INTERIM RECOVERY PLAN NO. 153

THROMBOLITE (STROMATOLITE-LIKE MICROBIALITE) COMMUNITY OF A COASTAL BRACKISH LAKE (Lake Clifton)

INTERIM RECOVERY PLAN

2004-2009

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Photograph: Val English

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FOREWORD

Interim Recovery Plans (IRPs) are developed within the framework laid down in Department of Conservation and Land Management (CALM) Policy Statements Nos. 44 and 50.

IRPs outline the recovery actions that are required to urgently address those threatening processes most affecting the ongoing survival of threatened taxa or ecological communities, and begin the recovery process.

CALM is committed to ensuring that Critically Endangered, and where appropriate and feasible, other threatened ecological communities are conserved through the preparation and implementation of Recovery Plans or Interim Recovery Plans and by ensuring that conservation action commences as soon as possible and always within one year of endorsement of that rank by the Minister.

This Interim Recovery Plan will operate from June 2004 to May 2009 but will remain in force until withdrawn or replaced. It is intended that, if the ecological community is still ranked Critically Endangered, this IRP will be reviewed after five years and the need for a full Recovery Plan assessed.

This IRP was given regional approval on 30 October, 2003 and was approved by the Director of Nature Conservation on 15 June, 2004. The allocation of staff time and provision of funds identified in this Interim Recovery Plan is dependent on budgetary and other constraints affecting CALM, as well as the need to address other priorities.

Information in this IRP was accurate at June 2004.

ACKNOWLEDGMENTS

The Endangered status of the microbial community at Lake Clifton was identified under the Australian Nature Conservation Agency funded project entitled 'identifying and conserving threatened ecological communities in the South West Botanical Province' (English and Blyth 1997).

The following people provided valuable advice and assistance in the preparation of this Interim Recovery Plan;

Philip Commander	Water and Rivers Commission
Steve Dutton	Ranger in charge, Yalgorup National Park
Jacob John	Associate Professor in Aquatic Biology, Curtin University of Technology
Sarah Goater	University of Western Australia
Brenton Knott	Senior Lecturer, University of Western Australia
Jim Lane	Principal Research Scientist, CALM's Science Division
Linda Moore	Principal Environmental Consultant, ENV Australia
Fiona O'Connor	Lake Clifton Landcare Group
Jane O'Malley	Environmental Officer, City of Mandurah

SUMMARY

Name: Thrombolite (stromatolite-like microbialite) community of a coastal brackish lake (Lake Clifton)

Description: Thrombolite community formed by biologically influenced precipitation of aragonite in a coastal brackish lake (Lake Clifton). The community occurs on a relict foredune plain on Holocene sands at Lake Clifton, southwest of Mandurah and is a complex association of photosynthetic cyanobacteria and purple sulphur bacteria, eukaryotic microalgae and what are known as 'true bacteria'. Thrombolitic structures (those that have an internal clotted structure as opposed to those that have a laminated organisation which are stromatolitic) are formed through precipitation of calcium carbonate within the microenvironment of microbes as a result of photosynthetic and metabolic activity.

CALM Region: Swan

CALM District: Swan Coastal

Local Government Authority: City of Mandurah; Shire of Waroona

Recovery Team: Established as the Lake Clifton Thrombolites Recovery Team in May 2002. Membership: representatives from CALM's Swan Region (Chair) and Swan Coastal District, City of Mandurah, Science Division, City of Mandurah, University of Western Australia, Water and Rivers Commission, CSIRO, Lake Clifton Landcare Group, Agriculture WA, and CALM's WA Threatened Species and Communities Unit. The Recovery Team will report annually to CALM's Corporate Executive.

Current status: The thrombolite community of Lake Clifton was initially assessed as Endangered in 1996. Due to the increase in nutrient concentrations it was then reassessed on the 18 February 2000 as Critically Endangered. It currently meets Critically Endangered (CR) under criteria Bi and Bii due to a highly restricted distribution with very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes which are likely to result in total destruction throughout its range in the immediate future.

Habitat requirements: the growth of the community is probably dependent upon continuing supply of fresh water rich in calcium, bicarbonate and carbonate. Calcium carbonate is precipitated out by the biological activity of the microbes. These microbes include cyanobacteria dominated by *Scytonema*, and other photosynthetic bacteria that depend on light for growth and survival. The source of the calcium in the waters of Lake Clifton is probably groundwater that has passed through sand dunes that surround the lake. Lake Clifton is poikilosaline: it shows seasonal trends in salinity, a reflection of the Mediterranean climate, but until the last 10 years has remained less saline than sea water in historical times.

The coastal dune formation contains Pleistocene aeolian sands overlying Tamala Limestone, which in turn overlies a stratum of Lower Cretaceous sands, siltstones and mudstone.

Habitat critical to the survival of the species, and important populations: Given that this community is listed as Critically Endangered it is considered that all known habitat is habitat critical.

Benefits to other species/ecological communities: Recovery actions implemented to improve the quality or security of the community are likely to improve the status of any species within the community.

International Obligations: This plan is fully consistent with Australia's responsibilities under the Convention on Wetlands of International Importance especially as Waterfowl Habitat 1975 (Ramsar Treaty), under which Lake Clifton is listed, and with the aims and recommendations of the Convention on Biological Diversity, ratified by Australia in June 1993. The plan will assist in implementing Australia's responsibilities under these conventions.

Role and interests of indigenous people: Some artefacts have been discovered within the Yalgorup National Park. However, no recognised archaeological sites within the Park are listed on the Department of Indigenous Affairs' Aboriginal Heritage Sites Register. The area has not been examined in detail and it is possible that sites exist within the Park. The Winjan Aboriginal Corporation and Bibbulum groups represent Aboriginal people in the Peel Region but no groups are actively involved in relation to the management of Yalgorup National Park. The Yalgorup National Park Management Plan recommends a number of actions related to the protection and conservation of the Park's Aboriginal cultural values. These recommended actions will be implemented during the implementation of this plan.

Social and economic impacts: The implementation of this recovery plan has the potential to have some limited social

and economic impact, as the catchment area for the lake is located on private property. Recovery actions refer to continued liaison between local landowners.

Evaluation of the Plan's Performance: CALM, in conjunction with the Recovery Team will evaluate the performance of this IRP. The plan is to be reviewed within five years.

Critical habitat: The critical habitat for the thrombolite community of coastal brackish lakes is Lake Clifton itself and the groundwater and associated catchment that contribute to the lake waters.

