Merimbula Bay Algal Bloom Study

FINAL REPORT
Prepared for
Bega Valley Shire Council
Zingel Place, Bega

9 January 2013
PROJECT REFERENCE: JN12061

elgin
associates

Document Information

Author (s): Dr Nicholas Yee

Andrew Roberts

Project Manager: Dr Nicholas Yee

Reviewed by: Dr Jaimie Potts (OEH)

Date: 9 January 2013
Status: Final

Filename: JN12061_Merimbula Bay Algal Bloom_R100c

Project: Elgin JN12061 Merimbula Bay Algal Bloom Study

Contact:
Elgin Associates Pty Ltd ABN 59123488639
Level 1, 45-47 Church Street, PO Box 829
Bega, New South Wales, 2550
Telephone: +61 400 365 234 Fax: +61 3 86486336 www.elgin.com.au

Record of Report Distribution

Nº of copies	Status	Date	Prepared for:
1 digital	Draft	26 September 2012	OEH
1 digital	Draft	1 November 2012	OEH, BVSC
1 digital	Final	9 January 2013	OEH, EPA, BVSC

ACKNOWLEDGEMENTS

This study was undertaken in consultation with OEH Coastal Studies Section with financial support provided by NSW EPA (Queanbeyan) and Bega Valley Shire Council. Persons whom provided information, advice and/or expertise to the study are gratefully acknowledged and include:

Dr Jaimie Potts (OEH Coastal Studies Section)

Rene Diocares (Stable Isotope Laboratory – Griffith University)

Nigel Sargeant (NSW EPA)

Janine Goodwin (NSW EPA)

Daniel Madigan (BVSC)

Derek Van Bracht (BVSC)

Ken McLeod (BVSC)

Jim Collins (BVSC)

Dr Alan Millar (Botanic Gardens And Domain Trust)

Dr Greg Rouse (Scripps Oceanographic Institute)

Dr Robin Wilson (Museum Victoria)

Dr Hannelore Paxton (Macquarie University)

Charles High

Bill Devlin

Michael Maguire

EXECUTIVE SUMMARY

In 2008, a collaborative study commenced between Bega Valley Shire Council (BVSC) and the NSW Environment Protection Authority (EPA) to investigate the effects of effluent discharged from the Merimbula sewage treatment plant (STP) ocean outfall on the occurrence of periodic algal blooms in Merimbula Bay.

Merimbula Bay is a large open embayment that periodically experiences large blooms of drifting macroalgae most frequently during the warmer months from November to March. There is widespread community concern that large drifting blooms of macroalgae in Merimbula Bay are being sustained for longer periods and in greater abundance than normal due to sewage derived nutrients discharged from the ocean outfall situated mid-way between Pambula and Merimbula beaches.

Central to this study was the analytical approach of using nitrogen stable isotopes to determine whether the nitrogen present in drifting macroalgae in Merimbula Bay is derived from sewage effluent. Previous studies have demonstrated that macroalgae grown in the presence of sewage derived nutrients have a greater ^{15}N:^{14}N ratio (*i.e.* isotopically enriched in ^{15}N) than macroalgae grown in waters where sewage derived nutrients are absent or depleted.

The key findings of the study include:

- The dominant bloom-forming alga in Merimbula Bay during the 2008-12 study period was the filamentous brown alga *Hincksia sordida*. Large masses of drift algae in Merimbula Bay have at times included a range of other algal taxa that have either been exported from the Merimbula and Pambula estuaries or have been inadvertently detached from nearby rocky reefs. While these once-attached algal taxa may survive for a short period in a drifting raft, they generally would not be increasing biomass that is typical of an 'algal bloom'. According to anecdotal and archived local media reports, blooms prior to 2008 were also likely to have been *H. sordida.*
- *Hincksia sordida* is common to the southern and eastern Australian seaboards from Tasmania to Queensland where it may form large blooms in protected marine embayments and estuaries. In recent times massive drift blooms of *H. sordida* have also been regular occurrences in Port Phillip Bay, Victoria and Noosa, Queensland. The alga has fast growth rates and demonstrated rapid assimilation of nutrients typical of an alga with high surface area to volume ratio. Studies have shown the species is able to efficiently scavenge nitrogen at low concentrations and assimilate excess nitrogen than is required for immediate growth at high concentrations. It has been noted that *H. sordida* generally has a low propensity for nitrogen storage and is inclined to be nitrogen limited. However, in an environment where nitrogen inputs are continuous or regularly pulsed, *H. sordida* has a clear competitive advantage over other algae that have low nutrient uptake rates but the capacity for large intracellular stores of nitrogen.
- The origin of the *Hincksia* blooms in Merimbula Bay is not clear. Surveys of the coastline and of estuaries (open to the ocean) north and south of Merimbula Bay did not locate a potential source for the drifting blooms. The preferred environment of *Hincksia sordida* is calm, protected embayments and estuaries where it may form long filaments and cover large areas of the benthos. *Hincksia* blooms have been recorded from a number of estuaries in the BVSC region including Wallagoot Lake (2008, 2009, 2011, 2012), Bega River (2012) and Cuttagee

Lake (2012). Though blooms of *Hincksia* were not observed in either of Pambula or Merimbula lakes during the study period (2008-2012), these lakes represent a potential supply source of *Hincksia* to the Merimbula Bay environment.

- Surveys also confirmed the alga's absence from sub-tidal reef habitats within Merimbula Bay. It is considered unlikely that *H. sordida* would be a natural component of the macroalgal assemblages within Merimbula Bay due to the moderate to highly exposed nature of these habitats. The species is also present in Twofold Bay (Eden) where it similarly forms drifting blooms that periodically appear on the beach. Unlike most other macroalgal taxa that require a substrate for attachment, *H. sordida* is able to grow and persist free-floating over the benthos. Evidence suggests *H. sordida* may be resident within the confines of Merimbula Bay throughout the year, free-floating over the benthos and at times in high biomass, able to be transported around the bay according to local hydrodynamic conditions. The frequency with which *H. sordida* washes up and persists on local beaches is then, simply a function of the required wind and swell conditions.
- Blooms appeared in the near-shore wave zone with greater frequency during spring and summer when easterly winds were most prevalent supporting previous observations recorded by local residents. Sustained north to northeasterly winds invoke Ekman transport where the sea surface currents move away from the coast with this net movement of surface water acting to draw up bottom waters towards the near-shore zone. It is these bottom currents that resuspend *Hincksia* thalli in the water column and play a large role in shifting the biomass of *Hincksia* towards the nearshore zone in the first instance. Persistence of blooms in the near-shore zone is then influenced by wave action and prevailing wind direction.
- An assessment of whether *H. sordida* was isotopically enriched with nitrogen derived from sewage effluent was made based upon a dataset limited by inadequate spatial and temporal sampling. The δ^{15}N signature of effluent was highly variable with values ranging from 13.2 – 32‰. The background δ^{15}N signature of algae sampled from locations not directly influenced by sewage effluent was 6.6 – 7.9‰ determined for the closely related species, *H. mitchelliae*. Data collected in 2008 suggests effluent had a negligible influence on the algae while data from 2011-12 suggest effluent derived nitrogen was assimilated by the algae as evidenced by the elevated δ^{15}N signature during that period compared to 2008.
- A number of studies have successfully used algae and nitrogen stable isotopes to trace the spatial effects of sewerage effluent. However these studies employed attached algal species to provide a reliable indicator of their source nitrogen with sampling conducted over small and large spatial scales. In contrast, the sampling regime of this study relied upon the opportunistic sampling of *H. sordida* when present at the near-shore zone. Consequently, variation in the δ^{15}N signal of algae due to spatial and temporal factors could not be controlled or accounted for and limits interpretation of the available data. Being a drift algae with high turnover of tissue nitrogen presents a potential case in which *H. sordida* may utilise effluent derived nutrients where available and then drift away to areas of the bay where the influence of effluent derived nutrients is diminished. After a few weeks have elapsed, the isotopically

enriched $\delta^{15}N$ signal of effluent in the algae may be replaced with a depleted $\delta^{15}N$ signal thereby confounding any assessment regarding the influence of effluent on the algae.

- Algae in Merimbula Bay, including *H. sordida,* would utilise effluent derived nutrients where available. However, effluent represents just one source of available nutrients with diffuse source inputs from the catchments, periodic upwelling of slope water, groundwater discharge and the release of nutrients from the bay sediments all-contributing to the pool of bioavailable nitrogen in Merimbula Bay. However, assessing the relative contribution of nutrients from these diffuse sources is difficult due to the episodic nature of those sources and the lack of available data. What we do know is that discharge of effluent to Merimbula Bay provides a relatively continuous supply of inorganic nutrients at high concentrations compared to diffuse sources. Dilution effects would effectively attenuate effluent nutrient concentrations over relatively small spatial and temporal scales when consideration is given to hydrodynamic processes. Nevertheless, *H. sordida* and other algae in Merimbula Bay would be using nutrients derived from effluent when available.
- Anecdotal accounts from several long-term Merimbula residents indicate macroalgal blooms have been a regular occurrence in the bay environment as early as the 1950's. This is prior to the commissioning of the Merimbula STP in 1971 and before the discharge of large volumes of effluent to the bay commenced. These historical accounts demonstrate that macroalgal blooms have been a regular natural occurrence in Merimbula Bay and it is likely that blooms may continue to occur even when strategies to reduce nutrient concentrations in effluent and advances in STP management are implemented.

Recommendations made in light of the study's findings include:

- Addressing the limitations of the current dataset that relied on opportunistic sampling of the bloom algae. The spatial and temporal limitations encountered during this study may be controlled by implementing a series of replicated cages containing algal tissue that are fixed in location along the coastline and within Merimbula Bay for a standardised period of time.
- Continue to investigate options for further reducing the loads of inorganic nutrients in the sewage effluent. Reducing the discharge of nutrients in sewage effluent discharged to the environment will minimise the likelihood that macro- and microalgal blooms will be exacerbated by effluent inputs.
- Raise community awareness of the natural phenomena of algal blooms via existing modes of communication (*i.e.* council website) and consider distributing information in the form of printed leaflets.
- Continue to monitor and record the occurrence of algal blooms in Merimbula Bay and other coastal locations as required. This information will be useful to assess whether blooms are increasing in frequency and severity and whether management strategies are being effective.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES, DRAWINGS & APPENDICES

List of Tables (in text)

Table 2	Chronology of media articles discussing the algal bloom issue
Table 3	Summary of groundwater quality of Merimbula dunal aquifer
Table 4	Sources of nutrients to Merimbula Bay and their documented loads and/or concentrations
Table 7	Summary of $\delta^{15}N$ signatures of algae sampled during the study
Table 8	Indicative $\delta^{15}N$ ratios of anthropogenic and natural nitrogen sources
Table 9	Macroalage used as isotopic tracers of sewage effluent in other studies

List of Tables (attached)

Table 1	Summary of environmental conditions prior to bloom events
Table 5	Algal stable isotope data
Table 6	Effluent stable isotope data

List of Figures

Figure 1	Location of Merimbula STP and beach outfall
Figure 2	*Hincksia sordida* sampled from bloom events
Figure 3	STP pump-out drain from where treated effluent samples were collected for stable isotope analysis
Figure 4	Habit and attributes of the filamentous brown alga *Hincksia sordida*
Figure 5	Coastal locations identified as potential reference locations and surveyed during Phase 1
Figure 6	Blooms of *Hincksia sordida* and aggregations of other algal taxa drifting over the seabed in Merimbula Bay
Figure 7	Generalised hydrodynamic models of Merimbula Bay
Figure 8	Merimbula STP site layout
Figure 9	STP beach outfall
Figure 10	Merimbula STP dunal exfiltration ponds and groundwater monitoring bore BH10
Figure 11	Merimbula STP total annual effluent volumes
Figure 12	Annual TN and TP loads discharged to Merimbula Bay from 2007 to 2011

List of Appendices

Appendix A	DECC Study Proposal – Potts and Pritchard (14 February 2008)
Appendix B	NSW DPI scientific collection permit

LIST OF TABLES, DRAWINGS & APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ANZECC	Australia and New Zealand Environment Conservation Council
BVSC	Bega Valley Shire Council
CERAT	Coastal Eutrophication Risk Assessment Tool
DO	Dissolved oxygen
DECC	NSW Department of Environment and Climate Change
EC	Electrical conductivity
EPA	Environment Protection Authority
FRP	Filterable Reactive Phosphate (*also known as* ortho-phosphate)
Km^2	Kilometers squared
m^2	Metres squared
NATA	National Association of Testing Authorities
NTU	Nephelometric Turbidity Units
OEH	Office of Environment and Heritage
pH	Measure of the acidity or alkalinity of a solution
SRCMA	Southern Rivers Catchment Management Authority
SEPP	State Environment Protection Policy
SIA	Stable isotope analysis
STP	Sewage treatment plant
t	Tonne
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
NOx	Oxides of nitrogen including nitrate (NO_3^-)and nitrite (NO_2^-)
TSS	Total Suspended Solids
µg/L	Micrograms per litre
µM	Micromolar
mg/L	Milligrams pre litre
N/A	Not Applicable

GLOSSARY

diploid	having two sets of chromosomes (*2n*) in each nucleus; the condition of cells following fertilisation and before meiosis.
gametophyte	the haploid phase of the life history which produces gametes; fusion of two haploid gametes (*i.e.* egg and sperm) produce a diploid zygote.
haploid	having a single set (*n*) of chromosomes; the condition of cells following meiosis and before fertilisation.
meiosis	the process of nuclear division which results in the halving of the chromosome count from the diploid number (*2n*) to the haploid number (*n*)
microphytobenthos	the microscopic, photosynthetic eukaryotic algae and cyanobacteria that live on seafloor habitats ranging from wave swept beaches to detritus-laden backwater lagoons.
mitosis	the process of nuclear division which results in both daughter nuclei receiving identical sets of chromosomes following replication of the chromosomes during the preceding cell cycle
sporophyte	the diploid phase of the life history in which meiospores (by meiosis) or mitospores (by mitosis) are produced.
thallus	the algal body; also used in relation to other simply constructed, non-vascular plants; pl. thalli.

INTRODUCTION

In 2008, the NSW Department of Environment and Climate Change (DECC, then incorporating the EPA and now known as Office of Environment and Heritage – OEH) proposed a study to investigate the effects of effluent discharged from the Merimbula sewage treatment plant (STP) ocean outfall on the water quality and occurrence of periodic algal blooms in Merimbula Bay. Central to this study was the analytical approach of using nitrogen stable isotopes to determine whether the nitrogen present in drifting macroalgae in Merimbula Bay is derived from sewage effluent.

