management Plan (Conservation Commission, 2003)

5.1 Vegetation

- landforms, soils and vegetation as a basis for management studies on Garden Island (McArthur and Bartle, 1981)
- Rottnest Island (White and Edminston, 1974)
- Shoalwater Islands Nature Reserve vegetation communities, Penguin Island (CALM, 1992)
- local text on dune vegetation with relevance to islands (Rippey, 1995)
- Rottnest Island vegetation types (McArthur and Bartle, 1981)
- changes in vegetation on Carnac Island (Abbott et al., 2000)

5.2 Reptiles

- biological survey of Garden Island, birds and reptiles (Brooker et al., 1995a)
- additional species of reptile for Rottnest Island (Smith, 1997)

5.3 Insects

- butterflies on Garden Island and Rottnest Island (Williams, 1997)
- butterflies on Rottnest Island (Powell, 1998)

5.4 Birds

Rottnest Island

- insectivorous birds (Wheeler, 1993; Wheeler and Calver, 1996)
- fairy terns (Serventy, 1951)
- avifauna (Storr, 1964)
- osprey nesting (Holsworth, 1965)
- birdlife (Saunders and de Rebeira, 1985a)
- breeding bird populations (Saunders and de Rebeira, 1985b)
- biology of silver gulls (Thomas, 1993)
- breeding of the wedge-tailed shearwater (Garkaklis et al., 1998)
- population ecology of wedge-tailed shearwaters (Sims, 1993)

Garden Island

- birds (Brooker et al., 1995a)
- little penguins (Cannell, 2002)

Carnac Island

- seabirds (Dunlop and Storr, 1981)
- the effect of seabirds on vegetation (Abbott et al., 2000)

Penguin Island

- biology and diet of the little penguin (Klomp, 1987)
- breeding patterns of little penguins (Wienecke, 1989)
- Bridled terns *Sterna anaethetus* (Garavanta, 1991)
- reproductive behaviour of bridled terns (Garavanta, 1991)

General "Islands"

- birds of the islands (Serventy, 1938)
- birds of small islands near Perth (Abbott, 1976)

5.5 Mammals

- quokkas on Rottnest Island (Rottnest Island Authority, 2003)
- terrestrial mammals of Garden Island (Brooker et al., 1995b)
- quokka ecology on Rottnest Island (Blumstein et al., 2001)

5.6 General

- fauna of Rottnest (Thomson, 1951)
- fauna of a sandy shore at Careening Bay, Garden Island (Burbidge et al., 1963)
- fauna and flora of rocky shores of Carnac Island (Marsh and Hodgkin, 1962)

5.7 Development

- water supply and wastewater treatment on Rottnest Island (EPA (WA), 1991)

- water supply and wastewater treatment system on Rottnest Island, Public Environmental Review (Rottnest Island Authority, 1991)

5.8 Gaps in the knowledge island ecology and

It was beyond the scope of this project to identify gaps in knowledge for this section. Perusal of various island management plans might provide some direction.

6 MARINE BIRDS AND ANIMALS

6.1 Birds

Marine birds appear to have been studied in some detail in the SCC region. Areas of attention have been birds of Rottnest, Penguin and Carnac Islands. Individual species examined include little penguins, bridled terns, silver gulls, wedge-tailed shearwaters, ospreys and fairy terns. The effect of the Leeuwin current on bird populations has also been examined. Examples specific to Islands have been included in the Island Ecology section. Other literature is summarised below.