IRP Objective(s): To maintain or improve the overall condition of Lake Clifton thrombolites and reduce the level of threat.

Criteria for success:
- Improved understanding of the lake processes enabling recovery management
- Reduction of nutrient levels in Lake Clifton
- Salinity levels appropriate for the survival of the thrombolitic microbial community
- Maintenance of the vigour and extent of the microbial community including maintenance of the composition of the microbial species.

Criteria for failure:
- Significant and sustained detrimental changes to water quality or water levels in Lake Clifton
- Significant decline in area of living thrombolites
- Major shift in composition of the microbial community.

Recovery Actions:
1. Coordinate recovery actions.
2. Map critical habitat.
3. Clarify the extent and condition of the community.
4. Seek creation and protection of a suitable native vegetation buffer for the lake.
5. Conduct biological research to clarify threats to the thrombolites and help design recovery actions.
6. Manage access to site.
7. Ensure areas containing the microbial community are protected from physical damage.
8. Manage physical impacts to thrombolites through provision of information.
9. Undertake ongoing monitoring of physical condition and microbial assemblage of thrombolites.
10. Monitor water quality and hydrology.
11. Determine the range of normal fluctuations for hydrological regimes and attempt to maintain them within that range.
12. Manage water quality.
13. Provide information to surrounding landholders to ensure actions on their lands do not impact the thrombolites.
14. Cooperate with appropriate agencies to manage land uses to ensure appropriate water quality within the lake.
15. Liaise with the EPA to encourage the updating of Bulletin 864 and the formulation of an Environmental Protections Policy.
16. Collect relevant baseline information and ongoing monitoring data for the vegetation that provides a buffer for the thrombolite community.
17. Control weeds and rehabilitate plant communities on eastern side of lake.
18. Develop and implement an approved fire management strategy.
19. Ensure maintenance of strategic firebreaks on occurrences or construction of new strategic fire breaks on surrounding lands to help prevent fire spreading to community.
20. Report on success of management strategies for the thrombolite community.
21. Review the need for a full Recovery Plan.

1. BACKGROUND

1.1 History, defining characteristics of ecological community, and conservation significance

Three basic types of microbial structures ('microbialites') formed in benthic areas exist: Stromatolites, thrombolites, and structures that have a less tangible internal framework. Stromatolites have a laminated internal structure, thrombolites have a clotted internal appearance and others such as algal mats and tufa have an ill-defined structure. Microbialites occur in marine, fresh or hypersaline waters, from sub-tropical to cool temperate environments (Moore 1993).

Fossilised stromatolites are the earliest record of life on earth. They dominated the Pre-Cambrian period - between 3.5 billion and 600 million years before present. These formations declined, probably due to the evolution of grazing and burrowing animals that disturbed the structures, around 570 million years ago (early in the Phanerozoic era). The thrombolites then became more dominant as they were probably more resistant to grazing and burrowing animals. An increase in the availability of free oxygen led to the evolution of faster-growing marine organisms such as corals and macroalgae, which then led to the decline of the thrombolites as a result of spatial competition (Moore 1991).

Microbialites are therefore interesting and have great scientific importance, as they provide the oldest evidence of life on Earth and the evidence of historical environments through information encrypted within their structure. Worldwide, these structures are restricted to a few areas of limited extent including the Bahamas, Mexico, Bermuda and Western Australia (Moore *et al*. 1984).

Western Australia contains the oldest microbialite fossils, at 3.5 billion years (Moore 1993). The State also contains the greatest number and most varied occurrences of living microbialites in the world (Moore 1993). Perhaps the best known microbialites in Western Australia occur at Hamelin Pool, Shark Bay. Living microbialites in the south west of the State that are not as well known also occur at Pink Lake (Esperance), Sea Cliffs (Augusta), Lake Clifton, Pamelup Pond - Lake Preston (Yalgorup); Government House Lake (Rottnest Island); Lake Thetis (Cervantes) and at Lake Richmond in Rockingham (Moore 1993). Each of these constitutes a distinct and very significant community in terms of history, structure, and morphology (Moore 1993). Lake Clifton supports the largest known examples of living non-marine microbialites in the southern hemisphere (Department of Conservation and Land Management 1995).

Lake Clifton is the second largest and the most northern lake in the Yalgorup National Park. It is a poikilosaline lake located southwest of Mandurah on the southern Swan Coastal Plain. Lake Clifton measures approximately 21.5km long by 1.5km, with the waterbody covering about 17.8km^2 in maximum extent (Commander 1988). Most of the lake is less than 1.5m deep, with certain areas up to 3.5m in depth. Both the deep basin and the mean annual water level are generally lower than sea level (Moore 1991).

The microbial structures occur in a zone about 15 m wide on the eastern side of the lake, occupying a total area of over 4km^2 (Moore 1991). The structures have been sectioned and the internal structure indicates that the microbialites are thrombolitic in formation.

The thrombolites exhibit a range of external morphologies and vary in size up to 1.3m high. Their external morphology is controlled primarily by fluctuations in water depth, sedimentation rates and prevailing winds and currents (Moore 1991). The minimum net growth rate of the stromatolites at Lake Clifton is around 0.1mm per year (Moore 1993; Moore and Burne 1994). Calcium and carbonates in the water are probably essential for growth of the microbialite structures.

Radiocarbon dating indicates that the age of the thrombolites in Lake Clifton is likely to be approximately 1950 years BP to modern (Moore and Burne 1994). They are likely to have been formed after the isolation of the lake from the sea that occurred between 4,670 and 3,890 years BP (Coshell and Rosen 1994), leaving a 2000 year gap between the lake formation and the start of the thrombolites.

The dunes around the lake were classified as part of the Spearwood Dune System by McArthur and Bettenay (1960). The coastal dune formation contains Pleistocene aeolian sands overlying Tamala Limestone, which in turn overlies a stratum of Lower Cretaceous sands, siltstones and mudstone (Commander 1988; Moore *et al*. 1984).

The Yalgorup Lakes system (which includes Lake Clifton) is listed as one of the Wetlands of International Importance under the RAMSAR and is also included on the Register of the National Estate (Australian Nature Conservation Agency 1996). A Management Plan has also been written for the Yalgorup National Park in 1995 and includes general management specifications for Lake Clifton (Department of Conservation and Land Management 1995). Management objectives in the Plan for Yalgorup National Park relate to the preservation of the thrombolites, namely:

- to protect and conserve lake flora and fauna communities, structures, diversity, distribution and the natural processes that sustain them;
- to protect and conserve quality and quantity of surface water and groundwater and protect special conservation values associated with the lake system; and
- to enhance knowledge of lake hydrology and its function in the lake ecosystem.