Elgin Associates Pty Ltd (Elgin Associates) was engaged by the Bega Valley Shire Council (BVSC) to work with OEH and EPA scientists to undertake the study.

This report presents the results and findings of that investigation.

1.1 Background Setting

Merimbula Bay is a large open embayment that periodically experiences large blooms of drifting macroalgae most frequently during the warmer months from November to March. A range of different algal taxa have been collected from these drifting blooms with taxonomic analysis indicating all algae are local, native, non-toxic and attached sessile species that have most likely been detached from rocks to form drifting rafts (Dr Alan Millar, *Botanic Gardens and Domain Trust*). Detached macroalgae typically remain viable for hours to days but some taxa may sometimes be sustained for weeks to months, continuing to photosynthesise and grow. However, new individuals can only grow attached to substrates such as rocky-reef. The biomass of these drifting blooms varies seasonally and is a function of nutrient availability (Dr Alan Millar, *Botanic Gardens and Domain Trust*).

Issue: The regular occurrence of drifting macroalgal blooms along the beaches of Merimbula Bay has been a long-standing issue for the communities of Pambula and Merimbula. There is widespread community concern that large drifting blooms of macroalgae in Merimbula Bay are being sustained for longer periods and in greater abundance than normal due to sewage derived nutrients.

Secondary treated sewage effluent is discharged from the Merimbula Sewerage Treatment Plant (STP) ocean outfall situated in the foredunes mid-way between Pambula and Merimbula beaches. Effluent is discharged directly onto the beach (maximum of ~4 ML per day) and travels over the sand to the ocean. Due to the high porosity of the sand it is likely that some of the effluent is seeping into groundwater, though to date, potential losses to groundwater have not been estimated. The location of the STP is shown in Figure 1, below.

Since 2006, discharge of effluent to the bay has been restricted to cooler months in an effort to minimise impact of increased nutrients in bay water. Nonetheless, large drifting blooms of macroalgae persisted during the warmer months of 2007-08, 2008-09, 2010-11 and 2011-12.

1.2 Study Design

In 2008, OEH water studies section proposed a study using nitrogen stable isotopes to investigate the effects of sewerage-derived nutrients on the occurrence of periodic algal blooms in Merimbula Bay (see proposal attached in Appendix A). The approach involves characterising the ratio of $^{15}N:^{14}N$ stable isotopes in the bloom forming algae within Merimbula Bay and at a number of other locations not affected by STP effluent (*i.e.* reference locations). Numerous studies (Costanzo *et al.* 2001; Gartner *et al.* 2002; Savage and Elmgren 2004; Rush 2007) have demonstrated that macroalgae grown in the presence of sewage derived nutrients have a greater $^{15}N:^{14}N$ ratio (*i.e.* isotopically enriched in ^{15}N) than macroalgae grown in waters where sewage derived nutrients are absent or depleted. Characterising the $^{15}N:^{14}N$ signature of the algae from other locations not affected by sewage effluent is vital as it provides an estimate of natural background $^{15}N:^{14}N$ variability (*i.e.* sources of nitrogen from the surrounding catchment or ambient oceanic sources) and allows a robust assessment of whether the $^{15}N:^{14}N$ signature of algae from Merimbula Bay is isotopically enriched.

A key underlying assumption of the study design was that the algae forming blooms in Merimbula would also occur and be easily collected from other locations. Further information regarding the stable isotope approach is provided in Section 2.5 below.

Figure 1. Location of the Merimbula STP and beach outfall.

1.3 Study Objectives

The study design consisted of two phases with the following objectives:

Phase 1 – Determining the identity of the algae responsible for the blooms, locating the source/s of the algae and surveying adjacent coastal embayments not subjected to influences of sewage effluent for the presence of the algae for use as reference locations. This phase would also involve characterising natural background levels of $^{15}N:^{14}N$ in the algae at these reference locations. Outcomes of Phase 1 would address the following questions:

- Identify the target algae forming blooms in Merimbula bay *i.e.* Are blooms composed of one or multiple species?
- What are the sources or origins of the bloom algae? and
- Determine natural background $^{15}N:^{14}N$ signature in algae.

Phase 2 – Conduct simultaneous sampling of the target algae when in bloom in Merimbula Bay and at reference locations. Sample effluent to characterise the $^{15}N:^{14}N$ ratio of the Merimbula STP effluent. Outcome of Phase 2 would principally address the following question:

- Is the bloom algae of Merimbula bay isotopically enriched with nitrogen derived from sewage effluent?

1.4 Scope of Work

The scope of work undertaken to address the project objectives, incorporating the key element of nitrogen isotope analysis, included:

- Confirm identity of target alga or algae forming blooms in Merimbula Bay;
- Conduct additional coastal surveys to sample target algae from adjacent reference locations;
- Undertake sub-tidal surveys of deep water habitats in Merimbula Bay to confirm potential source areas of the target alga;
- Taxonomic identification of algal samples and preparation of samples for Stable Isotope Analysis (SIA);
- Inspections of the Merimbula STP, collection of effluent samples and preparation of samples for SIA;
- Desktop review of background historical information including community perspectives, environmental setting and sources of nutrients to Merimbula Bay;
- Interviews with long term local residents regarding algal blooms in Merimbula Bay;
- Nitrogen stable isotope analysis of algal and effluent samples; and
- Preparation of this report.

1.5 Project Timeline

Elgin Associates was engaged by BVSC in early 2008 to work with OEH scientists and provide expertise in algal taxonomy and execute the field program with guidance provided by OEH. The field program included surveying the coast for reference embayments and collecting algal samples for isotope analysis. Phase 1 of the project was completed with results that did not correspond with the objectives and underlying assumptions of the study design. Principally that the target alga could not be located at reference locations along the coastline, thus limiting the execution of Phase 2 of the study to date.

Congeners and closely related algal taxa were found at reference locations and these were sampled to compare with the target algae from Merimbula Bay. A number of project meetings involving BVSC, OEH, and Elgin Associates were held between 2008 and 2009 discussing the progress of the study, the data gathered and the limitations encountered. Among the limitations were that an insufficient number of effluent samples were collected for characterising the ^{15}N:^{14}N ratio of effluent and this remained a data gap that needed to be addressed. In late 2011, a field program was initiated to address the effluent data gap with simultaneous collection of additional algal samples for isotope analysis. Detailed information regarding the outcomes of the study phases is included in Section 3 – Results and Discussion.

In 2012, BVSC engaged Elgin Associates to compile this report that includes compilation of historical background data, review of the ecology and biology of the algae forming blooms in Merimbula Bay with analysis and interpretation of the stable isotope dataset.

The project timeline is summarised in the following major points:

February 2008	Project commences
March – September 2008	Phase 1, identifying algae forming blooms and finding suitable reference locations
August 2008	Project progress meeting
October – December 2008	Phase 1, deep water surveys of Merimbula Bay to determine if local reefs are the source of the bloom algae
September 2008	Effluent samples collected
February 2009	Project progress report - decision made to cease Phase 1 in light of limitations encountered
September 2009	Project progress meeting
November 2011 to February 2012	Collect additional effluent samples and new algal samples Desktop Review of background information
March to August 2012	Project Reporting

METHODOLOGY

The methodology adopted for the various study components outlined in the scope of work are contained in the following sections.

2.1 Confirming identity of bloom algae

The initial task of the study required the identity and nature of the alga or algae forming 'blooms' in Merimbula Bay, to be confirmed. Information provided by BVSC regarding reports of past algal blooms, taxonomic reports and opinions were reviewed. In addition, algal samples were collected and inspected from blooms as soon as notification of a bloom event was received.

The alga largely responsible for forming nuisance blooms in Merimbula Bay and hence the target alga for this study was determined to be the filamentous brown alga *Hincksia sordida*. Further details regarding the determination of *Hincksia sordida* as the target species and its ecology and biology is discussed in Sections 3.1 and 3.2.

2.2 Phase 1 - Coastal Surveys

Surveys of coastal embayments situated to the north and south of Merimbula Bay were undertaken between April and December 2008 to locate the presence of the target species, *Hincksia sordida*. These surveys had two objectives: 1) to identify reference locations for the isotope study, and 2) identify the location/s where *Hincksia sordida* naturally occurs and may be the source of the drifting blooms observed in Merimbula Bay.

2.2.1 Reference Locations

Potential reference locations (*i.e.* locations not affected by direct discharge of sewage effluent) were identified using maps and Google Earth™ prior to commencing field surveys. In the BVSC coastal region STPs are present in the townships of Bermagui, Tathra, Tura and Eden (in addition to Merimbula). However, of these only Bermagui and Eden STPs are licensed to discharge treated effluent directly to the open ocean. Coastal locations nominally within a 5 km radius of the effluent discharge points were excluded as potential reference locations. Field reconnaissance surveys were undertaken at numerous estuaries and small embayments along the BVSC coastline from Cuttagee in the north to Bittangabee Bay in the south between April to December 2008. Surveys were undertaken on snorkel and focused on the preferred environments for *Hincksia sordida,* namely the shallow subtidal zone of protected open and enclosed waters. Results of coastal surveys is presented and discussed in Section 3.3.

2.2.2 Merimbula Bay Deep-water Surveys

Sub-tidal surveys of deep-water habitats within Merimbula Bay were undertaken on SCUBA in October and December 2008 to determine the presence or absence of *Hincksia sordida* and to document the general macroalgal ecology of the areas surveyed. Surveys were completed for locations at Long Point, Haycock Point, Hunter Rock, and the seabed in the direct vicinity of Merimbula STP outfall. A summary of the survey results is presented in Section 3.3.1.

2.3 Algal samples

Algal samples were collected from reference locations by hand while samples of algae from bloom events were collected using a mesh net. Samples were collected under DPI scientific collection permit P08/0025-1.0. A copy of the permit is contained in Appendix B.

2.3.1 Samples from reference locations

Samples of brown filamentous algae representing putative *Hincksia sordida* were collected from a variety of substrates at reference locations. Substrates included rocky reef, other larger macroalgae, seagrasses, and sand. Whole algal thalli were collected by hand into clean plastic containers with seawater, collection details logged and stored on ice. Samples were examined under light microscope at x200 and x400 magnification to determine genus and species identity where possible with portions of sample collections set aside for preservation as voucher specimens.

2.3.2 Samples from bloom events

Samples of algae were collected from bloom events in Merimbula Bay opportunistically when notification was received that algae was washing up on the beach. Blooms were typically composed of algal rafts drifting on the ocean surface and suspended throughout the water column via the action of breaking waves and rips. Samples were collected from the wave and wash zone by wading into the water and scooping the algae with a wide 250 µm mesh net.

Netted samples were then transferred to a white tray and immersed in seawater to remove majority of sand particles and other algal taxa or drift wrack (*i.e.* seagrass leaves) inadvertently netted as they drifted with the bloom though clearly not part of the bloom (see Figure 2 below). A sample was collected from the white tray into to a clean plastic container, details logged, stored on ice and kept in the dark for transport back to Elgin Associates, Bega office. Samples were then further sorted in petri dishes under stereomicroscope to ensure all the algal material was monospecific prior to preparation for isotope analysis. Algal thalli were examined under light microscope at x200 and x400 magnification to confirm identity and portions set aside for preservation as voucher specimens.

Notes regarding the environmental conditions in the week preceding the occurrence of bloom events were also recorded to determine whether particular climatic trends correlate with a bloom event. These findings are presented in Section 3.3.4.

2.3.3 Voucher specimens

Voucher specimens representative of each sample collection were preserved with 4% formalin-seawater solution in 5 ml vials and or pressed on herbarium paper to be lodged at the National Herbarium of NSW.

Details of algal specimens collected during the study, including scanned images of herbarium voucher specimens is contained in Appendix C.

Figure 2. *Hincksia sordida* sampled from bloom events. Netted samples were first transferred to a large tray to remove sand and other drift wrack that were inadvertently collected (*left image*), a final sample was then sorted under stereomicroscope to ensure all algal material prepared and sent to the laboratory for isotope analysis was monospecific (*right image*).

2.4 Desktop Review

A review of the algal bloom issue in Merimbula Bay was undertaken to provide context to the study and present an overview of local and regional environmental conditions and processes that influence primary productivity in the bay environment. This included a review of:

- Community perspectives – media coverage, anecdotal reports of impacts related to algal blooms, and interviews with local long-term residents;
- Environmental setting – description of physical characteristics and hydrodynamic processes (eg. ocean currents, wind driven currents, upwellings) of Merimbula Bay, a description of the Merimbula STP; and
- Anthropogenic and natural sources of nutrients to Merimbula Bay – discharge of effluent from the STP and catchment and oceanic nutrient sources.

A chronology of community perspectives of the issue as presented by local media sources was compiled by searching the online archives of Merimbula News Weekly, Eden Magnet and local radio South East ABC. These perspectives include anecdotal reports of algal bloom related impacts. In addition, a number of long-term Merimbula residents were interviewed either by phone or in person, to obtain an historical perspective of algal blooms in the Bay dating back to the 1950-60s. A review of community perspectives is provided in Section 3.4.

Background information regarding the environmental setting, anthropogenic and natural sources of nutrients to the Bay is based upon review of meteorological data, scientific literature, and information and previous studies commissioned by BVSC. This review of background information is presented in Sections 3.5 to 3.6.

2.5 Stable Isotope analysis (SIA)

Batches of algal and effluent samples were sent to the Centre for Riverine Landscapes (CRL) at Griffith University, Queensland, for analysis of nitrogen and carbon stable isotopes. Documentation of each sample batch and laboratory analytical reports is contained in Appendix D.

Results and discussion of stable isotope analysis is presented in Section 3.7.

2.5.1 Preparation of algal samples

Following identification of algal samples, whole thalli were processed for SIA either on the same day as collection or within 24 hours according to CRL sample preparation procedures. Algal thalli free of epiphytes and other contaminants were oven-dried at 60-70°C for approximately 1-1.5 hours until completely dry. Dried thalli were then ground into a fine powder using mortar and pestle, transferred to airtight, labeled 5 mL plastic vials and stored in the dark to minimise risk of sample degradation. Scanned images of herbarium voucher specimens representing samples submitted for SIA are contained in Appendix C.