- ocean birds of Perth beaches (Glauert, 1943)
- birds of Warnbro Sound (Serventy and White, 1943)
- marine birds of the eastern Indian Ocean (Dunlop et al., 1988)
- breeding in silver gulls (Meathrel, 1991)
- breeding phenology and behaviour of the little Penguin (Nicholson, 1994)
- status of seabirds in Western Australia (Burbidge, 1996)
- bird database (CALM, 1996)
- foraging behaviour of Little Penguins (Cannell and Cullen, 1998)
- waders at Woodman Point (Singor, 1999)
- survey from Port Lincoln to Fremantle mainly over continental shelf waters (Surman and Wooller, 2000)
- status of little penguins in Western Australia (Cannell, 2001)
- radio tracking penguins in Victoria, may be of local relevance (Weavers, 1991)
- effects of increases in populations of cormorants on island vegetation (Rippey et al., 2002)

6.2 Seals

Seals or sea-lions are distributed along the temperate coast of Western Australia. Colonies inhabit Carnac Island, Seal Island (in the Shoalwater Marine Reserve) and Little Island (in the Marmion Marine Park). Regulations are in place to minimise disturbance to these colonies (see management plans). The biology, movements and distribution of sea lions has received attention in the literature and some references from the database are listed below.

- biology and movements of Australian sea-lions (Gales et al., 1992)
- distribution of sea-lions and fur seals in Western Australia (Abbott, 1979)
- sea lions (Bennett, 1997)
- Shoalwater Islands Nature Reserve (CALM, 1992)
- tuberculosis in seals (Cousins et al., 1993)
- seals in Western Australia (Ling, 1982)
- Marmion Marine Park, Seal Island (Pobar, 1992)
- Carnac Island Management Plan (Conservation Commission, 2003)
- Breeding biology and movements of Australian sea-lions (Gales et al., 1992)

6.3 Gaps in knowledge marine birds and mammals

It was beyond the scope of this project to identify gaps in knowledge for this section. To identify gaps would require an understanding of the distribution and biology of bird and mammal species in the SCC region, and of particular threats such as predation by introduced species. This information may be available in the broader literature pertaining to the temperate west coast of Western Australia. Potential gaps could be discussed with the Department of Conservation and Land Management.

7 FISH BIODIVERSITY

There are a number of excellent books on the distribution and identification of temperate fishes that cover the SCC region (Kuiter, 1996; Allen, 1997; Edgar, 1997; Hutchins and Swainston, 1999; Hutchins and Thompson, 2001). There is also a global information system on fishes called Fishbase (World Fish Center, 2004) that includes images, distribution and biological characteristics of all known fish species. The Leeuwin current brings warm northern waters to the coast of Rottnest Island. This has influenced the structure of fish assemblages at Rottnest with a number of tropical species noted (Hutchins and Pearce, 1994). Hutchins (1977; 2001b; 2001a) has done a substantial amount of work on the distribution and diversity of fish assemblages at Rottnest and at some areas along the metropolitan coast. However, no other assessments of fish biodiversity in the SCC region were located.

7.1 Gaps in the knowledge of fish biodiversity

Information is lacking on the biodiversity of fishes in the SCC region. Studies should examine how fish populations change seasonally in response to temperature fluctuations, the ecological role of fishes and include quantitative information on exploited and unexploited species.

THREATENING PROCESSES

1 SEA LEVEL RISE

The literature search revealed one study that addressed the threat of sea-level rise in the SCC region (Kay, 1996). The lack of other studies may be due to information being in literature with a broader focus. There was historical information on sea level changes at Rottnest Island (Teichert, 1950; Playford and Leech, 1977; Stirling et al., 1998; Baker et al., 2001) and the role of sea level fluctuations in coastal processes on the Swan Coastal Plain (Seddon, 1972; Sanderson et al., 2000).

1.1 Gaps in the knowledge: sea level rise

This issue may require further investigation as very little information was discovered in the literature search. However, as stated, information may be contained in broader planning documents.

2 DEVELOPMENT

Coastal developments may affect water quality, seagrasses, reef habitats, hydrodynamics and coastal processes such as sediment transport. However, this very much depends on the nature of the development. Physical removal of seagrasses through dredging may be a threatening process but must be taken in context with rehabilitation programs and the amount of seagrass loss in a given area.