Environmental Protection Authority Bulletins (788, 864) have also been produced to protect the water quality and hydrological balance of Lake Clifton. They provide environmental criteria for land use planning on private land within the catchment of the lake. The criteria refer to limits on:

1. Horticultural developments;
   - No horticultural development on the Vasse soils.
   - Horticulture to be set back a minimum from the lake of 150m, with at least 20m of unused Spearwood sand between the crop and the Vasse soils.
   - Horticulture to be on soil with a minimum depth to groundwater of 2m.
   - A vegetated buffer of at least 20m should be retained within the horticulture exclusion zone.
   - No surface water run-off from the horticultural area.
   - Maximum fertilizer rates (in the cropped area) of Nitrogen $200 kg^{-1} ha^{-1} year^{-1}$ and Phosphorus $100 kg^{-1} ha^{-1} year^{-1}$.
   - The Water and Rivers Commission, Agriculture WA and the two local authorities should work together so that new applications for horticultural well licences comply with these criteria, through development of an appropriate farm plan which include the minimum requirements described above
   - Land use management should include soil testing, so that fertilizer application rates can be modified where testing indicates that there is spare phosphorus and nitrogen in the soil.
2. Rural residential developments;
   - For any subdivision within the catchment, the average lot size should not be less than 5ha. In achieving the average lot size, no lot should have an area of less than 2ha. Further subdivision of the same land, or part thereof, should not be permitted where this would result in an average lot size less than the 5ha as originally determined.
   - Domestic water allocation to be 1500KL per lot per year.
   - Conventional septic systems should not be permitted, instead alternative effluent systems using amended soil with high nutrient retaining capacities to treat the effluent should be used.
   - Stock should only be allowed in the area of the lot between the building envelopes and the edge of the lot as an occasional fire control measure on those lots already parkland cleared.
   - Stocking rates should be determined based on area of cleared land, and not total lot size.
   - Only stocking rates should be set as those for dry pasture, with no importation of feed allowed.
   - For lots adjacent to the lake, either the number of lots abutting the lake should be minimised, or appropriate management measures should be applied to reduce uncontrolled human access to the lake, the vegetated buffer and the thrombolites.
   - Building envelopes should:
     not be located on the Vasse landform type,
     be set back at least 150m from the high water mark of the lake, and
     be set back at least 20m between the edge of the Vasse landform and/or freshwater wetland (area of groundwater intrusion at edge of lake).
   - Intensive land uses requiring high water and fertilizer should not be permitted.

- For lots covered with native vegetation, clearing of vegetation should be restricted to the provision of services and building envelopes.
- For lots parkland cleared, it should be possible in most cases to avoid the loss of trees through careful design of the lot.
- Unless otherwise determined by the WAPC, and in accordance with the Coastal and Lakelands Planning Strategy, subdivision should be supported by Town Planning Scheme provisions, where appropriate, to ensure that these criteria can be met.

3. Tourist developments;
   - Tourist developments must be consistent with the management plan for the Lake and Yalgorup National Park as prepared by CALM, and may require referral to the EPA for environmental impact assessment.
   - The City of Mandurah and the Shire of Waroona, in consultation with the local tourist industry and CALM, should develop a coordinated strategy to manage day tourist visitors to Lake Clifton.
4. Other proposals;
   - Proposals involving revegetation, or the replacement of existing native vegetation with high water-using tree species should be referred to the EPA for environmental impact assessment.
5. Proposals not meeting these criteria;
   - Where a proposal initially cannot meet the above criteria, then it is likely that the impacts are considered to be of such significance to warrant formal assessment by the EPA. Where it is not possible to modify the proposal to meet the criteria, then it is likely that the EPA would recommend to the Minister for the Environment that the proposal be refused environmental approval.

1.2 Extent and location of occurrences

Occurrence Number	Location	Estimated area
Occurrence 1	Lake Clifton, SW of Mandurah	Approximately 4km^2 of thrombolites

The thrombolites extend down the eastern side shore of the lake for 14km. In the north eastern section the thrombolites form an extensive reef approximately 10km long and up to 30m wide. The total area of the thrombolites (approximately 4km^2), is within the Yalgorup National Park (Moore 1993).

Additional occurrences of thrombolites containing the same microbial assemblage are considered extremely unlikely.

1.3 Biological and ecological characteristics

Thrombolites are formed by complex associations of photosynthetic prokaryotes (that is cyanobacteria and purple sulphur bacteria), eukaryotic microalgae (for example diatoms), and both chemoautotrophic and chemoheterotrophic microbes (ie, true bacteria) (Moore 1991). This assemblage of microbes forms the Benthic Microbial Community (BMC). Cyanobacteria (‘blue-green algae’) generally dominate microbial communities involved in the formation of thrombolites (Moore 1991).

Scytonema, a cyanobacterium, is the dominant microbe at Lake Clifton and grows in fresh to brackish waters with low nutrient status (L. Moore personal observation). Other cyanobacteria in the thrombolites include the genera *Oscillatoria*, *Dichothrix*, *Chroococcus*, *Gloeocapsa*, *Johannesbaptistia*, *Gomphosphaeria* and *Spirulina* (Moore 1991). Numerous species of diatoms also occur in the thrombolites. The thrombolites of Lake Clifton are probably formed by precipitation of a particular form of calcium carbonate, termed aragonite, within the microenvironment of the community as a result of growth and metabolic activity (Moore 1993). Light and fresh water rich in carbonates are likely to be essential to the growth and survival of the thrombolites.

Microbial communities occur in a range of salinity levels from relatively fresh at Lake Richmond (0.4gL^{-1} to 0.14gL^{-1}) (Kenneally *et al*. 1987) to hypersaline at Lake Thetis (39gL^{-1} to 53gL^{-1}) (Grey *et al*. 1990). Each of these however, contains a unique microbial assemblage. Changes to physical parameters, such as an increase or decrease in salinity, may cause a shift in the microbes that dominate the thrombolites possibly replacing these with a different microbial community that does not facilitate carbonate deposition and thrombolite formation (L. Moore personal observation[1]).

Lake Clifton as a whole has many unusual features including the original invertebrate assemblage and abundant charophytic algae (stonewarts).