2.5.2 Collection and preparation of effluent samples

Samples of treated effluent were collected from the Merimbula STP effluent pump station (NSW EPA identification point 4) located at the southern end of the STP as shown in Figure 3, below. Effluent for disposal flows to this pump station and is pumped directly to the beach outfall pipe or the dunal exfiltration ponds. Using an extendable pole, effluent samples were collected into 1 L laboratory supplied bottles, details logged and stored on ice before being frozen as recommended by CRL sample procedures for waters. Batches of frozen effluent samples were sent to CRL by courier for further preparation that included freeze-drying to reduce each effluent sample into a dry powder.

Figure 3. Merimbula STP effluent pump station from where treated effluent samples were collected for stable isotope analysis.

2.5.3 Isotope Analysis

Isotope analysis was performed by CRL with typical analytical procedure summarised as follows:

- A small quantity of dried, ground sample is weighed into a tin capsule and oxidised at high temperatures.
- Samples are combusted in a EuroEA 3000 (EuroVector, Italy) elemental analyser and the resulting N_2 and CO_2 gas chromatographically separated and fed into IsoPrime (Micromass, UK) isotope ratio mass spectrometer. This measures the ratio of heavy and light isotopes in a sample and compares them to a standard.
- Ratios are expressed in %C and %N by mass as well as δ notation and are parts per million ($^{0}/_{00}$), defined as:

  $$\delta\ (^{0}/_{00}) = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 10^{3}$$

  Where R_{sample} and R_{standard} are the isotope ratios of the sample and standard respectively.
- Isotopic standards used are referenced to PeeDee Belemnite (PDB) for carbon, and atmospheric air for nitrogen (Peterson and Fry 1987).

RESULTS AND DISCUSSION

3.1 Identification of the bloom-forming alga

Prior to the commencement of this study in 2008, large masses of macroalgae observed drifting in Merimbula Bay (and washing up on Merimbula and Pambula beaches) were reported to consist of either one alga or a mixture of a number of algal taxa. These algae had previously been identified as:

- filamentous brown algae of the Order Ectocarpales;
- calcareous red alga *Jania micrarthrodia;*
- brown alga *Phyllospora comosa;*
- brown alga *Sargassum* sp.; and
- filamentous brown alga *Hincksia* sp.

The origin of some of these drift algae could be attributed to sources near to Merimbula Bay. The coralline alga *Jania micrarthrodia* is commonly found in the Merimbula and Pambula River estuaries as an epiphyte on the seagrass *Posidonia australis*, while the large brown algae *Phyllospora comosa* and *Sargassum* sp. are common taxa of macroalgal assemblages on nearby rocky reefs at Long Point and Haycock Point. The presence of these once-attached algal taxa in drifting rafts is due to having been inadvertently detached from their substrate. While these taxa may survive for a short period unattached, they typically become senescent (as is the case for most marine macroalgae when unattached) and would not be increasing biomass as is typical of an ‘algal bloom’ and therefore these taxa were excluded as target species. However, the brown algal group known as the Ectocarpales, and in particular the member genus *Hincksia,* consists of a number of opportunistic, fast-growing species known to form large blooms in protected waters.

In early March 2008, large algal blooms were observed drifting in the wave zone at Aslings Beach, Eden, and concurrently at Merimbula main beach. Taxonomic analysis of samples showed that the drifting algal biomass at both localities was mono-specific and determined to be *Hincksia sordida* based on taxonomic analysis (Elgin Associates, *pers. obs*. 6 March 2008) and descriptions provided in Womersley (1987) and Clayton (1974).

Since 2008, large blooms of drifting macroalgae have been observed in Merimbula Bay on numerous occasions over various seasons. Majority of blooms have been mono-specific, composed of *H. sordida* (Elgin Associates, *pers. obs*. 2008-2012). A number of other alga taxa have been found in drifting blooms in minor proportions. These have included fragments of senescent *Colpomenia sinuosa,* the superficially similar *Ectocarpus fasiculatus,* and an unidentified red alga belonging to Family Ceramiaceae. However, *H. sordida* has been the recurring dominant bloom forming species in Merimbula Bay during the time period 2008-2012, and was the target alga for this study.

3.2 Target Species - *Hincksia sordida*

Hincksia sordida is a non-toxic alga native to Australian coastal marine waters. It typically occurs in calm, sheltered conditions where it can form prolific blooms. It has been recorded in coastal waters from South Australia, Victoria to Tasmania and along the New South Wales coast to southern Queensland and has also been recorded from Lord Howe Island and New Zealand (Algaebase 2012, Kraft 2009, Womersley 1987, Phillips 2006).

3.2.1 Classification

The genus *Hincksia* currently contains 23 species worldwide with eight species recorded from Australia including *H. sordida*. The current classification of *H. sordida* is:

Class Phaeophyceae, Order Ectocarpales, Family Acinetosporaceae

Hincksia sordida (Harvey) P.C.Silva 1987

Type locality: Tamar river estuary, Georgetown, Tasmania [leg. Harvey 1859]
Synonyms (earlier names): *Ectocarpus sordidus* (Harvey 1859), G*iffordia sordida* (Harvey) Clayton 1974.

3.2.2 Biology

Hincksia sordida is a filamentous brown alga characterised by irregularly branched, uniseriate (one cell thick) filaments with main axes measuring up to 0.05 mm in diameter. Filaments are typically long and sparingly branched with short tapering lateral branches often present. Cells are cylindrical becoming elongate with age and each cell contains multiple discoid plastids. Its habit can range from tufts of short filaments a few centimetres long to loose tangled masses of filaments reaching lengths of up to 100 cm long depending on the environment in which it is growing.

The species has diffuse growth with intercalary meristems (localised active growth regions) scattered over the filaments. Owing to this growth strategy, fragmentation of the alga due to disturbance from wave action or heavy swell conditions may create many small pieces of filaments each with the ability to continue growth and increase algal biomass.

The life cycle can involve the regular alternation of diploid (sporophyte) and haploid (gametophyte) thalli. However studies conducted by Clayton (1974) found that reproduction in *Hincksia* was predominantly asexual and is achieved via spores released from plurangia. Majority of *Hincksia* specimens sampled from blooms in Merimbula Bay were non-fertile (*i.e.* reproductive plurangia were absent on thalli). Of the few specimens collected that were fertile, plurangia were ovoid to conical-shaped organs and typically sessile on filaments. Occasionally some plurangia were found supported by a short, 1-2 celled pedicel.

Figure 4 (below) shows the habit and biological attributes of *H. sordida*.

3.2.3 Ecology

Hincksia sordida is found throughout the year and is typically loosely entangled on other macroalgae or seagrasses or may occur as an unattached raft of filaments. In Merimbula Bay, the alga shows the atypical habit of small individual tufts of filaments, no larger than a few centimetres, that aggregate to form large drifting rafts which accumulate over the seabed (Elgin Associates 2009). These rafts may become suspended in the water column and on the ocean surface following disturbance induced by wave action and currents or when the algal rafts drift into the nearshore wave zone.

The filamentous construction of *H. sordida* provide it with a high surface area to volume ratio enabling rapid and efficient rates of nutrient uptake compared to other algal species with lower surface area to volume ratios. Controlled experiments in a study by Campbell (1999) have shown *H. sordida* is efficient at sequestering inorganic nitrogen (as ammonium) in low and high concentrations potentially giving the species a competitive advantage over other macroalgal species.

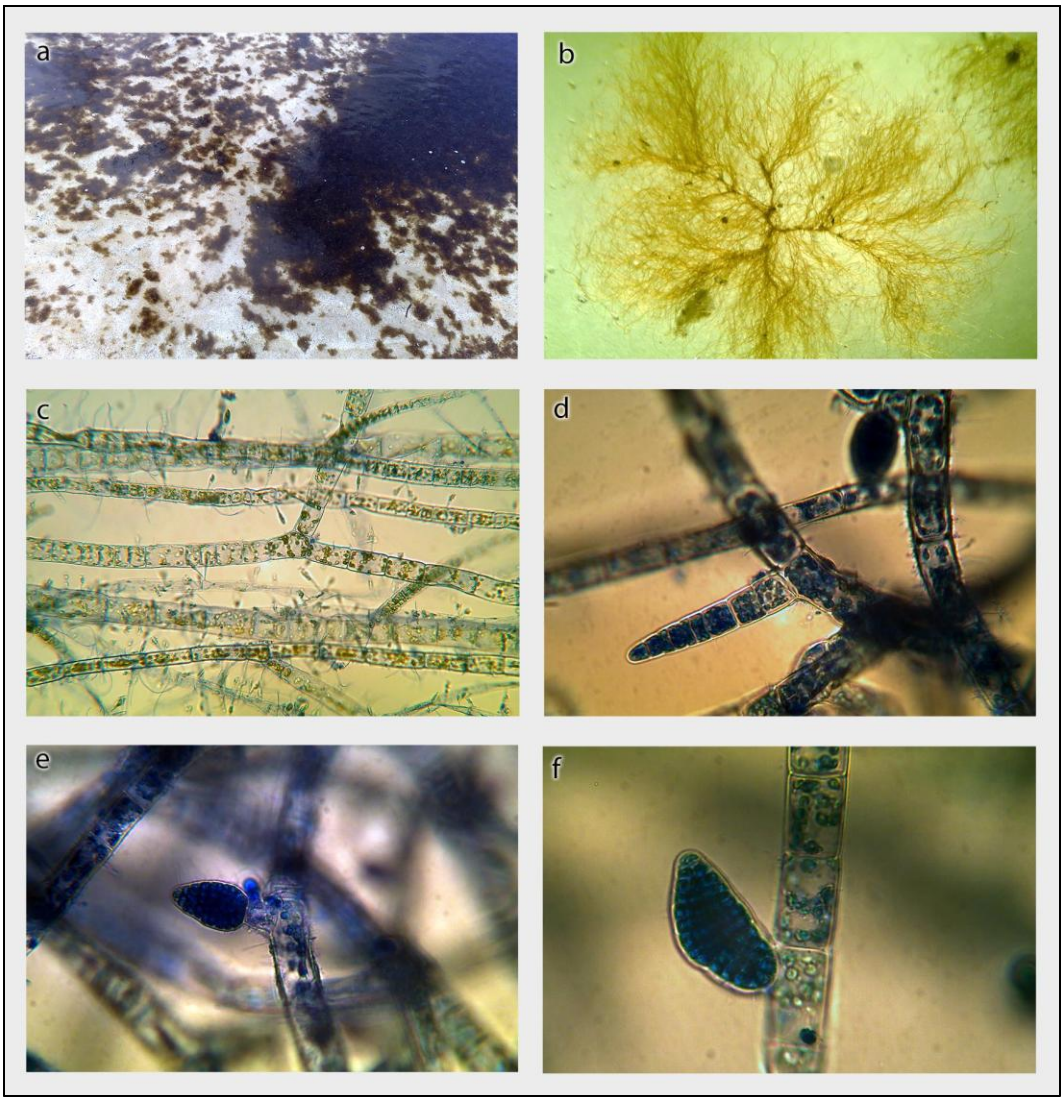

Figure 4. Thallus habit and attributes of the filamentous brown alga *Hincksia sordida* collected from blooms in Merimbula Bay and Twofold Bay. **a)** Drifting rafts of *H. sordida* washing up on the beach, **b)** An individual thalli showing the typically tufted habit of the alga sampled from blooms in Merimbula Bay, **c)** Uniseriate filaments showing cells with discoid plastids, and in this specimen the filaments are also fouled with stalked diatoms, **d)** A short tapering lateral branch that are

present along main axes, **e)** & **f)** Reproductive plurangia (pedicellate - *left image*, sessile – *right image*) on fertile specimens which release spores to enable asexual reproduction.

3.2.4 Case studies of other *Hincksia* blooms

Blooms of *Hincksia sordida* have been well documented from other Australian locations including Port Phillip Bay, Victoria (Campbell 1999, 2001) and Noosa, south east Queensland (Phillips 2006, Lovelock *et al.* 2008).

Port Phillip Bay *Hincksia* bloom

A massive bloom of *H. sordida* was first noticed in the western arm of Port Phillip Bay in 1992 with blooms recorded on an annual basis thereafter (Campbell 1999). The development of the blooms was directly attributed to nutrient inputs from the Western Treatment Plant. Campbell (1999) conducted detailed studies of the nutrient uptake strategies used by *H. sordida* to provide a physiological understanding as to why *H. sordida* was able to proliferate while other algal taxa exposed to the same nutrient inputs did not. Campbell (1999) demonstrated that *H. sordida* had fast growth rates and displayed rapid assimilation of nutrients typical of an alga with high surface area to volume ratio. More importantly, Campbell (1999) found that *H. sordida* showed a bi-phasic uptake strategy allowing the alga to efficiently scavenge nitrogen at low concentrations and assimilate excess nitrogen than was required for immediate growth (*i.e.* surge uptake) at high concentrations. It was noted that *H. sordida* generally had a low propensity for nitrogen storage and was inclined to be nitrogen limited. However, in an environment where nitrogen inputs are continuous or regularly pulsed, *H. sordida* has a clear competitive advantage over other algae that have low nutrient uptake rates but may have large intracellular stores of nitrogen.

Noosa *Hincksia* bloom

A bloom of *H. sordida* was first reported at Noosa in 2002 and blooms of increasing severity were reported in subsequent years during spring and early summer. Numerous hypotheses were advanced to explain the origin and increasing frequency and severity of the Noosa blooms. These included nutrient enrichment of coastal waters and the likelihood the blooms were developing in protected waters elsewhere such as Fraser Island or Noosa estuary and subsequently transported by currents to Noosa main beach. While unable to address the origin or transport hypothesis for the blooms, Lovelock *et al.* (2008) demonstrated that the drifting blooms of *H. sordida* were not senescent (as had been suggested) but showed high rates of growth in a marine setting characterised by typically low levels of inorganic nitrogen. Furthermore, analysis of N:P content of algal tissue indicated that *H. sordida* was nitrogen limited during the blooms (Lovelock *et al.* 2008). The study of Noosa blooms by Lovelock *et al.* (2008) support the findings of Campbell (1999) that the species may be sustained at low levels of available nutrients.

3.3 Phase 1 - Coastal Surveys

Fourteen locations along the coast were identified as potentially suitable reference locations for the purposes of the study as discussed in Section 2.2.1 and shown in Figure 5 below. These locations were systematically surveyed between April and October 2008 to collect samples of *Hincksia sordida*. Previous studies have indicated *H. sordida* to be present throughout the year (Clayton 1974) and large blooms of *H. sordida* were known to form during cooler seasons in other locations (eg. Swan Bay, Port Phillip Bay, *pers. obs.* N. Yee, Elgin Associates). As *H. sordida* was unable to be positively identified in the field due to its microscopic characteristics, all brown filamentous, turfing algae either attached or free-floating were sampled as potential samples for SIA.