Where large areas of the ocean are reclaimed for buildings or marinas there will obviously be a loss of habitat whether that is reef, seagrass or sandy bottoms. It is also likely that physical structures will affect the natural movement of sand. Marina and harbour developments in the SCC region include the Sorrento Boat Harbour (Scott & Furphy Engineers Pty. Ltd. and LeProvost Semeniuk & Chalmer, 1984; Department of Conservation and Environment, 1985), Mindarie Keys (Environmental Protection Authority, 1985; Scott & Furphy Engineers Pty. Ltd. et al., 1985), Ocean Reef Marina (Harbours and Rivers Branch, 1978; DAL, 2000) and Jervoise Bay Southern Harbour (Environmental Protection Authority, 1998; Halpern Glick and Maunsell, 1998; DAL, 1999; 2001; 2002; Tunbridge, 2002).

The impacts of onshore developments may not have the same environmental footprint as marinas and harbours but may have runoff or effluent issues to address. Most information on coastal developments is contained in consultant reports. These are usually in the form of Consultative Environmental Reviews (CERs), Public Environmental Reviews (PERs) or Environmental Review and Management Plans (ERMPs). These documents are assessed by the Department of Environment who release a "Report and Recommendations" on whether the development should proceed, and impose certain guidelines to ensure adequate monitoring and minimisation of impacts. Users of the Endnote library should search under consultant reports, and then look for the relevant EPA Report and Recommendations. If consultant reports are not available in libraries requests should be made direct to the relevant company, however some reports may regarded as confidential.

Large scale industrial development impacted seagrass meadows in Cockburn Sound in the 1960s (see section on seagrasses). The Cockburn Sound Management Council may have more information on past and present impacts or threats in this region.

2.1 Gaps in the knowledge: coastal developments

Given the amount of industrial development along the shores of Cockburn Sound, and the history of seagrass loss in the region, ongoing monitoring of seagrasses and water quality is imperative. Some coastal developments may provide a physical habitat for marine organisms and this should be investigated.

3 COASTAL EROSION

There have been a number of studies on coastal erosion in the SCC region. Erosion issues should also have been raised in consultant reports on coastal marina developments and the corresponding Environmental Protection Authority Reports and Recommendations. Coastal erosion can be caused or exacerbated by nearshore seagrass loss, unmanaged beach access over vegetated dunes, or coastal developments. Some references from the database, on coastal erosion and coastal processes, are listed below.

- sand movement in Cockburn Sound, approaches to Fremantle and its application to beach erosion problems, at Cottesloe (Kempin, 1949; 1976)
- shoreline stability from Fremantle to Cape Peron (Andrews, 1979)
- impact of sea-breezes on nearshore and foreshore processes (Pattiaratchi et al., 1997)
- the effects of breeding birds on vegetation and erosion (Rippey et al., 2002)
- coastal shoreline movements (WALIS, 2004)
- dune rehabilitation at Leighton Beach (Woods, 1979)
- coastal processes and sand movement (Hegge, 1994)
- Shoreline salients, cuspate forelands and tombolos on the coast of Western Australia (Sanderson and Eliot, 1996)
- changes in beach morphology (Masselink and Pattiaratchi, 2001)

- coastal management in Western Australia (Department of Conservation and Environment, 1980)

3.1 Gaps in the knowledge: coastal erosion

Gaps in the knowledge were not assessed for this section. Large scale assessment of coastal sand movement could be achieved using aerial photography or the Skyview facility provided by the Department of Land Administration (Department of Land Information, 2004). Information on coastal erosion and dune management may also be included in local government management plans or strategies.

4 NUTRIENTS

Potential sources of nutrients to marine waters of the SCC region are wastewater outfalls, groundwater discharge, the Swan River and urban runoff. Some of these issues are discussed in the sections on water quality, stormwater and wastewater outfalls. The Water Information Database contains information on nutrient characteristics of groundwater (Water and Rivers Commission, 2004). Seabase contains nutrient information for coastal waters (DALSE, 2004). Other articles of relevance are listed below.