1.4 Hydrology and Water Quality

Most of the Yalgorup lakes are seasonally or permanently hypersaline. Lake Preston ranges in salinity up to $90gL^{-1}$ TDS in the southern part of the lake. The salinity of Martins Tank Lake ranges up to $190gL^{-1}$ TDS (Commander 1988; Shams 1999). Lake Clifton shows strong seasonal trends in salinity but until over a decade ago, was predominantly hyposaline throughout the year (Moore *et al*. 1984). Lake Clifton is a groundwater sink, with a fresh water flow system with an underlying body of hypersaline water (Commander 1988).

There are no natural drainage channels into Lake Clifton. The lake is either replenished by winter rains or from underground water, with an extensive aquifer emptying into the lake along the eastern shoreline (Moore *et al*. 1984). This inflow of fresh groundwater probably provides calcium enriched water critical to the survival of the micro-organisms and the growth of the thrombolites.

The groundwater flow system discharging into Lake Clifton covers an area of about $115km^2$. Discharging fresh groundwater from the flow system overlies a body of hypersaline water ($42gL^{-1}$). The salinity of this underlying groundwater is much higher than the lake salinity (Commander 1988). The processes maintaining this difference are not well understood, but it is likely to be due to density differences (Moore, personal communication).

1.5 Critical Habitat

Critical habitat is habitat identified as being critical to the survival of a listed threatened species or listed threatened ecological community. Habitat is defined as the biophysical medium or media (a) occupied (continuously, periodically or occasionally) by an organism or group of organisms; or (b) once occupied (continuously, periodically or occasionally) by an organism, or group of organisms, and into which organisms of that kind have the potential to be reintroduced (sections 207A and 528 of Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)).

The critical habitat for the thrombolite community of coastal brackish lakes is Lake Clifton itself and the groundwater and associated catchment that contribute to the lake waters.

1.6 Habitat critical to the survival of the species, and important populations

Given that this community is listed as Critically Endangered it is considered that all known habitat is habitat critical.

1.7 Benefits to other species/ecological communities

Recovery actions implemented to improve the quality or security of the community are likely to improve the status of any species within the community.

1.8 International Obligations

Lake Clifton is listed as a Ramsar Convention Wetland in the Australian Nature Conservation Agency (ANCA) Directory of Important Wetlands in Australia and on the Register of the National Estate. This plan is fully consistent with Australia's responsibilities under the Ramsar Treaty and with the aims and

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recommendations of the Convention on Biological Diversity, ratified by Australia in June 1993, and will assist in implementing Australia's responsibilities under these conventions.

1.9 Role and interests of indigenous people

Some artefacts have been discovered within the Yalgorup National Park (Novak 1975). However, according to the Department of Indigenous Affairs Aboriginal Heritage Sites Register, there are currently no recognised archaeological sites listed for the Yalgorup National Park. But as the area has not been examined in detail it is possible that sites exist (Department of Conservation and Land Management 1995). The Winjan Aboriginal Corporation and Bibbulum groups represent Aboriginal people in the Peel Region but no groups are actively involved in relation to the management of Yalgorup National Park. The Yalgorup National Park Management Plan recommends a number of actions related to the protection and conservation of the Park's Aboriginal cultural values. These recommended actions will be implemented during the implementation of this plan.

1.10 Social and economic impacts

The implementation of this recovery plan has the potential to have some limited social and economic impact, as the catchment area for the lake is located on private property. Recovery actions refer to continued liaison between local landowners.

1.11 Evaluation of the Plan's Performance

CALM, in conjunction with the Recovery Team will evaluate the performance of this IRP. The plan is to be reviewed within five years.

1.12 Historical and Current Threatening Processes

The microbialite community of Lake Clifton has been subject to historical disturbance by alterations to the levels of salinity and nutrients, lake level and other water quality parameters; physical crushing and disturbance due to mining of marl in the bottom of the lake; and disturbance of the native vegetation buffer around the lake. The thrombolites are also likely to be subject to future threats, mainly from hydrological, chemical and physical changes as follows (in approximate order of the level of threat posed);

Declining water levels

The level of the lake is likely to be crucial for maintaining the thrombolites, as they rely on sufficient water to cover the growing surface of the structures while still having adequate levels of light and raw materials such as calcium and carbonate ions for their growth. Further, the fresh groundwater flowing into the lake on the eastern side is thought to be essential to the survival and growth of the thrombolites as it provides the ions for mineralisation. The water level at Lake Clifton fluctuates seasonally by up to 1m. It rises in winter through direct rainfall and increased groundwater input, and declines over summer by evaporation, exposing most of the thrombolites (Moore 1991; Moore and Burne 1994). The groundwater levels may vary yearly with climatic conditions and land uses (Lindsay 2002). However, if groundwater abstraction for agricultural, urban or other purposes in the groundwater catchment of Lake Clifton results in lowering of the water level in the lake, or reducing the inflow of fresh groundwater, this may expose the thrombolites and the BMC more frequently preventing growth of the structures.

Increasing salinity

A decline in the lake volume would also increase the salinity and concentrate all other constituents of the lake water. As mentioned, an increase in salinity may lead to a change in the dominant microbes. A salinity increase is likely to have more significant impacts to the function of the thrombolites than would a decrease.

The impact of changes in salinity levels and other water quality parameters on the thrombolites may be dependent on the level of stratification and mixing groundwater and water that occurs in the lake. The thrombolites occur in an area where there is an inflow of fresh groundwater and they may be relatively unaffected by alterations to the salinity of the lake as a whole. However, if mixing within the lake is substantial, then hydrological changes will impact the thrombolites (Moore 1991).

Two different sampling methods have been used to measure the salinity of Lake Clifton. The first method included measuring salinity in September and November from 1985 to 2003, from one point in the lake (at the boardwalk). This sampling showed the salinity of the lake rose from 15 to $22gL^{-1}$ from 1985 to 1992 and then from 22 to $28gL^{-1}$ from 1994 to 2000. Another significant jump in lake salinity then occurred in 2002 to around 33 to $34gL^{-1}$ (Knott, B. unpublished data; Lane, J. unpublished data). The second method included measuring salinity along four transects (three points per transect) in the lake monthly for a year throughout 1985/86 (Knott, B. unpublished data) and then again by CALM staff in 2000/2001 (Lane, J. unpublished data). This sampling confirmed a lake wide increase in salinity from 1985 to 2001.