Surveys resulted in 14 samples of algae from seven discrete open coast locations including: Cuttagee, Aragunnu, Pinic Point, Tathra, Bournda Island, Haycock Point, and Bittangabee Bay. However, the target species *H. sordida* was not encountered at any of these reference locations. Taxonomic analysis of the samples resulted in eight taxa representing five genera and seven species, all of which have filamentous, tuft-like thalli and are morphologically similar to *H. sordida*. The eight taxa collected from reference locations included the cogeners *Hincksia mitchelliae and Hincksia granulosa, Feldmannia globifera, Feldmannia* sp., *Ectocarpus fasiculatus, Ectocarpus siliculosus, Sphacelaria rigidula and Bachelotia antillarum.*

Figure 5. Coastal locations identified as potential reference locations and surveyed during Phase 1 of the study (image from Google Earth).

A number of letter reports were submitted to BVSC and OEH scientists during Phase 1 to provide an update on the progress of field surveys and sampling undertaken. Copies of letter reports are provided in Appendix E, and contain images of some of the algal taxa collected from reference locations.

3.3.1 Merimbula Bay Deep-water Surveys

Surveys of deep-water habitats at Long Point, Haycock Point, and Hunter Rock were conducted in October and December 2008. These locations had been hypothesised as potential supply sources of the bloom forming species *H. sordida.* However, broadscale and targeted surveys of these reefs did not record the presence of *H. sordida* attached to substrates at any of the locations surveyed (Elgin Associates 2009).

The sub-tidal environments of Long Point and Hunter Rock are moderate to highly exposed and subject to strong currents. The likelihood that *H. sordida* would exist attached to substrates at either of these locations was considered minimal (Elgin Associates 2009). In contrast, the sub-tidal environment near Merimbula wharf and Haycock Point adjacent to Bar Beach were less exposed than other locations and considered more favourable for *Hincksia sordida*. However, the target alga was not recorded attached to substrates at either of these locations.

The seabed in the direct vicinity of the STP ocean outfall was also surveyed. A large bloom of *H. sordida* and aggregations of other algal taxa were observed drifting over the seabed with the swell surge, from 300 m to approximately 1 km offshore in depths ranging from 5 – 12 m (Figure 6). Other algal taxa included the brown algae *Asperococcus bullosus* and *Colpomenia sinuosa*, and the articulated coralline red alga *Jania micrarthrodia*. None of these algal species naturally occur in the sandy bay environment but were likely transported via currents and wave action from Merimbula Lake where they do naturally grow (Elgin Associates 2009).

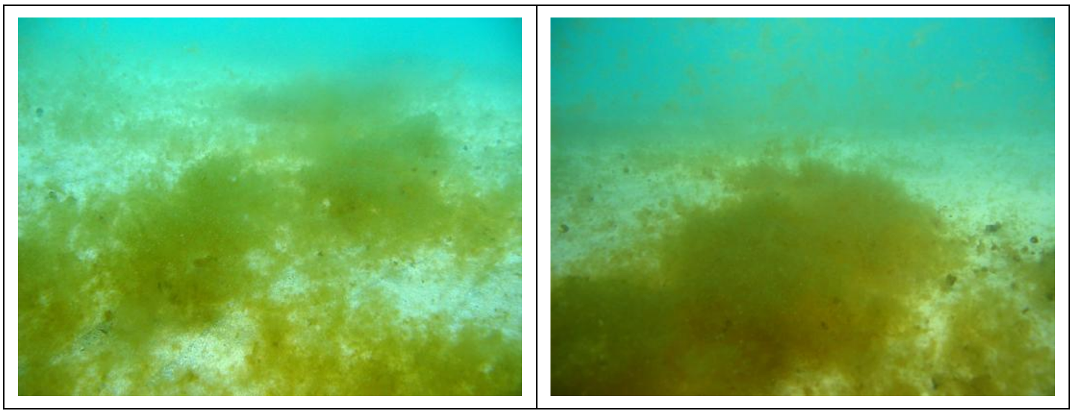

Figure 6. Blooms of *Hincksia sordida* and aggregations of other algal taxa were observed drifting over the seabed in Merimbula Bay in October and December 2008. Photographs captured approximately 700 m offshore at 6 m depth.

The *H. sordida* bloom observed offshore from the STP beach outfall in October 2008 was subsequently observed 6 weeks later (December 2008) at the Pambula Rivermouth, having been transported by local currents an estimated 2.5 km in that time period. On both occasions the bloom was mostly confined to the deeper waters rolling back and forth with the swell surge and at the time of surveys was not a visible presence on adjacent beaches.

The nature of the *Hincksia* bloom observed during deep-water surveys provides some evidence that the alga may naturally exist within the confines of Merimbula Bay, free-floating and at times in high biomass, able to be transported around the bay according to local hydrodynamic conditions. The frequency that *H. sordida* washes up and persists on local beaches is then, simply a function of the required swell conditions (Elgin Associates 2009).

A copy of the Elgin Associates (2009) report is contained in Appendix F.

3.3.2 Limitation to the study design

A meeting was held between BVSC, OEH scientists and Elgin Associates in late 2008 to discuss the limitations to the study design that were encountered following the outcomes of the phase 1 coastal surveys. The principal limitation was that the target alga, *H. sordida,* was not encountered at reference locations and thus not collected for isotope analysis. In light of this limitation, samples of species that were collected from reference locations during phase 1 including the closely related *Hincksia mitchelliae* were submitted for isotope analysis.

Attempts to execute phase 2 of the study, simultaneous sampling of algal blooms in Merimbula Bay and at reference locations, have not been made to date. Merimbula Air Services conduct daily flights along the coastline and have agreed to provide notification of when an algal bloom is occurring outside of Merimbula Bay. However none have been reported to date.

3.3.3 Algal Samples

A total of 44 algal samples were collected during the study. These include 14 samples from reference locations and 30 samples from Merimbula Bay and other locations such as Twofold Bay that also received inputs of STP effluent. *Hincksia sordida* was only recorded from Merimbula Bay, Twofold Bay and the closed estuary Wallagoot Lake.

For samples where algal biomass was plentiful (*i.e.* blooms), two to three replicate sub-samples were prepared for SIA. Thus a total of 42 samples were submitted for SIA.

Details of all algal samples collected during the study and voucher specimens in provided in Appendix C.

3.3.4 Environmental conditions

Environmental conditions including wind direction, inferred regional currents, anticipated inshore currents, and sea surface temperature were noted for the seven days prior to the nine bloom events sampled during the study period. These notes are summarised in Table 1 (attached) with satellite imagery from which regional currents were inferred contained in Appendix G.

A clear trend in environmental conditions preceding a bloom event was not apparent though the key points that can be drawn from notes include:

- Majority of bloom events were observed during spring and summer. Blooms were less frequent in winter months with just one event sampled twice over three days as it moved south along Merimbula beach towards Pambula.
- Blooms of *Hincksia sordida* were observed over a broad range of sea surface temperatures ranging from 12 to 23°C.

- Blooms were typically observed in the near shore wave zone. One exception to this was the bloom event observed on 26 October 2008, which was located offshore and was not present on, nor visible from the beach at that time. This event was observed during diving surveys (Elgin Associates 2009) and suggests that a large biomass of *Hincksia* may be present and drifting within the bay across all seasons.
- Blooms appearing on beaches during summer months were preceded by sustained winds from the north and east quadrants supporting previous observations of local residents and suggesting there may be an increased likelihood a bloom will appear on beaches under these wind conditions if it is already present in Merimbula Bay.
- Blooms were observed either at the northern or southern end of Merimbula Bay, with a higher frequency of blooms observed at the southern end adjacent to Pambula Beach and Jiguma Reserve. The regional broad scale current off the continental shelf was typically south flowing at the time of all bloom events (see Appendix G). However, the corresponding inshore current was not always south flowing. For summer blooms observed adjacent to Pambula and Jiguma on 5 Dec 2008, 16 Nov 2011, 25 Jan 2012, and 22 Feb 2012 the strong south flowing regional current resulted in a north flowing inshore current along the southern NSW coast. According to hydrodynamic modelling of Merimbula Bay (AECOM 2009), a north flowing inshore current may lead to the formation of a single large counter-clockwise eddy in the bay directing current flows towards Pambula beach. The modelling also predicted that two smaller current eddies may split in the middle of the bay under a south flowing inshore current and simultaneously direct flows towards Merimbula and Pambula beach.

The greater frequency of algal blooms observed at southern end of Merimbula Bay in summer months appears due to the combination of prevailing east and northeasterly winds driving algal biomass towards the coast and local currents pushing the blooms south towards Pambula beach under both south and north flowing inshore currents. Further information regarding hydrodynamnics of Merimbula Bay is provided in Section 3.5.2.

3.4 Community Perspectives

3.4.1 Media Coverage

An historical overview of the Merimbula Bay algal bloom issue can be gained from a search of local print and online media sources (Merimbula News Weekly, Eden Magnet, ABC News Online). A search using a combination of key words ‘algae’, ‘algal blooms’, ‘Merimbula’ and ‘Pambula’ returned 27 news articles. The earliest news article appeared on 19 February 2004 and the most recent published on 9 May 2012. It is evident the issue was more topical in some years compared to others which may be a reflection of the intermittent presence of the algae on local beaches. The issue does not appear in local print media prior to 2004. A chronology of media coverage of the issue is provided in Table 2 below, with copies of all articles contained in Appendix H.

Table 2. Chronology of local media coverage of the algal bloom issue.

Date and Media Organisation	Article Headline
2004	
19 February 2004 – *Eden Magnet*	Algal bloom detrimental to beach environment
3 March 2004 – *Merimbula News*	Council says sewer not to blame
3 March 2004 – *Merimbula News*	Sewer feeds ‘red tide’ in bay says residents
10 March 2004 – *Merimbula News*	Killing the coast
10 March 2004 –*Merimbula News*	Algae common non-toxic: council
10 March 2004 – *Merimbula News*	Public meeting about algae
18 March 2004 – *Merimbula News*	Sub committees to look at algal bloom issues
25 March 2004 – *Eden Magnet*	Council must protect Twofold Bay
8 April 2004 – *Eden Magnet*	EPA under fire
14 April 2004 – *Merimbula News*	EPA can’t say how effluent spreads in bay
29 April 2004 – *ABC SE News*	Sydney sewage linked to algal blooms
2005	
10 Feb 2005 – *Eden Magnet*	Sewage may have stained bay brown
16 March 2005 – *Merimbula News*	Surf carnival driven to Main Beach by weed
25 May 2005 – *Merimbula News*	Merimbula sewage scheme bogged down in red tape
2007	
19 January 2007 –*Eden Magnet*	Council: Aslings Beach one of best
31 January 2007 – *Merimbula News*	Tame or toxic?
14 February 2007 – *Merimbula News*	Divers enlist community help to nail pollies over algae
25 April 2007 – *Merimbula News*	Major breakthrough in battle against algae
28 November 2007 – *Merimbula News*	Algal bloom fouls our beaches
28 November 2007 – *Merimbula News*	Worm farmer observes changes to eco system
12 December 2007 - *Merimbula News*	Council on path to slay beach enemy
2008	
24 January 2008 – *Merimbula News*	Council to clean up act on region’s sewage
24 September 2008 – *Merimbula News*	Blitz on beach blight
24 September 2008 – *Merimbula News*	Analysis of algal bloom underway

2009	
9 April 2009 – *Merimbula News*	Clean water thwarts weed study
7 October 2009 – *Merimbula News*	Effluent: is it the bad beach bogey after all?
2010	
20 January 2010 – *Merimbula News*	Black Attack
2012	
11 January 2012 – *Merimbula News*	Testing continues on Merimbula Bay algae
9 May 2012 – *Merimbula News*	Stunner turns to Stinker

3.4.2 Anecdotal reports of effluent and algal bloom related impacts

Concerns most frequently expressed by the community regarding the discharge of effluent and algal blooms include aesthetic and health related concerns. As discussed in Section 3.1 (above), all algal taxa collected from drifting blooms since 2004 were found to be native, local non-toxic species that pose no threat to human health. However, one concern that remains unsubstantiated by scientific evidence is a perceived detrimental impact that effluent and algal blooms may be having on the condition and quality of beachworms collected from Merimbula Bay beaches.

Bait collector Gerald Hughes is licensed to commercially collect beachworms. These principally include the king worm *Australonuphis teres* among other species of the polychaete Family Onuphidae. In his observations, the condition and quality of beachworms that have been feeding on the algae deteriorate quickly and he is unable to sell these worms as bait. (Refer to Merimbula News article 28 November 2007 – Appendix H).

Though not part of this study's scope of work, a number of world experts in polychaete worm taxonomy and ecology were contacted for comment as to whether algal bloom impacts on beachworms have been demonstrated and or documented from other regions. Experts contacted for comment included:

- Prof. Greg Rouse – Curator of Benthic Invertebrates, Scripps Institution of Oceanography, La Jolla, California, United States
- Dr Robin Wilson – Senior Curator Marine Invertebrates, Museum Victoria, Melbourne
- Dr Hannelore Paxton – Honorary Researcher, Macquarie University, NSW

None of the three experts were aware of cases where macroalgal blooms were demonstrated to have a detrimental impact on the condition of beachworms. Beachworms are omnivorous, they are known to consume a variety of macroalgae and while they are scavengers are not associated with polluted areas (*pers. comm.* H. Paxton, 22 August 2012). Poor body condition is common in polychaete worms following spawning which the worms may undertake throughout the year (Paxton 1979) and it was suggested that spawning events may coincide seasonally when algal blooms occur.

While there is no known detrimental effect of macroalgae on polychaete worms, impacts from microalgae have been documented. A 1990 study investigated the mass mortalities of lugworms, another type of beachworm, in south Wales, United Kingdom (Olive and Cadnam 1990). A number of possible causes of worm mortality were investigated with circumstantial evidence pointing to the likelihood the mass mortality was caused by the toxic dinoflagellate *Karenia aureola* (as synonym *Gyrodinium aureolum*) (Olive and Cadnam 1990).