Groundwater discharge

- The effect of submarine groundwater on nutrient and salinity regimes in a coastal lagoon off Perth (Johannes and Hearn, 1985)
- Nutrient discharge beneath urban lawns to a sandy coastal aquifer, Perth (Sharma et al., 1996)
- discharge of nitrogen and phosphorus from groundwater into Cockburn Sound (Appleyard, 1994)
- groundwater quality in the Kwinana industrial area (Environmental Protection Authority, 1993a)
- impact of urban development on recharge and groundwater quality (Appleyard, 1995)

Swan River

- Managing urban water quality in Western Australia (Lord, 2000)
- Dynamics of the Swan River estuary (Stephens and Imberger, 1996)

4.2 Gaps in the knowledge: nutrients

More work may be needed on nutrient contributions from the Swan River to the receiving marine waters. Winter flows from the Swan River are at times carried many kilometres north of Fremantle.

5 INTRODUCED MARINE PESTS

A number of articles were located on introduced marine pests. The most notable in Western Australian waters may the fan worm *Sabella spallanzanii*. An outbreak of *Sabella* was recorded on Southern Flats in Cockburn Sound in the 1990s. This was investigated by Clapin (1995). However, further investigations in January 1997 revealed a massive die off of the worm. Other studies on *Sabella* include Lemmens (1996) and Ward (1996). The introduced seaweed *Undaria pinnatifida* has

colonised areas of the south coast of Australia and may threaten macroalgal diversity and food-web structure (Walker and Kendrick, 1998). Other relevant references are listed below.

- identifying marine pests (Department of Fisheries, 2000; Hayes and Sliwa, 2002)
- Temperature and salinity tolerances of the larvae of the Northern Pacific Sea star *Asterias amurensis* (Sutton and Bruce, 1996)
- Introduced species survey: Fremantle (CRIMP, 2000)
- Prevention and management of marine pest incursions (Department of Environment and Heritage, 2000)
- Ballast Water Management in Western Australia (Fremantle Port Authority, 2004a)
- Mapping the Australian ballast water uptake and discharge contingency zones (Hobday et al., 2002)

5.1 Gaps in the knowledge: marine pests

To identify gaps in the knowledge of marine pests will require examining literature of a broader geographical nature. The SCC region may be at risk of marine pest introductions but a review should be conducted covering all species that have been introduced to temperate waters similar to the SCC region and are regarded as pests.

6 STORMWATER AND WASTEWATER OUTFALL

6.1 Stormwater

There was very little literature on the effects of stormwater on the marine environment. Appleyard (1993) examined the impact of stormwater runoff from a light industrial area, a medium-density residential area, and a major arterial road on groundwater quality. This was not of particular relevance to the marine environment but highlighted the potential effects of stormwater. There is also some literature on the effects of stormwater and road runoff on the Swan River ecosystem and on methods to treat stormwater to remove nutrients.

- Biomarkers of exposure in fish inhabiting the Swan-Canning Estuary (Webb and Gagnon, 2002)
- Removing filterable reactive phosphorus from highly coloured stormwater (Lund et al., 2001)
- Distribution of heavy metals in near-shore sediments of the Swan River estuary (Rate et al., 2000)

6.2 Wastewater outfall (Beenyup, Swanbourne and Peron)

The Perth Long-term Ocean Outlet Monitoring (PLOOM) study is an ongoing assessment of the effect of three wastewater discharge outlets in the Perth metropolitan area at Ocean Reef, Swanbourne and Sepia Depression. There are risks associated with discharge of wastewater to the marine environment including elevated nutrient concentrations in receiving waters that may stimulate primary producers, bacteria that may affect human health and metals and pesticides that may be bioaccumulated by marine organisms. These risks are acknowledged in the PLOOM study and monitoring is aimed at evaluating the risks. The study is a collaborative effort between consulting firms and universities and is managed by DAL Science and Engineering on behalf of the Water Corporation. The information from the PLOOM study is generally restricted to the areas at risk in the vicinity of the three ocean outlets. The executive summary of the Perth Long-Term Ocean Outlet Monitoring Programme 2001–2002 (PLOOM 3) (DALSE, 2003) contains results on the contaminant concentrations, nutrient concentrations, bacterial concentrations, effluent toxicity, periphyton

biomass, epiphyte loads on seagrasses and changes in macroalgal composition. Also see section on Water Quality.