Several factors were considered that may have led to this increase in salinity. Firstly, 1994 was the year of the opening of the Dawesville Cut. Higher tide levels within the Harvey Estuary may have resulted in hydraulic effects, pushing up the highly saline water that underlies the lake. Secondly, low rainfall and groundwater abstraction may have resulted in a reduction in thickness of the freshwater lens overlying the saline groundwater, perhaps allowing the upconing/intrusion of saline water. Thirdly, salinity levels in the lake are influenced by rainfall and lake depth, due to dilution. Analysis has shown a high correlation between salinity, rainfall, and lake depth, with lake depth dropping below AHD (-0.005m AHD) in December 1993 (analyses by Phil Commander; J. Lane, unpublished data). However, Knott *et al*. (submitted) suggested that if rainfall was the only factor determining the lake's salinity then an increase in rainfall in the late 1990's and the subsequent water level rise, should have returned the salinity of the lake to the lower level observed in the 1980's, when the rainfall and water level were also similar. An important task is to clarify the contributions of these factors to the increase in salinity compared with possible effects of human activities.

In light of the increasing threat of salinity, a modelling project was undertaken in 2002 by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). This project aimed to investigate the water balance of Lake Clifton to help clarify the reasons and mechanisms behind the observed change in salinity. Information was collated on estimated water usage from bores, climate data, paleoclimatic data and chemical data. Four different climate regimes were modelled:

- average rain for last 100 years using data from Bureau of Meteorology;
- average data before 1972;
- average data post 1972; and
- a combination of the above.

The report concluded that the opening of the Dawesville Channel and the changes it has induced in the Harvey Estuary were unlikely to have had any effect on Lake Clifton. It noted that the major effect on the water levels and salinity of the lake is the climatic conditions (lower rainfall), with groundwater pumping in the vicinity of Lake Clifton making a smaller contribution (Barr 2003).

Nutrient enrichment and increases in other pollutants

With increasing subdivision and subsequent rise in land use for agricultural practices on the eastern side of Lake Clifton, the concomitant rise in runoff of nutrients and other pollutants from adjacent properties may be a threat to the growth and survival of the thrombolites. Excessive irrigation and fertiliser application in the catchment, for example on agricultural land, private lawns and market gardens, has the potential to result in pollution of the lake due to leaching of contaminants to groundwater or through surface runoff. The first heavy rains in winter are known to flush large amounts of nutrients from urban and agricultural areas into wetlands (Davies and Lane 1996).

Lake Clifton had the highest concentration of organic nitrogen of the Yalgorup Lakes but the lowest of phosphate concentration, suggesting a well oxygenated, oligotrophic lake (Rosen *et al*. 1996). Groundwater discharge to the eastern portion of Lake Clifton is $7.7 \times 10^6 m^3$ per year with 15 tonnes per year of nitrogen and 0.4 tonnes per year of phosphorus (Shams 1999). Over the last 20 years the nutrient levels in Lake Clifton have been increasing. In July 1979 the total phosphorus measured in the lake water was $0.048mgL^{-1}$ and increased to $0.186mgL^{-1}$ in August 1988 (Moore 1993). In 1991 and 1992, the average phosphorus level in the groundwater was 0.008mgL^{-1} and 0.006mgL^{-1} respectively (Rosen *et al*. 1996) and increased to 0.04mgL^{-1} in November 1995 and 0.046mgL^{-1} in April 1996 (Shams 1999). These measurements are above guideline levels (0.005 to 0.05 mg L^{-1}) for phosphorus. An excess of nitrogen and phosphorus has the potential to cause macroalgal and planktonic blooms of other algae that may smother the thrombolites (Moore 1991). However, any increase in the nutrient discharge into the lake through groundwater may not be detected by measuring nutrient concentrations in the lake water, as nutrients are rapidly taken up by macroalgae (Rosen *et al*. 1996).

Competition can occur between thrombolitic benthic microbial communities (BMC) and macroalgae and/or planktonic cyanobacteria as a result of increased nutrient levels. Blooms of the green alga *Cladophora* have been noted as a result of nutrient enrichment of waters entering the lake (Moore 1991). This alga effectively competes for light with the microbes forming the thrombolites. It can lead to decreased light penetration that reduces or prevents photosynthesis of the thrombolite forming benthic microbial community, and has the potential to prevent thrombolite formation and growth.

Physical crushing

The thrombolites have been subject to some 15 years of physical crushing underfoot by visitors to Lake Clifton. Visitors are likely to be unaware of the significance of the thrombolites unless they have noted the interpretive information that occurs at the site of easiest access. Active recreation such as fishing and canoeing would have significant impact on the thrombolites through crushing. Cattle from adjacent properties have also been observed on the lake crushing the thrombolites. As the population of the area increases, the impact of crushing is likely to increase unless actions are taken to ameliorate visitor impacts. A visitor information bay, which provides information about the lake and the thrombolites, was developed in 1996 through a Regional Environmental Employment Program (REEP). A boardwalk was also constructed at the same time on the eastern edge of the lake to allow visitors to view the thrombolites without crushing them.

Alterations to surrounding vegetation

The vegetation buffer has been impacted historically by clearing for agricultural use, and more recently by visitors. Vegetation near the lake shore can be important in areas of surface and groundwater intrusion as a buffer can significantly reduce the level of nutrients entering the lake from surface flow. A complete survey of the width of vegetation along the lake boundary, in particular adjacent to the thrombolites, has not yet been undertaken and is necessary so that particular areas may be targeted for rehabilitation. A 200m vegetated buffer from the high water mark would be considered a minimum in sandy soils for an effective buffer area to prevent nutrient enrichment in wetlands (Davies and Lane 1996).

The major weeds among the sedges at the edges of the lake are *Carduus pycnocephalus* (thistle), *Avena fatua* (oats), *Stenotaphrum secundatum* (buffalo grass), *Aster subulatus* (bushy starwort), *Polypogon monspeliensis* (annual barbgrass), *Gomphocarpus fruticosus* (narrowleaf cotton bush). The risk of fire is increased by the presence of grassy weeds in the understorey, as they are likely to be more flammable than the original native species in the herb layer. Fire in the vegetation buffer would also result in a short term flush of nutrients being washed into the lake, both because of the removal of the retentive plant barrier, and due to release of nutrients from the burnt vegetation. Thrombolites are likely to be impacted by the release of nutrients into the lake, the loss of the dense sedges as a physical barrier to walkers trampling on the structures, and by the release of sediment immediately following fire in the remnant buffer near the lake. Chemicals used for weed control may impact on the thrombolites if used immediately adjacent to the structures.