3.4.3 Local Resident Interviews

A number of Merimbula residents can recount the occurrence of algal blooms in Merimbula Bay from as early as the 1950s. These anecdotal observations are valuable in that they demonstrate the natural occurrence of algal blooms in Merimbula Bay from more than five decades ago and from a time period approximately 10-20 years prior to the commissioning of the STP in 1971 and before large volumes of sewage effluent were discharged to the bay. Excerpts from these interviews are provided below.

Charles High

Proprietor of Woodbine Park Eco Cabins, Tura Beach

Charles operated a charter boat from Merimbula during the 1950s. He recalls algal blooms being a problem during that time period.

"...the algae would wash up on the beach much like it does today. We just called it slime. You couldn't fish the central part of the bay because the slime would build up on your line. It wouldn't be there every year, some years were worse than others. When it was bad we wouldn't even bother to fish. Certainly the blooms we see today are no worse than what we experienced back then (1950s)."

Bill Deveril

Charter Boat Operator, and Professional Fisherman

Bill has been a Merimbula resident since 1953. His knowledge of the local coastline and of the Merimbula Bay environment is based on more than 50 years of experience as a surfer, professional fisherman and charter boat operator. Bill has also been involved with the Pambula Surf Lifesaving Club since 1957 and remembers algal blooms being a regular occurrence in the bay over five decades ago.

Bill recalls *"...the algal blooms that we are regularly seeing in the bay, these were present in the bay during the late 1950's and early 1960's. Some years would be worse than others, but they were a regular occurrence even back then. The southern end of the bay at Pambula was affected by the algae more than the Merimbula end. I remember competing in surf carnivals and the algae would stick to your body get stuck in your budgie-smugglers. As a fisherman in the early 1970's, we would see huge amounts of the stuff (algae) in the bay and at times off the headlands. It would coat your lines and your bait....we would have to move to other locations to avoid the algae. I currently operate a charter boat out of Merimbula and the presence of the algae in the bay at times will determine where we can fish. To my knowledge, algal blooms have been a regular occurrence in Merimbula Bay since the 1950s....they're a part of nature."*

Michael McGuire

Proprietor Pacific Heights Holiday Units, Merimbula

Michael was a Merimbula resident between 1950-1974 and returned to Merimbula in 2010. He was a member of the Pambula Surf Life Saving Club from 1961-1973, a branch champion surf and belt swimmer in that period. Michael has recollections of algal blooms at Pambula Beach during the period he was an active member at the surf club.

" I joined the surf club in 1961 as a 12 year old. Rather than nippers we were called 'gremlins' back then. I

recall the algae being thick at times. We would still swim and surf through it, the algae would get stuck in your swimmers, we would have to hit the showers to get it off our bodies. I also remember swimming in a surf carnival in Lakes Entrance in the late sixties, the algae was horrific that day. The algae would attach itself to the cotton surf line weighing it down and causing the line to sink and become much heavier. Bill Deveril was my first linesman in the team that day, and his experience enabled me to win the race, his instructions were to "pull" the line through his hands allowing the least amount of line in the water as possible. You do not get that experience unless you have experienced the problem (the algae) before, which reiterates Bill's comments."

3.5 Environmental Setting

3.5.1 Physical Characteristics of Merimbula Bay

Merimbula Bay is located on the far south coast of New South Wales with the townships of Merimbula and Pambula situated on its northern and southern shoreline respectively. It is a large sandy embayment bounded by the rocky headlands of Long Point at the north and Haycock Point at the south. It is the receiving environment of the Merimbula and Pambula River estuaries whose ocean entrances are situated at the northern-most and southern-most extent respectively.

The embayment has an easterly aspect and bathymetric charts show seabed depth gradually increases with increasing distance from the shoreline. The seabed of Merimbula Bay is predominantly sand with extensive sub-tidal reefs extending from Long Point and Haycock Point and a large isolated sub-tidal reef surrounded by sand, known as Hunter Rock, exists approximately 500 m north of Haycock Point. These reefs represent the only hard substrata in the bay that support communities of macroalgae and sessile invertebrates. Each reef system is exposed to different swell conditions and swell regimes and represent a potential supply source of drift algae to the bay environment; where during heavy seas, algae may be detached from these reefs and eventually wash-up on Merimbula and Pambula beaches.

The bay is characterised by typically low turbidity and consequently the sandy sediments and microphytobenthos are well illuminated under normal conditions. An exception would be during floods events where plumes of turbid water expelled from the Pambula River and Merimbula estuaries would diminish light levels. The microphytobenthos are an assemblage of benthic microalgae typically including diatoms and dinoflagellates but many other algal groups may be found in this benthic algal community. The microphytobenthos of Merimbula Bay, though inconspicuous, represent an important contribution to primary productivity and nutrient cycling in the bay.

3.5.2 Hydrodynamics of Merimbula Bay

The hydrodynamic processes of Merimbula Bay have a direct influence on when and where drift algae and algal blooms appear on the beaches in Merimbula Bay. The reasons why drift algae move around the embayment and may congregate at the southern-end with greater frequency compared to the northern-end at certain times of the year requires an understanding of these hydrodynamic processes.

RESULTS AND DISCUSSION

The hydrodynamics of Merimbula Bay is influenced by a combination of broadscale oceanographic circulation, local wind advection (wind strength and direction) and bathymetry. It is variously influenced by the East Australian Current (EAC), which brings warm, typically nutrient-poor, subtropical water from the Coral Sea down the east coast of Australia. The EAC is Australia's largest ocean boundary current, its maximum speed exceeding 4 knots (7 km per hour) near the surface and its effects extending to several thousand meters in depth (Cresswell 2001). It flows as a continuous current along the edge of the continental shelf south to Smoky Cape, where it typically breaks into a series of counter-clockwise-rotating, warm core eddies up to 250 km in diameter (Cresswell 2001; Short and Woodroffe 2009). These eddies spiral further south along the continental margin producing strong currents and rapid changes in water temperature along the coastline of southern NSW.

The continental shelf waters offshore of Merimbula are dominated by the EAC eddy field, although the complex nature of the EAC and its eddies means that its influence on coastal and offshore conditions is highly variable. It is estimated that the warm waters of the EAC influence the inshore marine environment of southern NSW approximately 10% of the time (Pollard *et al.* 1997) with its effects most noticeable during summer and autumn when its flow is strongest (CSIRO Australia 2001). For the most part, the waters of Merimbula Bay are dominated by temperate conditions associated with a northward flow of cooler, well-mixed waters originating from Bass Strait driven by local winds and coastal-trapped-waves, an oceanographic feature influencing ocean circulation in the shelf zone (Church *et al.* 1986; Griffin and Middleton 1991; Zann 2000).

Near-shore effects of the EAC are also observed even when the main current is flowing well offshore, as intrusions of EAC onto the shelf are an important mechanism for driving upwellings of cold, nutrient-rich waters from the continental slope towards the coast (Cresswell 2001). These upwelling events usually result in increased phytoplankton abundance (Oke and Middleton 2001) which in turn may drive increased productivity at higher levels of the food chain. Coastal winds generating waves and driving near-shore currents are another important mechanism for upwellings. In NSW, N to NE wind generates a south-flowing coastal current, which is deflected offshore due to the Coriolis effect (Short and Woodroffe 2009). As surface waters move offshore an upwelling effect is created which draws cooler waters up from the seabed, a phenomenon known as Ekman transport. Upwellings may result in a sudden decrease in sea surface temperature by as much as 5-7 ° Celsius. Conversely, a strong southerly wind blowing along the NSW coast drives a northerly current that is deflected towards the coast. This brings oceanic water to the coast and usually returns near-shore sea surface temperatures to a more stable average. Further information regarding the delivery of nutrients to the nearshore zone via upwellings is presented in Section 3.6 below.

In addition to ocean boundary and wind driven currents, the tidal flux of the Merimbula and Pambula River estuaries also influence the local hydrodynamics within Merimbula Bay. Hydrodynamic modelling under ebb and flood tide conditions combined with either a south or a north flowing current have shown the likelihood for eddies to form in Merimbula Bay (AECOM 2010). Whilst these models have not been validated, the tendency for drift algae to move around the embayment over periods of days and weeks provide some evidence that localised eddies may be responsible. Under a north flowing current, models show the formation of a single large counter-clockwise eddy directing inshore flows to Pambula beach. In contrast, under a south flowing current, models show the formation of two smaller eddies that split in the mid-region of the embayment and direct flows to either end of the bay (AECOM 2010). The formation of current eddies in Merimbula Bay are generalised in Figure 7 below.

Figure 7. Hydrodynamic models of Merimbula Bay have shown the likelihood of current eddies to form under north and south flowing coastal currents (refer AECOM 2010). Arrows are indicative of generalised current directions as modelled by AECOM (2010) and should not be interpreted as actual currents.

3.5.3 Merimbula Sewage Treatment Plant (STP)

The Merimbula STP is an activated sludge plant (‘Port Macquarie Tanks’) with chlorine disinfection and effluent storage .The sewage treatment process relies on the natural activity of bacteria and other microorgansims to coagulate and biochemically degrade (oxidise) organic matter to simpler substances like carbon dioxide and nitrate. Three consecutive cycles - aeration, settlement and decant - are programmed to run in the extended aeration tanks 6 to eight 8 times a day (*i.e.* 180 to 240 minute cycles). Solids settle out during the settlement phase and the clear surface water or effluent is withdrawn during the subsequent decant phase and directed to the catch pond. Effluent from the catch pond is dosed with liquid sodium hypochlorite to reduce the number of viable microorganisms in the effluent (disinfect). Following disinfection, the effluent is stored in the effluent storage pond for between 5 and 9 days (detention time dependent on outflow volumes) from where it is pumped to either the golf course for reuse or the dunal ex-filtration ponds or ocean outfall for disposal. Under high rainfall conditions, when inflows are elevated, the effluent may be directed to the wet-weather overflow pond for temporary storage for pumping back to the effluent pond upon the return of dry weather flows. The STP site layout is shown in Figure 8.

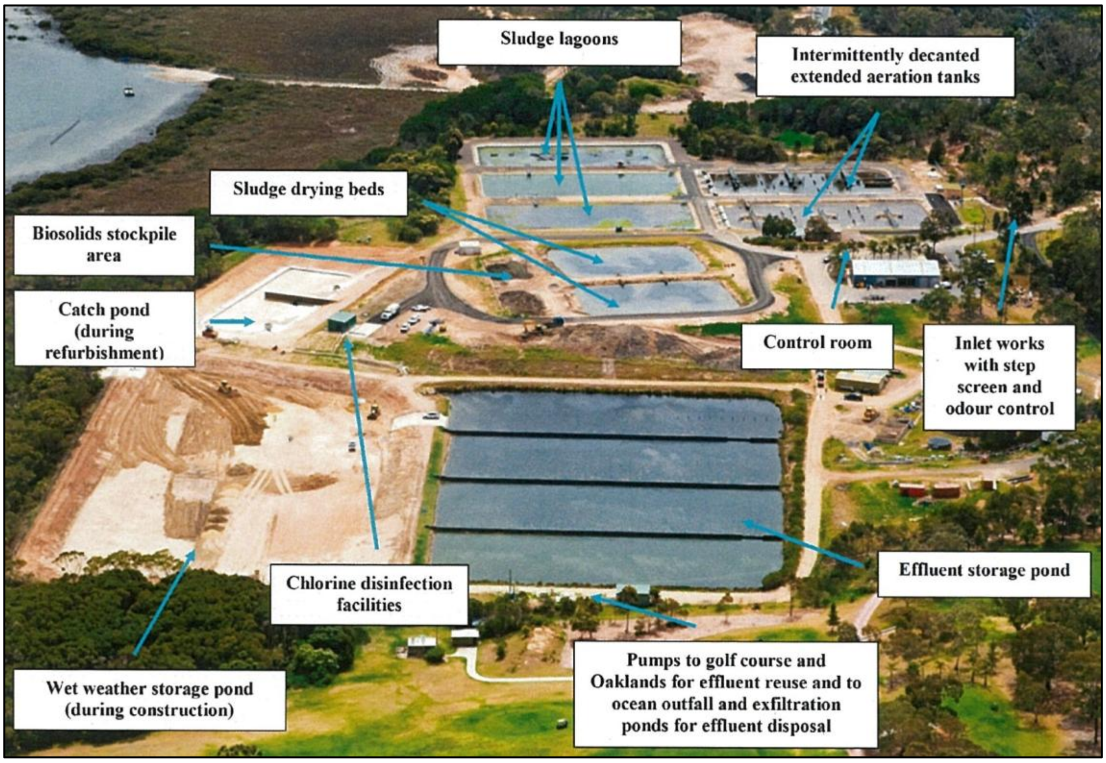

Figure 8. Merimbula STP - Site Layout (*image provided by BVSC*)

Figure 9. Merimbula STP ocean outfall pipe terminating in the foredunes (*left image*); discharged effluent flows across the beach to the ocean as evidenced by scouring of beach sands (*right image*).

The ocean outfall consists of a pipeline that extends from the STP and currently terminates in the dunes midway between Merimbula and Pambula beaches (Figure 9). Treated effluent is discharged from this pipe onto the beach where it flows to the ocean. When the STP was built and commissioned in 1971, the pipeline originally extended into the wave zone but was damaged by storms in the early 1970s and was not reinstated to original design. Discharge of effluent to the ocean outfall pipe is undertaken at night to minimise the risk of public contact. Typically, maximum flows to the ocean occur during winter and wet conditions when there is little or no golf course irrigation demand.

RESULTS AND DISCUSSION

The alternative effluent disposal system is the dunal exfiltration ponds. Use of the ponds for effluent disposal is determined by the groundwater level near the ponds and season. When the groundwater level at monitoring bore BH10 is below 1.5 metres AHD, the ponds may be used. The groundwater level near the ponds is allowed to fall leading up to the summer peak tourist season between December and February to enable the ponds to be used instead of the outfall during this time period. Once the groundwater level at BH10 rises above 1.5 metres AHD, as a result of dunal exfiltration and/or rainfall, the ponds are taken off-line and the groundwater level allowed to fall away again. The outfall is then brought back on-line and used instead for effluent disposal. Typically the exfiltration ponds have capacity to dispose of about 100 to 250 ML of effluent from the STP each year, depending on rainfall and groundwater levels.

Figure 10. Merimbula STP dunal exfiltration ponds - empty (*left image*); monitoring bore BH10, adjacent to the ponds, used to measure groundwater levels for ponds usage (*right image*).