There are over 50 references in the Endnote library that contain the term outfall or outlet. These include assessment of the Ocean Reef outlet duplication (Water Authority of Western Australia, 1988a; b; CALM, 1990; Environmental Protection Authority, 1990; 1994; Lord and Hillman, 1995) and reports that make up the Perth Coastal Waters Study, the Southern Metropolitan Coastal Waters Study and the Perth Long Term Ocean Outlet Study.

Gartner (2000) and Gartner and Lavery (2002) examined the use of stable isotopes of nitrogen to trace sewage from the Ocean Reef outfall. The results suggested a relationship between algal functional form and isotopic signatures that could be applied to determine the dispersal of sewage over different timescales. DALSE (2003) also noted that spring periphyton samples indicated stable nitrogen isotopes can be applied as a monitoring tool for Beenyup treated wastewater. They are proposing to investigate these trends in future PLOOM programmes.

7 CONTAMINATION INCLUDING TRIBUTYLTIN

Heavy metals and pesticides may accumulate in the marine environment as a consequence of sewage disposal, antifouling paints and industrial discharges. Tributyltin (TBT) has been recorded in concentrations above environmental quality guidelines in Jervoise Bay northern and southern harbours, at the Kwinana Bulk Terminal and at the Kwinana Bulk Jetty (Cockburn Sound Management Council, 2004b). TBT may lead to imposex (the imposition of male characteristics on female gastropods) and the gastropod *Thais orbita* is often used to as a bioindicator of TBT contamination. Imposex in *Thais orbita* was greater than the environmental quality standard in Jervoise Bay, Challenger Beach and Colpoys Point (in Cockburn Sound) in 1999 (Cockburn Sound Management Council, 2004b). Since July 1991, the use of TBT in antifouling paints has been limited to vessels greater than 25m in length. Studies of relevance to contamination issues are listed below.

7.1 Tributyltin and imposex

- The use of *Thais orbita* as a bioindicator for environmental contamination of tributyltin (Field, 1993)
- A comparative survey of heavy metals in the mussel *Mytilus edulis* from Cockburn Sound (Burt and Scrimshaw, 1993)
- Organic pollutants in mussels and sediments of the coastal waters off Perth (Burt and Ebell, 1995)
- Contaminant inputs inventory of the southern metropolitan coastal waters of Perth (Martinick, 1992)
- Imposex of *Thais orbita* at Rottnest (Kohn and Almasi, 1993)
- Imposex in *Lepsiella vinosa* from Southern Australia (Nias et al., 1993)
- Imposex in Morula granulata as bioindicator of tributyltin (TBT) contamination (Reitsema and Spickett, 1999)
- Biomarkers in the environmental risk assessment process: tributyltin as a case study (Reitsema, 2002)
- Imposex still evident in eastern Australia 10 years after tributyltin restrictions (Gibson and Wilson, 2003)
- Surveying imposex in the coastal waters of Perth, Western Australia, to monitor trends in TBT contamination (Reitsema et al., 2003)
- TBT in Cockburn Sound (Cockburn Sound Management Council, 2004b)
- The management of tributyltin (TBT) anti-foulants in Western Australia (Fremantle Port Authority, 2004b)