Introduced fauna

The introduction of new fauna, such as black bream (*Acanthopagrus butcheri*) and snails, to the lake may have a had a significant impact on the original lake fauna and may also threaten the thrombolites. Bream and snails are thought to graze on the microbial layer that forms the thrombolites, as do numerous other species of metazoan (Konishi *et al*. 2001). Nutrients from the faecal material of bream may also alter the nutrient levels within the lake. It is not known exactly when bream were introduced to Lake Clifton, but shortly after the boardwalk was completed in 1996 they were being caught from the boardwalk by local anglers. The bream have been dated to be up to 18 years old by Murdoch University. Morphological changes also indicate that there is more than one generation (Sarre *et al*. 1999).

1.13 Guide For Decision-Makers

Section 1.6 above provides details of current and possible future threats. Proposed developments in the region of Lake Clifton require assessment. No developments should be approved unless the proponent can demonstrate that they will have no significant impact on the lake, its hydrology or the thrombolites. Developments should meet the environmental criteria listed in EPA Bulletins 788 and 864. Impacts on the surface or groundwaters, leading to either changes in water quality or levels in the lake, would be expected to have a significant impact on the threatened ecological community.

1.14 Conservation status

The thrombolite community of coastal brackish lakes meets the following criteria for Critically Endangered **(CR)** ecological communities:

i) current distribution is limited and currently subject to known threatening processes which are likely to result in total destruction in the immediate future (within approximately 10 years) if trends continue; and
ii) current distribution is limited and there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes.

1.15 Strategies for recovery

- To influence the management of Lake Clifton and the land management within its catchment area, so maintaining natural biological and non-biological attributes and processes of the site and the current area covered by the community. In particular to ensure implementation of recommendations in EPA Bulletins 788 and 864.

- To conduct appropriate ecological research on the community to develop further understanding about the management actions required to maintain or improve its condition.

- To update the EPA criteria for land use developments in the catchment of Lake Clifton suggested in EPA Bulletins 788 and 864.

2. RECOVERY OBJECTIVE AND CRITERIA

Objective: To maintain or improve the overall condition of Lake Clifton thrombolites and reduce the level of threat.

Criteria for success:
- Improved understanding of the lake processes enabling recovery management
- Reduction of nutrient levels in Lake Clifton
- Salinity levels appropriate for the survival of the thrombolitic microbial community
- Maintenance of the vigour and extent of the microbial community including maintenance of the composition of the microbial species.

Criteria for failure:
In the event of one or more of these criteria being met then the recovery team needs to meet to determine immediate action.
- Significant and sustained detrimental changes to water quality or water levels in Lake Clifton
- Significant decline in area of living thrombolites
- Major shift in composition of the microbial community.

3. RECOVERY ACTIONS

The following recovery actions are roughly in order of descending priority; however this should not constrain addressing any of the priorities if funding is available for ‘lower’ priorities and other opportunities arise.

3.1 Coordinate recovery actions

The Lake Clifton Recovery Team has been established and consists of representatives from CALM’s Swan Region (Chair) and Swan Coastal District, Science Division, City of Mandurah, University of Western Australia, Water and Rivers Commission, CSIRO, Lake Clifton Landcare Group, Agriculture WA, and CALM’s WA Threatened Species Unit. The Recovery Team will continue to coordinate recovery actions for the Lake Clifton thrombolite community. Input and involvement will also be sought from any indigenous groups that have an active interest in Lake Clifton. The Recovery Team will include information on progress in their annual reports to CALM’s Corporate Executive and funding bodies.

Responsibility: Recovery Team; CALM (Swan Coastal District)
Cost: $2,000 per year (to run team)
Completion date: Ongoing

3.2. Map critical habitat

It is a requirement of the EPBC Act that spatial data relating to critical habitat be determined. Although critical habitat is described in Section 1, the areas as described have not yet been mapped and that will be done under this action. If any additional occurrences are located, then critical habitat will also be determined and mapped for these locations.

Responsibility: Recovery Team; CALM (Swan Coastal District)
Cost: $2,000 in the first year
Completion date: Year 1

3.3 Clarify the extent and condition of the community

Funds will be sought to develop and implement a strategy to determine, through detailed survey, the extent (including number of individual structures if possible), size and condition of the thrombolite structures at Lake Clifton, to provide baseline data for future comparison.

Visual inspection of the structures for the presence of constructive filamentous cyanobacteria and macroalgae (indicative of algal blooms) will be done on a bi-annual basis.

Responsibility: Recovery Team; CALM (Swan Coastal District)
Cost: $5,000 in Year 1
Completion date: Initial studies completed, monitoring ongoing

3.4 Seek creation and protection of a suitable native vegetation buffer for the lake

A 200m wide vegetated buffer measured from the high water mark will be sought to help provide effective protection for the thrombolite community. General disturbance should be minimised within this zone and the area should not be utilised for other purposes such as retention basins or filtering ponds.

Responsibility: Recovery Team; DEP, Western Australian Planning Commission (WAPC), City of Mandurah, Shire of Waroona; CALM (Swan Coastal District); adjacent developers in response to Ministerial Conditions
Cost: Costs of all liaison $2,000 per year
Completion date: Ongoing

3.5 Conduct biological research to clarify threats to the thrombolites and help design recovery actions

The ‘health’ or viability of the thrombolites has been established through a biological/petrographic study of the structures and this indicated that they were healthy at December 2000 and that the organisms that formed them are still dominant. The health of the thrombolites will be monitored through compositional and structure studies. The impact of introduced fauna, such as bream and snails, will also be examined. Studies will also include identification of where macro-algae occurs in the lake.

Responsibility: Recovery Team; CALM (Swan Coastal District); Water and Rivers Commission (WRC)
Cost: $3,000 for Year 1 (microscope), $2,000 per year for monitoring
Completion date: Ongoing

3.6 Manage access to site

Ensure scientific and public access and research on the thrombolite community is undertaken in a coordinated and organised way with minimal disturbance and physical damage.

Responsibility: Recovery Team, CALM (Swan Coastal District)
Cost: $1,000 in Year 1 to develop protocol, $500 per year to manage system
Completion date: Ongoing

3.7 Ensure areas containing the microbial community are protected from physical damage

Actions will include the upgrading of the boardwalk at the site and the placement of signs at the site informing visitors not to step on the thrombolites. Liaison will also occur with the local landowners to ensure that their fencing is maintained as to prevent their stock entering the lake and crushing the thrombolites.