Approximately 160 ML of effluent was disposed via the ocean outfall during the first year of operation in 1971. By 1980 the volume of effluent discharged to the ocean had increased to approximately 400 ML/year, due to the rapid population growth of the 1970's. In 1980, effluent reuse on the golf course commenced helping to reduce the volume of effluent disposed to ocean from year to year. In 1991, the dunal exfiltration ponds were commissioned providing another disposal option. Since 2007, the volume of effluent discharged to the ocean has ranged between 230 and 400 ML/year (*in. lit. K. McLeod* - BVSC, 8 June 2012). Figure 11 (below) shows the total annual volume of effluent generated from Merimbula STP and the volumes reused and disposed over the seven (7) year period, 2005 to 2012. The increased volumes of effluent disposed to the ocean in 2010-11 and 2011-12 was due to above average rainfall in these years reducing golf course irrigation demand and increasing groundwater level in the dunes (limiting the availability of the exfiltration ponds for effluent disposal).

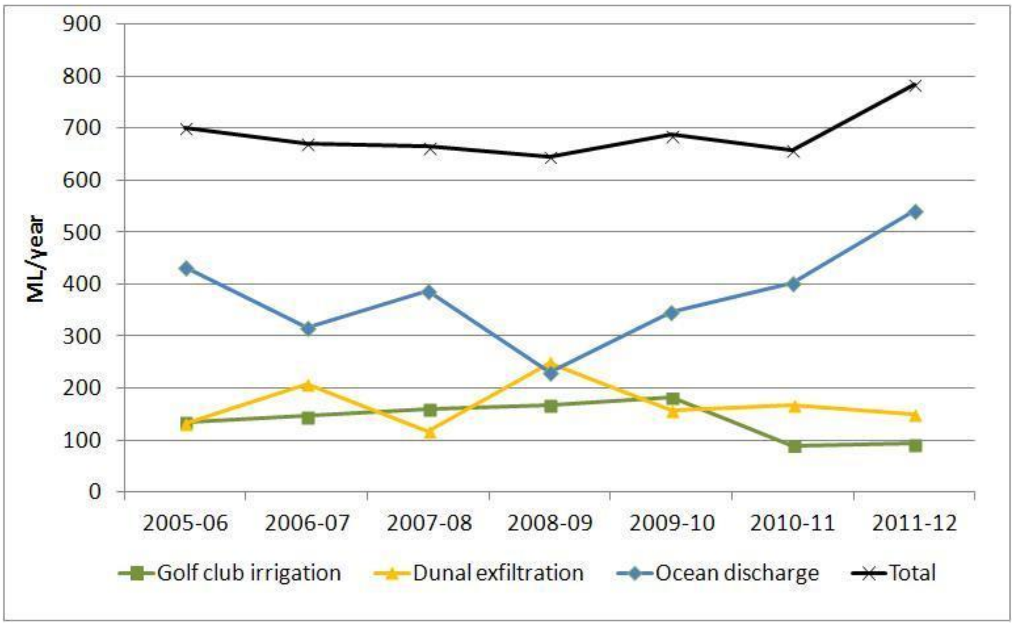

Figure 11. Merimbula STP total annual effluent volumes. Chart shows effluent volumes reused (golf club irrigation) and disposed (dunal exfiltration and ocean discharge).

At the time of this report, the Environment Protection Licence (EPL 1741) for the Merimbula STP permits a maximum daily disposal volume of 4 ML to the ocean outfall or dunal exiltration ponds (EPA 2012). BVSC has committed to discontinuing effluent disposal via the existing beach outfall and are currently investigating alternative options for the disposal and reuse of effluent. This includes working towards commissioning an additional effluent reuse scheme at Oaklands farm, on the Pambula River flats.

3.6 Sources of Nutrients

While this study focused on assessing the influence of effluent derived nutrients to the formation of algal blooms in Merimbula Bay, it is also important to consider other sources contributing nutrients to the bay. As with many other coastal waters, Merimbula Bay receives nutrients from a combination of both diffuse and point source inputs. Diffuse source inputs include nutrients transported in the cumulative stormwater runoff from urban, industrial, agricultural and forested lands of the Pambula River and Merimbula catchments, groundwater discharge, as well as from occasional oceanic upwellings of waters from the continental slope. Direct discharge of effluent from the Merimbula STP represents a point source input.

Nutrients enter Merimbula Bay in either particulate organic forms or dissolved inorganic forms. It is the latter, dissolved inorganic forms of nitrogen and phosphorous that is readily assimilated by algae in the bay including the phytoplankton (pelagic microalgae), microphytobenthos (microalgae living on seafloor) and macroalgae (seaweeds).

3.6.1 Merimbula STP

Discharge of effluent from the Merimbula STP provides a relatively continuous source of dissolved inorganic nutrients to Merimbula Bay with the exception of times when the exfiltration ponds are used for disposal and the golf course is able to use all the effluent from the STP. Typical nutrient concentrations of Merimbula STP effluent include nitrogen at ~5 mg/L (mostly as nitrate), ammonia at <1 mg/L (mostly as ammonium) and phosphorous at ~10 mg/L (mostly as dissolved ortho-phosphates). These dissolved inorganic forms of nutrients are bioavailable and would be readily assimilated by algae. Effluent also contains suspended solids at ~5 mg/L and faecal coliforms at 65 cfu/100mL (median values).

Under the EPA discharge licence, BVSC are required to report assessable loads of contaminants discharged to the environment on an annual basis. This information is available online at the EPA Protection of the Environment Operations (POEO) register (EPA 2012). Data show that annual nutrient loads discharged to Merimbula Bay varies from year to year with the average annual load of nitrogen at 1,663 kg/year and phosphorous at 3,090 kg/year based on data from the five year period, 2007-2011. These data are shown graphically in Figure 12, below.

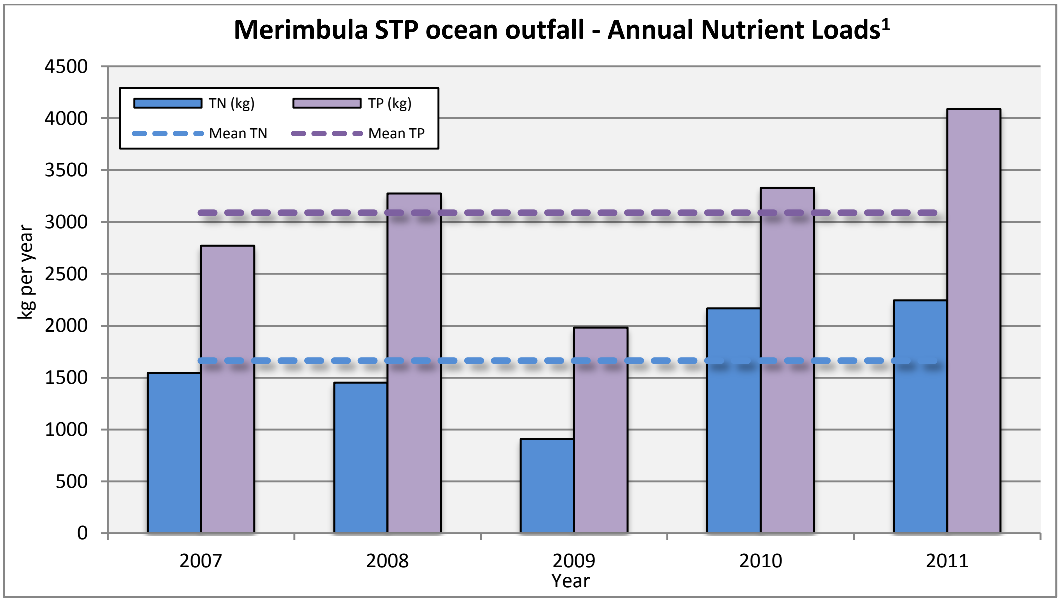

Figure 12. Annual TN and TP loads discharged to Merimbula Bay from 2007 to 2011, based on BVSC Load Based Licensing data ([1]Data from the EPA - Protection of the Environment Operations register).

3.6.2 Pambula and Merimbula catchments

Coastal catchments contribute nutrients to coastal waters mostly via estuaries though contributions are highly episodic depending on catchment inflows generated by rainfall runoff. Merimbula Bay receives outflows from the Pambula River and Merimbula estuaries whose catchment areas are 296.5 km^2 and 37.9 km^2 respectively. OEH has undertaken modelling for all NSW estuaries including Pambula and Merimbula using the Coastal Eutrophication Risk Assessment Tool (CERAT), which provides estimates of the amounts of nutrients and sediments delivered to the estuaries from their catchments.

According to CERAT modelling (DECCW 2009), the average annual nutrient yields from the Pambula and Merimbula catchments and delivered to the estuaries are estimated to be:

	TN load (kg/year)	TP load (kg/year)	TSS (kg/year)
Pambula	*34,532*	*3,037*	*719,637*
Merimbula	*6,128*	*798*	*135,025*

These estimates are based on catchment characteristics and land-uses and have not been field validated. Therefore these values may overestimate actual catchment yields. Nonetheless, it is expected that only a small proportion of the total annual nutrient load would be exported from the estuaries to Merimbula Bay under normal flow conditions. This assumption is based on trends established by a number of studies that show majority of catchment inputs are retained within estuaries (Sinclair Knight Merz 1997; Eyre and Pepperell 1999; Pritchard *et al.* 2003). This is due to various physical and biological processes including nutrient sorption by estuarine sediments and nutrient assimilation by macrophytes and algae reducing catchment nutrient loads as they are transported from their sources downstream to estuarine receiving waters. Sedimentary denitrification alone has been estimated to remove more than 50% of total nitrogen input to estuaries and up to as much as 80% in some systems dependent on water residence times (Seitzinger 1988; Harris 1999). The net effect is an overall reduced load of nutrients that may be carried to coastal waters during normal tidal flows. An exception to this would be during flood events where high loads of suspended solids and nutrients may be exported to Merimbula Bay.

Surface water quality data collected on a quarterly seasonal basis from the Pambula and Merimbula estuary basins (Elgin Associates 2010-2012) provides some estimate of the upper limit of nutrient concentrations that may be exported to the bay environment during normal tidal flow conditions (see 90th percentile values in Table 4 below). Data (Elgin Associates 2010-2012) show that majority of nutrients in surface waters of these estuaries are typically bound in particulate organic forms with dissolved inorganic nitrogen and phosphorous in minor proportions and at lower concentrations compared to other diffuse sources of nutrients contributing to Merimbula Bay (see Table 4).

3.6.3 Oceanic upwellings

Upwellings or intrusions of cold nutrient-rich water from the continental slope, though transient and episodic in nature, represents a significant source of nutrient supply to the coastal zone. As mentioned in Section 3.5.2 (above), upwelling events occur under particular oceanographic and climatic conditions with seasonal trends indicating a higher prevalence for upwellings to occur during spring and summer in NSW (Pritchard *et al.* 2003). Slope waters are typically characterised by low temperatures (<14°C) and low salinity (<35.3 psu) with studies showing these waters to carry high concentrations of bioavailable nitrate (>70-250 µg/L) and phosphate (>22 µg/L) (Pritchard *et al.* 2003, Suthers *et al.* 2011). As upwellings operate over large spatial scales of hundreds of kilometres, these nutrient concentrations represent a significant contribution of nutrients to the coastal zone. Pritchard *et al.* (2003) considered the various sources of nutrients to the coastal zone of the Sydney region and found slope water to be the dominant source of nutrients during upwelling events with daily nutrient loads exceeding STP effluent and riverine discharges by orders of magnitude.

The frequency of upwellings on the NSW south coast like many other regions have been inferred from satellite images showing phytoplankton blooms as a response to these events. However, the contribution of nutrients delivered to nearshore areas of the NSW south coast and in particular Merimbula Bay are not known and it can only be assumed that the findings of Pritchard *et al.* (2003) would apply to other NSW coastal waters. Recently in 2011, the NSW node of the Integrated Marine Observing System (IMOS) have installed oceanographic instruments off the coast of Narooma in an effort to gather data regarding the oceanographic conditions including upwelling events in the NSW far south coast region.

3.6.4 Groundwater

The peninsula that separates Merimbula Lake from Merimbula Bay is characterised by Quaternary dune and beach sand deposits up to 26 m thick, underlain by Tertiary fluvial sand and clay deposits (IGGC 2012). Hydrogeological studies commissioned by BVSC show an unconfined aquifer exists within the Quaternary sand deposits with inferred groundwater flow discharging to shoreline areas of both the lake and the bay (IGGC 2012). As mentioned in Section 3.5.3 (above), a proportion of treated effluent is discharged to exfiltration ponds located in the foredunes above Merimbula Bay. From these ponds the effluent slowly percolates through the sandy sediments into the groundwater aquifer.

The BVSC has established a network of monitoring bores in the dunes to monitor groundwater level and groundwater quality. Five bores are located in the vicinity of the exfiltration ponds and ocean outfall. The groundwater quality monitored in these bores is considered influenced by effluent disposal. Seven bores are located at a distance north away from the exfiltration ponds and ocean outfall. The groundwater quality monitored in these bores is considered to be representative of natural background conditions, unaffected by effluent disposal. Table 3 (below) provides a general summary of the data collected from the monitoring bores between 2004 and 2012.

Data show natural background levels of inorganic phosphorous (as PO_4^{3-}) in groundwater typically to be around 0.06 mg/L for both the central and coastal dune areas. Natural background levels of total inorganic nitrogen (TIN as NH_4 + NO_3^-) are more variable, ranging from around 0.21 mg/L in the central part of the dunes to 0.45 mg/L in the dunes closer to the coast. Nitrate concentrations are more variable temporally as well as spatially, reflecting the greater mobility of nitrate in groundwater. Groundwater quality in the bores influenced by effluent disposal show inorganic phosphorus elevated above natural background levels while the concentration of inorganic nitrogen is similar or slightly below natural background levels. Ammonium however is elevated in the bores influenced by dunal exfiltration, suggesting reducing groundwater conditions and associated reduction of nitrate to ammonium.

An approximation of nutrient loads delivered to Merimbula Bay via dunal exfiltration can be estimated by multiplying groundwater flow towards the ocean from the ponds by the concentrations of total inorganic nitrogen and phosphate for the coastal influenced bores.

Average groundwater flow from the ponds, effluent induced and natural, is estimated at around 315 m^3/day, based on estimated hydraulic conductivity, measured average hydraulic gradient and estimated aquifer cross-sectional area. Average concentrations of TIN (NH_4 + NO_3^-) and PO_4 are estimated at 1.16 mg/L and 2.26 mg/L respectively (Table 4 below). Nutrient loads to Merimbula Bay from groundwater influenced by the exfiltration of effluent are approximately 367 kg/year of TIN and 711 kg/year of PO_4^{3-}.