7.2 Other contaminants

- State of the Marine Environment Report for Australia: Pollution (Department of Environment Sport and Territories, 1995)
- State of the Marine Environment Report for Australia: State and Territory Issues (Department of Environment Sport and Territories, 1996)
- Perth Coastal Waters Management and Consultative Process (Department of Environmental Protection, 1998)
- Some heavy metals in Cockburn Sound sea water (Bell et al., 1979)
- Southern metropolitan coastal waters study (Department of Environmental Protection, 1996)
- Western Australian water quality guidelines for fresh and marine waters (Environmental Protection Authority, 1993b)
- A review of heavy metal and organochlorine levels in marine mammals in Australia (Kemper et al., 1994)
- Perth Long-Term Ocean Outlet Monitoring Programme 2001–2002 (PLOOM 3) (DALSE, 2003)
- Investigation of the environmental effects of an arsenic trioxide spill in Cockburn Sound (Masini and Manning, 2001)
- Heavy metal concentration in the muscle tissue of 12 species of teleost from Cockburn Sound (Plaskett and Potter, 1979)
- Distribution of cadmium in Cockburn Sound (Rosman et al., 1980)

7.3 Contaminants: gaps in the knowledge

Future coastal harbour developments may lead to local increases in tributyltin as shipping traffic increases. Kohn (1993) recorded imposex in 80% of female from seven *Conus* species on intertidal shore platforms at Rottnest Island in 1991. However, there was no effect in 1975. This might be due to TBT contamination in some areas and may warrant further investigation.

Gaps in the knowledge for other contaminants were not assessed. However, a critical review of the literature from the SCC region and elsewhere should be conducted. Further studies may be required to ascertain the extent of TBT contamination in SCC waters, particularly in areas that are subject to heavy traffic from ships greater than 25m in length. This might include Cockburn Sound, Gage Roads, HMAS Stirling, Fremantle Harbour and Ferry Terminals.

8 FISHING IMPACTS

8.1 Exploitation of finfish

The annual State of the Fishery report (Department of Fisheries, 2003) contains information on exploited fish species in Western Australia. The SCC region falls within the West Coast Bioregion, which extends from north of Kalbarri to the east of Augusta. The State of the Fishery report provides detail on commercial and recreational fisheries with estimates on amount retained, effort, and the proportions of commercial and recreational catch. Assessments are made on the effects of fishing on non-retained species (i.e. bycatch), the food-chain and habitat. The social and economic effects of fishing are also discussed. There was no assessment of food-chain effects for the Cockburn Sound Finfish Fishery or the West Coast Demersal Scalefish Fishery.

Potential impacts of fishing include overexploitation, targeting of vulnerable species and physical impacts to habitat from trawling or anchor damage. There is also evidence that fishing can affect the food-chain (Cole and Keuskamp, 1998; Pauly et al., 1998; Babcock et al., 1999b; Daskalov, 2002; Shears and Babcock, 2002; Shears and Babcock, 2003; Westera, 2003). This may occur when reductions in predatory fish lead to increases in the populations of their prey.

Fishes that are commonly targeted in the SCC region include pink snapper, dhufish, blue groper, harlequin fish, queen snapper, trevally and breaksea cod, among others (Department of Fisheries, 2002). Some of these fishes may be vulnerable to overfishing due to being limited in their movement (Holland et al., 1996; Parsons et al., 2003; Sumpton et al., 2003) and having low rates of growth, mortality and recruitment (World Fish Center, 2004). Some are also top-level predators that may influence marine food-webs. A greater understanding is needed of the ecosystem effects of fishing and this principle is being adopted by the Department of Fisheries (2003).

8.2 Rock lobster and other decapod crustaceans

There has been a significant amount of research into the biology and ecology of rock lobster (*Panulirus cygnus*) in Western Australia, due to the high economic value of the fishery. Information on catch, effort and biology is contained in annual reports on the rock lobster fishery (Chubb and Barker, 2003) and in the annual "State of the Fishery" report (Department of Fisheries, 2003).