Responsibility: Recovery Team, CALM (Swan Coastal District)
Cost: $15,000 for Year 1
Completion date: Ongoing

3.8 Manage physical impacts to thrombolites through provision of information

Continue to develop an education program through the use of information boards, brochures etc, that explain the importance of the site and features.

Responsibility: Recovery Team; CALM (Swan Coastal District)
Cost: $2,000 per year
Completion date: Ongoing

3.9 Undertake ongoing monitoring of physical condition and microbial assemblage of thrombolites

Using methods for monitoring condition, size and extent established under Recommendation 3.5, undertake ongoing monitoring. Such monitoring should include continuing assessment of the composition of the microbial community. The possibility of monitoring numbers of intact thrombolites along a transect to determine gross changes, and the use of photographic monitoring to measure the extent of physical crushing will be investigated. As the area of the thrombolite reef is quite large sub areas, and/or areas identified as being at high risk can be sampled.

Responsibility: Recovery Team; CALM (Swan Coastal District); WRC
Cost: $6,700 in year one, $1,700 per year thereafter
Completion date: Ongoing

3.10 Monitor water quality and hydrology

Undertake ongoing monitoring of the limnological status of the lakewaters and groundwaters. Data should include ionic composition, nutrient levels, nutrient input and collection of water level and water quality information from the lake middle and edges adjacent to thrombolites and from monitoring bores in adjacent areas of interest. Methods used to monitor salinity should be consistent with previous sampling regimes so that the data are comparable.

Responsibility: Water Corporation; Water and Rivers Commission (WRC); Recovery Team
Cost: To be determined following analysis of baseline monitoring data (between $12,000-$33,000 per year)
Completion date: Ongoing

3.11 Determine the range of normal fluctuations for hydrological regimes and attempt to maintain them within that range

The adequacy and appropriateness of current water level measurements needs to be assessed. Groundwater levels should also be measured, and specific actions may need to be initiated if levels decline below a certain point. Criteria that can trigger fuller investigation will be established during the term of this IRP and, if required, incorporated into the full Recovery Plan.

Baseline monitoring data on water level is already available for the lake from 1985 to 2000 (Lane, J. unpublished data). The period of inundation of the thrombolites will continue to be monitored.

Responsibility: CALM (Swan Coastal District), Recovery Team, Water Corporation; WRC
Cost: $1,000 per year
Completion date: Ongoing

3.12 Manage water quality

Liaise with land and water managers to respond to results of water monitoring as appropriate, for example limiting groundwater abstraction rates if saltwater intrusion occurs.

Responsibility: Recovery Team; CALM (Swan Coastal District); Water Corporation; WRC
Cost: To be determined as a result of monitoring actions prescribed in this IRP.
Completion date: Ongoing

3.13 Provide information to surrounding landholders to ensure actions on their lands do not impact the thrombolites

Such information should aim to minimise fertiliser use, avoid use of chemicals that may be toxic to the community and ensure other threatening processes are mitigated. A pamphlet that includes this information will be provided to people who purchase land adjacent to the lake.

Responsibility: Recovery Team; CALM (Swan Coastal District); liaison with surrounding landholders, the City of Mandurah and Shire of Waroona
Cost: $2,000 per year
Completion date: Ongoing

3.14 Cooperate with appropriate agencies to manage land uses to ensure appropriate water quality within the lake

CALM will cooperate with agencies, such as the City of Mandurah, Shire of Waroona, Department of the Environment, Water and Rivers Commission, and the Department of Agriculture, to achieve the implementation of recommendations made in EPA Bulletin 864 in relation to the management of land likely to influence Lake Clifton.

Responsibility: Recovery Team; CALM (Swan Coastal District); liaison with other agencies

Cost: $1,000 per year
Completion date: Ongoing

3.15 Liaise with the EPA to encourage the updating of Bulletin 864 and the formulation of an Environmental Protections Policy

The phosphorus levels found in the Yalgorup Lakes study (Shams 1999) were found to be above recommended guideline levels. EPA Bulletin 864 states that 'Where the Yalgorup Lakes study points to the need for greater controls on new land uses, then the EPA criteria will be updated accordingly. Further if the study reveals that existing land uses are causing significant environmental problems, an Environmental Protection Policy (EPP) may be formulated'. CALM will liaise with the EPA to seek the implementation of those commitments.

Responsibility: Recovery Team; CALM (Swan Coastal District); liaison with EPA
Cost: $1,000 in year 2
Completion date: Year 2

3.16 Collect relevant baseline information and ongoing monitoring data for the vegetation that provides a buffer for the thrombolite community

The vegetation buffer is important in controlling sheet flow and inhibiting the movement of sediment into the lake. A survey on the density, root mass, and the width of the vegetation buffer in the length of the 14km buffer adjacent to the thrombolites as well as the lake boundary will be undertaken. Weeds may contribute to sediment movement and susceptibility to fire and should therefore be controlled in the vegetation adjacent to the lake (see 3.17).

Responsibility: Recovery Team; CALM (Swan Coastal District)
Cost: $10,000 for initial vegetation survey; $1,000 every year thereafter for flora monitoring
Completion date: Ongoing

3.17 Control weeds and rehabilitate plant communities on eastern side of lake

Design and implement a strategy to rehabilitate degraded areas of the sedgeland and other plant communities on the eastern side of the lake that provide a buffer for the wetland containing the thrombolites. This will include carefully designed and monitored weed control - taking extreme care not to impact the thrombolites, and replanting as necessary (eg. where the plant communities have been impacted). Liaison with adjacent land owners on the eastern side of the lake is required to ensure that fences adjacent to the thrombolites are maintained.

Responsibility: CALM (Swan Coastal District), Recovery Team
Cost: $100,000 for Year 1, $30,000 per year thereafter
Completion date: Ongoing

3.18 Design and implement a Fire Management Strategy to sustain the vegetation buffer

3.18.1 Develop and implement an approved fire management strategy

The strategy will allow for the natural development of the sedgeland and adjacent plant communities that provide a buffer for the thrombolites. It should include an annual fire monitoring and reporting schedule.

There is a need for research into the effect of fire on the vegetation buffer and the implications for management. A fire history map of the area, which is updated annually, is also required.

These issues are considered in a general sense in the Management Plan for the Yalgorup National Park.