Table 3. Summary of groundwater quality of the Merimbula dunal aquifer. Data represent mean values from the 2004-2012 time period (*provided by BVSC*).

Bore location	**General WQ characteristics:** **Natural background/ Influenced by effluent**	**PO_4^{3-} (mg/L)**	**NO_3^- (mg/L)**	**NH_4 (mg/L)**	**TP (mg/L)**	**TN (mg/L)**
Central	Natural background. Slightly brackish, slightly alkaline, oxidizing.	0.06	0.17	0.04	0.08	0.45
Coastal	Natural background. Brackish to very brackish, slightly alkaline, oxidizing.	0.06	0.42	0.03	0.08	0.80
Central	Influenced by effluent. Slightly brackish, slightly acidic, slightly reducing to strongly reducing.	0.19	0.03	0.74	0.57	1.48
Coastal	Influenced by effluent. Slightly brackish, slightly alkaline , slightly reducing to oxidizing.	2.26	0.34	0.82	2.39	1.35
Low lying wetland	Influenced by effluent. Fresh, acidic, slightly oxidizing to slightly reducing.	0.03	0.01	0.12	0.28	1.73

PO_4^{3-} = phosphate, NO_3^- = nitrate, NH_4 = ammonium, TP = total phosphorous, TN = total nitrogen

3.6.5 Other nutrient sources

Atmospheric inputs of ammonia and nitrate via precipitation and the internal store of nutrients within the bay sediments represent other sources of nutrient inputs to the bay environment. However, the contribution from each of these sources is not known.

3.6.6 Summary of nutrient sources

A summary of the various sources contributing nutrients to Merimbula Bay is provided in Table 4 below. Assessing the relative contribution of these nutrient sources (other than STP effluent) is difficult when the transient nature of each source is considered together with the absence of comparable data. However, it is likely that majority of nutrients exported from the catchments via the estuaries is bound in particulate organic forms while STP effluent and upwellings of slope water represent the main contributors of dissolved inorganic nutrients to the bay environment.

Table 4. Sources of nutrients to Merimbula Bay and their documented loads and/or concentrations.

Nutrient Source	**TN load (kg/yr)**	**TP load (kg/yr)**	**Nitrate NO_3^- (mg/L)**	**Ammonium NH_4^+ (mg/L)**	**Phosphate PO_4^{3-} (mg/L)**
STP effluent discharging from ocean outfall	1,664 [a]	3,090 [a]	5 [b]	<1 [b]	8.5 [b]
Pambula catchment [c]	*34,532* [c]	*3,037* [c]	0.09 [d]	0.05 [d]	0.01 [d]
Merimbula catchment [c]	*6,128* [c]	*798* [c]	0.05 [d]	0.01 [d]	0.003 [d]
Upwellings of slope water	-	-	~0.25 [e] >0.07-0.14 [f]	-	22 [g]
Groundwater - influenced by dunal exfiltration ponds [h]	367	711	0.34 [h]	0.82 [h]	2.26 [h]
Groundwater - natural [i]	-	-	0.42[i]	0.03 [i]	0.06 [i]
Merimbula Bay sediments	-	-	-	-	-
Atmosphere	-	-	-	-	-

[a] Mean annual loads based on 2007-2011 Load Based Licensing data (POEO register - OEH 2012).

[b] Typical nutrient concentration values of STP effluent – information supplied by BVSC.

[c] Modeled catchment nutrient loads delivered to estuary (DECCW 2009). Note - nutrient load exported from the estuary to Merimbula Bay is considered to be a minor proportion of this total load.

[d] Surface water 90th percentile concentrations measured over the estuary basin during 2010-12 MER work (Elgin Assoc. *unpubl.)*

[e] From Suthers *et al.* (2011) – NO_3^- concentration of slope water reported as 4 µM (equivalent to 0.25 mg/L).

[f] From Tranter *et al.* 1986 and noted in Pritchard *et al.* (2003)

[G] From Cresswell 1994

[h] Groundwater influenced loads from an estimation of natural and effluent induced groundwater flow to ocean in the vicinity of the exfiltration ponds and water quality data obtained from the coastal “influenced” bores (Data from BVSC)

[i]. Groundwater quality representative of natural background conditions obtained from the coastal “natural” bores. Groundwater natural loads for TN and TP for entire dune system are unknown. (Data from BVSC).

- dash indicates no data available

3.7 Stable Isotope Analysis (SIA)

A total of 37 algal samples representing four different species and 15 effluent samples were submitted for nitrogen (N) and carbon (C) isotope analysis. Analytical data are presented in Tables 5 and 6 (attached) with charts and figures in Appendix I. Laboratory analytical reports are contained in Appendix D.

Data are presented for two time periods – for algal samples collected in 2008 during Phase 1 surveys, with more recent data from algal samples collected between November 2011 and February 2012. A summary of the main points that can be taken from the data collected from each time period is provided below.

3.7.1 2008 Data Summary

- δ^{15}N values of algae collected from Merimbula Bay in vicinity of the effluent outfall ranged between 5.9 - 8.4‰, represented by *Hincksia sordida* (δ^{15}N 5.9 - 8.4‰), *H. mitchelliae* (δ^{15}N 6.9‰) and *Colpomenia sinuosa* (δ^{15}N 7.9‰).
- Effluent had been discharged to Merimbula Bay on daily basis prior to algal samples being collected (Appendix I – Chart 3). Total volumes of effluent discharged to Merimbula Bay in the 7-day period prior to sampling algal tissue ranged from 1,100 kL to 11,049 kL (Table 5 attached).
- Background δ^{15}N values in algae ranged from 6.6 – 7.9, represented by samples of *H. mitchelliae* (δ^{15}N 6.8 - 7.9‰) and *Ectocarpus fasiculatus* (δ^{15}N 6.6 - 7.2‰) collected from reference locations 35 to 40 km north of the STP beach outfall.
- δ^{15}N value of the Merimbula STP effluent was characterised in late October (exact date is unknown) and was found to range from 13.2 – 16.8‰.
- Direct comparison of algal δ^{15}N signatures between Merimbula Bay and reference locations can only be based upon the available data for *H. mitchelliae* (a cogener of *H. sordida*), as δ^{15}N signatures of other algal taxa represents either Merimbula Bay or a reference location, but not both. *Hincksia sordida* was not encountered outside of Merimbula Bay in 2008.
- The δ^{15}N signature of *H. mitchelliae* from Haycock Point (Merimbula Bay) was 6.9‰ and similar to reference locations (Cuttagee and Pinic Point) where δ^{15}N was 6.8 – 7.9‰ (Table 7 below).
- The δ^{15}N signatures of other algal taxa including *H. sordida, E. fasiculatus and C. sinuosa* are similar to that of *H. mitchelliae*, and appear to be indicative of background δ^{15}N (Table 7 below).
- The algal δ^{15}N data suggest that effluent derived nitrogen was not the primary nutrient source being utilised by algae in Merimbula Bay as reflected by the low δ^{15}N values compared to the enriched δ^{15}N signal of the effluent (Table 6 below).
- δ^{15}N signatures of algae in 2008 are mapped on Figure I-1 (Appendix I).

3.7.2 2011-12 Data summary

- Mean δ^{15}N values of algae collected from Merimbula Bay in vicinity of the effluent outfall ranged from 8.7 – 13.8‰, as represented by *H. sordida* samples collected on 16 Nov 2011, 3 Jan 2012, 25 Jan 2012 and 22 Feb 2012.

- *Hincksia sordida* was not encountered outside of Merimbula Bay therefore a comparative background $\delta^{15}N$ signature of algae from reference locations is not available for this time period.
- The mean $\delta^{15}N$ signature of *H. sordida* on 16 Nov 2011 was 8.7‰ ± 0.1 where 11,884 kL of effluent had been discharged to Merimbula Bay in the 7-day period prior to sampling. The $\delta^{15}N$ signature of effluent for the time period 2-16 Nov 2011 ranged from 16.7 - 20.1‰ suggesting that effluent derived nitrogen was not the main nutrient source being utilised by algae in Merimbula Bay.
- Discharge of effluent to the beach outfall ceased on 22 December 2011 and no effluent was discharged directly to the ocean in the 7-day period prior to *H. sordida* being sampled on 3 Jan 2012, 25 Jan 2012 and 22 Feb 2012. However, for these sample dates the $\delta^{15}N$ signature of *H. sordida* was elevated with mean values of 9.9 - 13.8‰, suggesting effluent derived nutrients were likely assimilated by the algae.
- The $\delta^{15}N$ signature of effluent over the 2011-12 test period was highly variable ranging from 16.7 – 32‰, and consistently higher than the $\delta^{15}N$ signature of effluent characterised in 2008 (Table 6 attached).
- The elevated $\delta^{15}N$ signature of *H. sordida* from 3 Jan 2012, 25 Jan 2012 and 22 Feb 2012 coincided with effluent being discharged to the dunal ex-filtration ponds.
- $\delta^{15}N$ signatures of algae in 2011-12 are mapped on Figure I-2 (Appendix I).

Table 7. Summary of $\delta^{15}N$ signatures of algae sampled during the study with comparison to $\delta^{15}N$ signatures of sewage effluent.

Species	**$\delta^{15}N$ algae Reference location**	**$\delta^{15}N$ algae in vicinity of effluent outfall**	**$\delta^{15}N$ of sewage effluent**
Hincksia sordida – 2008	-	5.9 - 8.4	13.2 - 16.8
Hincksia mitchelliae - 2008	6.8 - 7.9	6.9	13.2 - 16.8
Ectocarpus fasiculatus - 2008	6.6 - 7.2	-	-
Colpomenia sinuosa- 2008	-	7.9	13.2 - 16.8
Hincksia sordida – 2011	-	8.7	16.7 - 20.1
Hincksia sordida – 2012	-	9.9 - 13.8	17.6 – 32*

Note: * effluent was not discharged to Merimbula Bay in early 2012

3.7.3 Rationale of the approach

The marine environment is generally considered to be oligotrophic (*i.e.* contain low available nutrients) and it is widely understood that among all the possible limiting elements, nitrogen most frequently limits the growth of macroalgae (Lobban and Harrison 1994). Consequently, macroalgae will assimilate any additional inputs of nitrogen from anthropogenic sources such as sewage effluent and agricultural fertilisers in stormwater runoff. In the last decade, a number of studies have used nitrogen stable isotopes in macroalgae to demonstrate the contribution of anthropogenic-derived nitrogen to the formation of macroalgal blooms (Lapointe *et al.* 2005;

Derse *et. al* 2007; Teichberg *et al.* 2010; Lapointe and Bedford 2011) as well as trace the dispersal and influence of sewage effluent (Costanzo *et al.* 2001, Gartner *et al.* 2002; Savage and Elmgren 2004). The stable isotope approach is based on the fact that natural and anthropogenic sources of nitrogen can be discriminated from one another by their distinctive nitrogen isotopic ratios (referred to as $\delta^{15}N$ ratio) and that primary producers such as macroalgae typically reflect the isotopic ratio of their nutrient source.

Nitrogen exists naturally as two stable isotopes: ^{14}N and ^{15}N. In the atmosphere, the vast majority of nitrogen exists as the lighter ^{14}N isotope (99.63%) with the heavier ^{15}N isotope being relatively rare (0.37%). However, biological processes can alter the relative abundance (ratio) of the stable isotopes by fractionation and it is this that underlies the ability to use stable isotopes as nutrient tracers in ecosystem studies. Nitrogen stable isotopes are conventionally reported in δ (‰) notation with respect to atmospheric nitrogen (which is used as a worldwide standard) and is described as:

$$\delta^{15}N\ (^{0}/_{00}) = (R_{\text{sample}}/R_{\text{atmosphere}} - 1) \times 10^{3}$$

Where R is defined as $^{14}N{:}^{15}N$ ratio (Peterson and Fry 1987).

Atmospheric nitrogen is used as a reference standard because the proportion of ^{14}N and ^{15}N in the atmosphere is essentially constant ($\delta^{15}N$ of 0‰). Various natural and anthropogenic sources of nitrogen will exhibit negative or positive $\delta^{15}N$ values depending on the degree of fractionation associated with the processes affecting the nitrogen. For instance, the natural microbial processes engaged during secondary and tertiary treatment of sewage selectively utilise ^{14}N over ^{15}N, resulting in an effluent where the remaining nitrogen is enriched with the ^{15}N isotope. Previous studies have shown treated sewage effluent to have elevated $\delta^{15}N$ values typically greater than 10‰ and may exceed 20‰. Effluent from the Merimbula STP showed considerable variation in $\delta^{15}N$ signatures with values ranging from 13.2 - 32‰. In contrast, industrial fertilisers that are manufactured from fixing atmospheric nitrogen typically show low $\delta^{15}N$ values ranging from -3 to +3‰. The range of indicative $\delta^{15}N$ values that have been documented for various sources of nitrogen are summarised in Table 8, below.

Table 8. Indicative $\delta^{15}N$ ratios of anthropogenic and natural nitrogen sources as reported in literature.

Source	**$\delta^{15}N$ ratio ($^{0}/_{00}$)**	**Reference**
Atmospheric nitrogen	0	Owens (1987)
Natural soils	2-5	Kendall (1998)
Inorganic fertiliser	-3 to +3	Heaton (1986)
Raw sewage effluent	6	Spies *et al.* (1989)
Treated sewerage effluent	13.5-25.3	Gartner *et al.* (2002)
Septic tank effluent	7-19	Lapointe *et al.* (2005)
Ambient oceanic Dissolved Inorganic N	5–7 6.8	Derse *et al.* (2007) Gartner *et al.* (2002)

Aquatic Sediments	5-13	Rush (2007)
Agricultural runoff (market gardens)	-3.5 to +8	Rush (2007)
Agricultural runoff (grazing animals)	8-22	Rush (2007)
Groundwater	-2 to +8	Macko and Ostrom (1994)

3.7.4 Use of macroalgae δ^{15}N signals to trace effluent in the environment

Isotope studies from Australia (Costanzo *et al.* 2001, 2005; Gartner *et al.* 2002; Rush 2007), Sweden (Savage and Elmgren 2004) and North America (Lapointe *et al.* 2011) have demonstrated the use of a variety of macroalgal taxa to trace sewage-derived nitrogen in the environment. These studies showed that the influence of effluent could be detected in algae more than 10 km from the point source with highest δ^{15}N values in algae adjacent to the source and the δ^{15}N signal of algae steadily declining moving further away from the effluent source. For these studies, the δ^{15}N signal of algae in the vicinity of effluent outfalls was approximately 40-300% greater than the background δ^{15}N signal as determined from reference locations. A summary of the macroalgae δ^{15}N signals relative to effluent from these studies is provided in Table 9, below.