There are numerous other research articles contained in the Endnote library on rock lobster that are relevant to the SCC region and users should search under the desired terms. These studies include modelling catches (Hall, 1997), the influence of the Leeuwin Current (Pearce and Phillips, 1988; Caputi et al., 1996; Griffin et al., 2001; 2002), the influence of water circulation (Hearn, 1983), foraging patterns (Jernakoff, 1987) and studies on density and growth (Jernakoff et al., 1994).

The Endnote library also contains some information on the blue manna crab (*Portunus pelagicus*). Most of the commercial prawn catch comes from areas outside the SCC region (Department of Fisheries, 2003). There appears to be less information available on other crustaceans in the SCC region, which may be due to the fact that they have no immediate economic value, are low in abundance or are cryptic by nature.

8.3 Gaps in the knowledge: fishing

To identify all gaps in the knowledge of fishing impacts is beyond the scope of this project. However, it appears that more knowledge should be obtained on the food-chain effects of some fisheries in the SCC region. There also appears to be a lack of quantitative information on non-targeted fish. These may play an important role as a food source for targeted fish, may have an important ecological role, or may be valued in terms of biodiversity and conservation. Knowledge exists on the distribution and biology of many non-exploited fishes but quantitative data may be lacking.

There is a lack of knowledge on unexploited assemblages of fish. We will never be able to understand *natural* levels of fish stocks because the SCC waters have been fished for many decades. However, knowledge is needed on how fish might build-up when fishing pressure is removed and how fish assemblages in closed areas might influence adjacent fished areas in terms of spillover of fishes and as a supply of eggs and larvae. Such studies should take into account the displacement effect, which is the redirection of fishing effort when certain areas are closed to fishing.

Recreational fishing is currently managed using bag and size limits. Estimates of recreational catch and effort exists from 1996-97 surveys, based on interviews with fishers at boat ramps (Sumner and

Williamson, 1999). There may be a need for ongoing quantification of recreational catch through some form of licensing and/or reporting. This will be controversial and must be discussed with representatives from the Department of Fisheries.

More work is needed on fish assemblages and fish ecology at Rottnest Island. The Rottnest Island Authority state that "the level of fishing pressure within the Reserve and the impact of this on fish stocks and marine communities is unknown" (Rottnest Island Authority, 2003).

Oral historical surveys, such as that conducted by Weaver (1998) at Ningaloo, can be a useful means to gain anecdotal information on how fishing may have changed in certain areas. Consideration should be given to conducting oral surveys on marine issues in the SCC region and these should include information from indigenous groups.

Other areas that could be investigated with respect to various fish species include age at maturity, fecundity, lifespan, larval lifespan and recruitment. These issues were beyond the scope of this project but would have application to temperate waters of the southwest of Western Australia, including the SCC region. These issues should be discussed with the Department of Fisheries.

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APPENDIX 1 – SEARCHES

Library Catalogues	Web address
Edith Cowan University	http://exlibris.curtin.edu.au/index.html
University of Western Australia	http://www.library.uwa.edu.au/catalogue/
Curtin University	http://exlibris.curtin.edu.au/index.html
Murdoch University	http://wwwopac.murdoch.edu.au/
LISWA - Library Information Service Western Australia	http://henrietta.liswa.wa.gov.au/
National Library of Australia	http://www.nla.gov.au/

UWA - information toolbox	ECU - Indoor databases
Aquatic network	Applied Science and Technology Plus - Proquest
Aquatic sciences and fisheries abstracts	AUSTROM
Australian Institute of Marine Science	Blackwell Synergy
Biological abstracts	ELIXIR (Natural Resources & Environment)
CAB abstracts	EVA: Environmental Abstracts
CSIRO marine research	General Science Plus
Current contents connect	Heritage & Environment
Digital Dissertations	Ingenta
El Nino theme page	ISI - Current Contents
FishBase : a global information system on fishes	REEF (Great Barrier Reef)
Fisheries Western Australia	ScienceDirect
GeoRef	STREAMLINE (Natural Resources)
IEEE Xplore	Web of Science (ISI)
Marine information	Zoological Record Plus
Marine web site	
Ovid	
ProQuest 5000	
Proquest science journals	