Responsibility: CALM (Swan Coastal District); Recovery Team; adjacent landowners; City of Mandurah; Shire of Waroona; Fire and Rescue service.
Cost: $850 to develop fire management strategy in Year 1
Completion date: Year 2

3.18.2 Ensure maintenance of strategic firebreaks on occurrences or construction of new strategic fire breaks on surrounding lands to help prevent fire spreading to community.

Maintenance of existing firebreaks is appropriate where firebreaks are already constructed, unless maintenance is likely to degrade the community. Where firebreaks are not deemed strategically necessary, they will be closed and allowed to rehabilitate.

Local CALM staff should be responsible for planning fire break construction and maintenance.

Responsibility: CALM (Swan Coastal District); Recovery Team; in liaison with surrounding landholders
Cost: Cost of firebreaks $2,500 per year; costs of liaison included in 3.18.3
Completion date: Ongoing

3.18.3 Liaise with adjacent landholders and Fire and Rescue service to ensure fire suppression strategy in adjacent areas does not impact community; eg avoidance of the use of chemicals that adversely impact the thrombolites and avoidance of construction of new tracks in the vegetation area adjacent to the lake for use in fire suppression.

The strategy for fire suppression procedures should be to minimise physical and chemical impacts on the thrombolites.

Responsibility: CALM (Swan Coastal District); Recovery Team; City of Mandurah; Shire of Waroona; liaison with adjacent landholders
Cost: Costs of all liaison included in Action 3.18.1
Completion date: Ongoing

3.19 Report on success of management strategies for the thrombolite community

Reporting on the success of overall strategies to maintain or improve condition of the thrombolite community will be done in annual reports prepared by the Recovery Team for CALM's Corporate Executive. A final report will be prepared at the end of five years, perhaps as part of the preparation of a full recovery plan (see 3.20 below).

Responsibility: CALM (Swan Coastal District); Recovery Team
Cost: $2,000 per year
Completion date: End of Year 5

3.20 Review the need for a full Recovery Plan

At the end of the fourth year of its five-year term this Interim Recovery Plan will be reviewed and the need for further recovery actions will be assessed. If the community is still ranked as Critically Endangered at that time a full Recovery Plan may be required.

Responsibility: CALM (Swan Coastal District and WATSCU) through the Recovery Team
Cost: $17,500 in Year 5 (if full Recovery Plan required)
Completion date: Year 5

Table 1: Summary of costs for each recovery action

Recovery Action	Year 1	Year 2	Year 3	Year 4	Year 5
Coordinate recovery actions	$2,000	$2,000	$2,000	$2,000	$2,000
Map critical habitat	$2,000				
Clarify the extent and condition of the community	$5,000				
Seek creation and protection of a suitable native vegetation buffer for the lake.	$2,000	$2,000	$2,000	$2,000	$2,000
Conduct biological research to clarify threats to the thrombolites and help design recovery actions	$5,000	$2,000	$2,000	$2,000	$2,000
Manage access to site	$1,500	$500	$500	$500	$500
Ensure areas containing the microbial community are protected from physical damage	$15,000				
Manage physical impacts to thrombolites through provision of information	$2,000	$2,000	$2,000	$2,000	$2,000
Undertake ongoing monitoring of physical condition and microbial assemblage of thrombolites	$6,700	$1,700	$1,700	$1,700	$1,700
Monitor water quality and hydrology	To be determined ($12,000-33,000)	($12,000-33,000)	($12,000-33,000)	($12,000-33,000)	($12,000-33,000)
Determine the range of normal fluctuations for hydrological regimes and attempt to maintain them within that range	$1,000	$1,000	$1,000	$1,000	$1,000
Manage water quality	To be determined				
Provide information to surrounding landholders to ensure actions on their lands do not impact the thrombolites	$2,000	$2,000	$2,000	$2,000	$2,000
Cooperate with appropriate agencies to manage land uses to ensure appropriate water quality within the lake	$1,000	$1,000	$1,000	$1,000	$1,000
Liaise with the EPA to encourage the updating of Bulletin 864 and the formulation of an Environmental Protections Policy		$1,000			
Collect relevant baseline information and ongoing monitoring data for the vegetation that provides a buffer for the thrombolite community	$10,000	$1,000	$1,000	$1,000	$1,000
Control weeds and rehabilitate plant communities on eastern side of lake	$100,000	$30,000	$30,000	$30,000	$30,000
Develop and implement an approved fire management strategy	$850				
Maintain firebreaks	$2,500	$2,500	$2,500	$2,500	$2,500
Report on success of management strategies for the thrombolite community	$2,000	$2,000	$2,000	$2,000	$2,000
Review the need for a full Recovery Plan					$17,500

Summary of costs over five years

Year 1 $160,550
Year 2 $50,700
Year 3 $49,700
Year 4 $49,700
Year 5 $67,200

Total $377,850

4. TERM OF PLAN

This Interim Recovery Plan will operate from June 2004 to May 2009 but will remain in force until withdrawn or replaced. After five years, the need to review this IRP or to replace it with a full Recovery Plan will be determined.

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GLOSSARY

Aeolian: brought in by the wind

AHD: Australian height data

Aragonite: a particular form of calcium carbonate that is chemically identical to calcite but differs in crystallisation, a higher specific gravity and less marked cleavage.

Benthic: from the bottom of the sea or a lake

BMC: Benthic microbial community

Chemoautotrophic microbes: microbes that are capable of producing complex organic nutritive substances from simple inorganic substances such as carbon dioxide

Chemoheterotrophic microbes: microbes that rely upon complex organic compounds to produce their own organic constituents

Cyanobacteria: "blue green algae" **-** photosynthetic bacteria

Eukaryotes: organisms whose cells have a nuclear membrane, membranes around their internal structures, and divide by mitotic division eg fungi, protozoa and higher animals and plants

Hypersaline: salinity level is equal to or above the level for sea water

Hyposaline: salinity level is below the sea water level

Lithified: composed of stone

Macroalgae: larger algae having a complex structure eg seaweed

Microalgae: microscopic simple algae eg diatoms

Microenvironment: within the minute immediate environment

Phanerozoic: Time span from 600 million years ago to present.

Pleistocene: From 1,600,000 up to 10,000 years of geological history

Poikilosaline: variable salinity where changes are substantial and often rapid

Prokaryotes: organisms that have no nuclear membrane or membrane around their internal cellular structures eg blue-green algae and bacteria

Spearwood Dune System: the second dune system from the coast around Perth, consisting of white sand over Tamala Limestone

Thrombolite: a structure produced by the growth and metabolic activity of microbes and which has a clotted internal framework