Murdoch - Digital Collections	Curtin - Database and Electronic Research Tools
ANRO - Aust Agriculture and Natural Resources Online	Not available without staff or student identification
Aquatic Sciences & Fisheries Abstracts	
AusStats - Australian Bureau of Statistics (1998-)	**Notre Dame**
Dissertation Abstracts	Not available without staff or student identification
Ingenta	
Oceanic Abstracts (CSA) (1981-)	
Proquest Digital Dissertations (Current and previous year)	
Science Citation Index (1992-)	
Springer journals online	
Streamline - Australia's Natural Resources Database (Informit) (1982 -)	

Government Departments and Government Libraries	
Agriculture Fisheries and Forestry - Australia	www.affa.gov.au
Australian Biological Resource Survey	http://www.deh.gov.au/biodiversity/abrs/
Australian Museum	http://www.amonline.net.au/
Australian Oceanographic Data Centre	http://www.aodc.gov.au/
Australian Government Index of Publications	http://www.nla.gov.au/oz/gov/agip.html
Department of Conservation and Land Management	http://www.calm.wa.gov.au/
Cockburn Sound Management Council	http://www.wrc.wa.gov.au/region/csmc/index.html
CSIRO Research - Introduced Marine Pests (CRIMP)	http://www.marine.csiro.au/crimp/

Department of Environment and Heritage - Library	http://www.deh.gov.au/about/library/index.html
Department of Environmental Protection (DOE)	http://www.environ.wa.gov.au/contents.asp?id=7
Department of Land Administration	http://www.dola.wa.gov.au/corporate.nsf
Environmental Protection Authority	http://www.epa.wa.gov.au/
Departmen of Fisheries, Western Australia	http://www.fish.wa.gov.au/res/index.html
Fisheries Research and Development Corporation	http://www.frdc.com.au/
Fremantle Port Authority	http://www.fremantleport.com.au/
Rottnest Island Authority	http://www.rottnest.wa.gov.au/rotto/
WA Museum library catalogue	http://library-srv.museum.wa.gov.au/menu.htm
Water Corporation	http://www.watercorporation.com.au/
Western Australian Land Information System (WALIS)	http://www.walis.wa.gov.au/cgi-bin/index.cgi?offset=121
Western Australian Tourism Commission	http://www.tourism.wa.gov.au/

Local Councils

City of Rockingham	www.rockingham.wa.gov.au
City of Cockburn	www.cockburn.wa.gov.au
City of Wanneroo	www.wanneroo.wa.gov.au
City of Fremantle	www.fremantle.wa.gov.au
Town of Cottesloe	www.cottesloe.wa.gov.au
Town of Mosman Park	www.townofmosmanpark.wa.gov.au
City of Stirling	www.stirling.wa.gov.au
Town of Cambridge	www.cambridge.wa.gov.au

Others

ATA Environmental (fomerly alan Tingay and Associates)	www.ataenvironmental.com.au
Centre for Water Research (CWR)	http://www.cwr.uwa.edu.au/
DAL Science and Engineering (DALSE)	http://www.dalse.com.au/publications.htm
Dalcon Environmental	http://www.environmental.dalcon.com.au/
Ecoscape (Australia) P/L	www.ecoscape.com.au
Gutteridge Haskins and Davies (GHD)	http://www.ghd.com.au/
Hart Simpson and Associates	http://www.amc.aunz.com/hsa.html
Marine and Freshwater Research Laboratory (MAFRL)	http://wwwscience.murdoch.edu.au/centres/mafrl/
Maunsell Australia P/L	http://www.hgm.com.au/home/home_default.asp
Sinclair Knight Merz	http://www.skm.com.au/index.cfm
World Wildlife Fund (WWF) - Australia	http://www.wwf.org.au/News_and_information/Publications/