Table 9. Macroalage used as isotopic tracers of sewage effluent in other studies

Species	δ^{15}N algae Reference location	δ^{15}N algae in vicinity of effluent outfall	δ^{15}N of sewage effluent	Reference
Ulva australis	6.1	8.8-12.8	13.47 – 25.33	Gartner *et al.* (2002)
Vidalia sp.	6.5	6.3-10.2		
Catenella nipae	~2	>9	-	Costanzo *et al.* (2001)
Fucus vesiculosus	4	8-9	24-38	Savage and Elmgren (2004)

3.7.5 Is *Hincksia sordida* isotopically enriched with nitrogen derived from sewage effluent?

The data from 2008 suggests effluent had a negligible influence on the algae while data from 2011-12 suggest effluent derived nitrogen was assimilated by the algae as evidenced by elevated δ^{15}N signatures during that period compared to 2008.

The δ^{15}N signatures of *H. sordida* collected from Merimbula Bay during 2008 were more similar to the background δ^{15}N signal (as represented by *H. mitchelliae* and *E. fasiculatus*) than they were to effluent suggesting effluent derived nutrients in Merimbula Bay had little influence on the total nitrogen uptake by the algae. The background signal represents the combined nutrient inputs from a variety of diffuse sources as discussed in Section 3.6 including catchment inputs and periodic upwellings. According to previous studies the δ^{15}N of ambient oceanic dissolved inorganic nitrogen (DIN) typically ranges from 5 – 7 (Derse *et al.* 2007, Gartner *et al* 2002). Majority of the algal δ^{15}N values from 2008 were within or slightly above the typical range of δ^{15}N values of ambient oceanic DIN. Similarly, there is a variety of other nutrient sources whose δ^{15}N signals (Table 8) may also be reflected in the δ^{15}N signal of the algae. The algae in Merimbula Bay would have assimilated effluent derived nutrients where available, but it represents just one source of available nutrients and evidently was not a major contributor to the nitrogen uptake of the algae through 2008.

In contrast, δ^{15}N signatures of *H. sordida* collected over the 2011-12 summer were elevated above the 2008 signal suggesting effluent derived nitrogen was assimilated by the algae and contributed more to the total tissue nitrogen compared to 2008. However, effluent was not being discharged directly to the ocean during the 2011-12 summer when the highest δ^{15}N signals were measured in the algae (11.6 - 15.8‰) but instead effluent was being discharged to the dunal ex-filtration ponds. It is known that fractionation of nitrogen may naturally occur within algal tissues, particularly when the alga is in late stages of senescence or decomposing. Decomposition results in a naturally elevated δ^{15}N signature that could be misconstrued as reflecting the ambient δ^{15}N of the surrounding environment. This was considered here as a possible explanation for the elevated δ^{15}N signals in *H. sordida* when effluent was not being discharged to the ocean. However, the samples of algae were examined under microscope prior to being processed for SIA with thalli showing new branches developing, active cell division noted at the meristems and thalli showing no signs of decomposition. It is also possible that errors in analytical procedures and or instrumentation resulted in the elevated δ^{15}N signals. However, correspondence with the laboratory manager (*pers. comm.* R. Diocares, June 2012) revealed the samples were re-analysed as part of standard QA/QC procedures with similarly high δ^{15}N values generated in the re-runs.

In the absence of direct discharge of effluent to Merimbula Bay via the beach outfall, the elevated δ^{15}N signal of the algae may be partly due to discharge of effluent impacted groundwater to Merimbula Bay via the dunal ex-filtration ponds.

3.7.6 Underlying Assumptions

It was assumed that *Hincksia sordida* is a reliable indicator of the ambient δ^{15}N signal of the environment. According to literature foliose or filamentous taxa are considered best to use as isotopic tracers compared to large leathery taxa as they are characterised by a high surface area to volume ratio and typically have high nutrient uptake and turnover rates. Gartner *et al.* (2002) showed that some foliose algae assimilated sewage derived nitrogen and displayed a measurably altered δ^{15}N signature within 7 days following exposure to sewage effluent (Gartner *et al.* 2002). Rush (2007) found the green alga *Microdictyon* had a fast nitrogen turnover rate and was able to reflect the δ^{15}N signature of its nutrient source after 5 days exposure. Campbell (1999) noted that *H. sordida* had high turnover of tissue nitrogen and relatively low propensity for nitrogen storage. It was therefore assumed that the δ^{15}N value of *H. sordida* would be indicative of the ambient δ^{15}N of the environment within the 7 days prior to sampling.

3.7.7 Interpretive Limitations of this dataset

The δ^{15}N signatures of algae are based on a number of discrete sampling events conducted over an extended period of time spanning different seasons and periods when effluent was and was not being discharged to Merimbula Bay. Ideally, all the algal samples from Merimbula Bay and reference locations would be collected within a short period of time, days apart, such that an assessment of ambient nutrient conditions across the whole study area could be made and the influence of effluent on the algae to be determined. This was the intention of the proposed Phase 2 of study design that focused on sampling the target bloom-forming alga, *H. sordida*. The fact that *H. sordida* was not encountered outside of Merimbula Bay was the principal limitation to the study design and the reason why Phase 2 of the study could not be executed.

A high rate of nitrogen turnover and the ability to freely drift around in the environment does not make *H. sordida* an ideal bio-indicator to assess the influence of effluent. The drifting blooms of *H. sordida* may reflect the δ^{15}N signal of the environment in which it is drifting on time scales shorter than 7 days. Therefore it is possible that *H. sordida* may utilise effluent derived nutrients in the vicinity of the outfall or where available and then drift away. After a few weeks have elapsed, the enriched δ^{15}N signal of *H. sordida* may be replaced with a depleted δ^{15}N signal indicative of background nutrient sources reflecting its current drift location. Consequently, attached algal species or anchoring algal thalli to a fixed location are best suited as bio-indicators or tracers of effluent using of stable isotopes.

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- The dominant bloom-forming alga in Merimbula Bay during the 2008-12 study period was the filamentous brown alga *Hincksia sordida*. Large masses of drift algae in Merimbula Bay have at times included a range of other algal taxa that have either been exported from the Merimbula and Pambula estuaries or have been inadvertently detached from nearby rocky reefs. While these once-attached algal taxa may survive for a short period in a drifting raft, they generally would not be increasing biomass that is typical of an 'algal bloom'. According to anecdotal and archived local media reports, blooms prior to 2008 were also likely to have been *H. sordida.*

- *Hincksia sordida* is an Australian seaweed common to the southern and eastern seaboards from Tasmania to Queensland where it may form large blooms in protected marine embayments and estuaries. In recent times massive drift blooms of *H. sordida* have also been regular occurrences in Port Phillip Bay, Victoria and Noosa, Queensland. The alga has fast growth rates and demonstrated rapid assimilation of nutrients typical of an alga with high surface area to volume ratio. Studies have shown the species is able to efficiently scavenge nitrogen at low concentrations and assimilate excess nitrogen than is required for immediate growth at high concentrations. It has been noted that *H. sordida* generally has a low propensity for nitrogen storage and is inclined to be nitrogen limited. However, in an environment where nitrogen inputs are continuous or regularly pulsed, *H. sordida* has a clear competitive advantage over other algae that have low nutrient uptake rates but the capacity for large intracellular stores of nitrogen.

- The origin of the *Hincksia* blooms in Merimbula Bay is not clear. Surveys of the coastline and of estuaries (open to the ocean) north and south of Merimbula Bay did not locate a potential source for the drifting blooms. The origin of the *Hincksia* blooms in Merimbula Bay is not clear. Surveys of the coastline and of estuaries (open to the ocean) north and south of Merimbula Bay did not locate a potential source for the drifting blooms. The preferred environment of *Hincksia sordida* is calm, protected embayments and estuaries where it may form long filaments and cover large areas of the benthos. *Hincksia* blooms have been recorded from a number of estuaries in the BVSC region including Wallagoot Lake (2008, 2009, 2011, 2012), Bega River (2012) and Cuttagee Lake (2012). Though blooms of *Hincksia* were not observed in either of Pambula or Merimbula lakes during the study period (2008-2012), these lakes represent a potential supply source of *Hincksia* to the Merimbula Bay environment.

- Surveys also confirmed the alga's absence from sub-tidal reef habitats within Merimbula Bay. Due to the moderate to highly exposed nature of these habitats, it is considered unlikely that *H. sordida* would be a natural component of the local macroalgal assemblages. The species is also present in Twofold Bay (Eden) where it similarly forms drifting blooms that periodically appear on the beach. Unlike most other macroalgal taxa that require a substrate for attachment, *H. sordida* is able to grow and persist free-floating over the benthos. Evidence suggests *H. sordida* may be resident within the confines of Merimbula Bay throughout the year, free-floating over the benthos and at times in high biomass, able to be transported around the bay according to local hydrodynamic conditions. The frequency with which *H.*

sordida washes up and persists on local beaches is then, simply a function of the required wind and swell conditions.

- Blooms appeared in the near-shore wave zone with greater frequency during spring and summer when easterly winds were most prevalent supporting previous observations recorded by local residents. Sustained north to northeasterly winds invoke Ekman transport where the sea surface currents move away from the coast with this net movement of surface water acting to draw up bottom waters towards the near-shore zone. It is these bottom currents that resuspend *Hincksia* thalli in the water column and play a large role in shifting the biomass of *Hincksia* towards the nearshore zone in the first instance. Persistence of blooms in the near-shore zone is then influenced by wave action and prevailing wind direction.
- An assessment of whether *H. sordida* was isotopically enriched with nitrogen derived from sewage effluent was made based upon a dataset limited by inadequate spatial and temporal sampling. The δ^{15}N signature of effluent was highly variable with values ranging from 13.2 – 32‰ while the background δ^{15}N signature of algae from locations not directly influenced by sewage effluent was 6.6 – 7.9‰ determined for the closely related species, *H. mitchelliae*. Data collected in 2008 suggests effluent had a negligible influence on the algae while data from 2011-12 suggest effluent derived nitrogen was assimilated by the algae as evidenced by elevated δ^{15}N signatures during that period compared to 2008.
- A number of studies have successfully used algae and nitrogen stable isotopes to trace the spatial effects of sewage effluent. However these studies employed attached algal species to provide a reliable indicator of their source nitrogen with sampling conducted over small and large spatial scales. In contrast, the sampling regime of this study relied upon the opportunistic sampling of *H. sordida* when present at the near-shore zone. Consequently, variation in the δ^{15}N signal of algae due to spatial and temporal factors could not be controlled or accounted for and limits interpretation of the available data. Being a drift algae with high turnover of tissue nitrogen presents a potential case in which *H. sordida* may utilise effluent derived nutrients where available and then drift away to areas of the bay where the influence of effluent derived nutrients is diminished. After a few weeks have elapsed, the isotopically enriched δ^{15}N signal of effluent in the algae may be replaced with a depleted δ^{15}N signal thereby confounding any assessment regarding the influence of effluent on the algae.
- Algae in Merimbula Bay, including *H. sordida,* would utilise effluent derived nutrients where available. However, effluent represents just one source of available nutrients with diffuse source inputs from the catchments, periodic upwelling of slope water, groundwater discharge and the release of nutrients from the bay sediments all-contributing to the pool of bioavailable nitrogen in Merimbula Bay. However, assessing the relative contribution of nutrients from these diffuse sources is difficult due to the episodic nature of those sources and the lack of available data. What we do know is that discharge of effluent to Merimbula Bay provides a relatively continuous supply of inorganic nutrients at high concentrations compared to diffuse sources. Dilution effects would effectively attenuate effluent nutrient concentrations over relatively small spatial scales when consideration is given to hydrodynamic processes. Nevertheless, *H. sordida* and other algae in Merimbula Bay would be using nitrogen derived from effluent when available.

CONCLUSIONS AND RECOMMENDATIONS

- Anecdotal accounts from several long-term Merimbula residents indicate macroalgal blooms have been a regular occurrence in the bay environment as early as the 1950’s. This is prior to the commissioning of the Merimbula STP in 1971 and before the discharge of large volumes of effluent to the bay commenced. These historical accounts demonstrate that macroalgal blooms have been a regular natural occurrence in Merimbula Bay and it is likely that blooms may continue to occur even when strategies to reduce nutrient concentrations in effluent and advances in STP management are implemented.

4.2 Recommendations

Recommendations made in light of the study’s findings include:

- Consider addressing the limitations of the current dataset that relied on opportunistic sampling of the bloom algae. The spatial and temporal limitations encountered during this study may be controlled by implementing a series of replicated cages containing algal tissue that are fixed in location along the coastline and within Merimbula Bay for a standardised period of time.
- Continue to investigate options for further reducing the loads of inorganic nutrients in the effluent wastewater stream. Reducing the discharge of nutrients to the environment will minimise the likelihood that macro- and microalgal blooms will occur and at least not be exacerbated by effluent inputs.
- Raise community awareness of the natural phenomena of algal blooms via existing modes of communication (*i.e.* council website) and consider distributing information in the form of printed leaflets.
- Continue to monitor and record the occurrence of algal blooms in Merimbula Bay and other coastal locations as required. This information will be useful to assess whether blooms are increasing in frequency and severity and whether management strategies are being effective.

REFERENCES

AECOM (2010). Pilot Water Quality Model – Merimbula Effluent Outfall. Report prepared for Bega Valley Shire Council, 30 September 2010.

Algaebase (2012). AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched on 16 February 2012.

Olive, P.J.W. and Cadnam, P.S. (1990). Mass mortalities of the lugworm on the South Wales Coast: A consequence of algal bloom? *Marine Pollution Bulletin*, 21 (11): 542-545.

Campbell, S. (1999). Uptake of ammonium by four species of macroalgae in Port Phillip Bay, Victoria, Australia. *Marine Freshwater Research*, 50: 515-522.

Campbell, S. (2001). Ammonium requirements of fast-growing ephemeral macroalgae in a nutrient-enriched marine embayment (Port Phillip Bay, Australia). *Marine Ecology Progress Series*, 209: 99-107.

Cresswell, G. (1994). Nutrient enrichment of the Sydney continental shelf. *Aust. J. Mar. Freshwater Res.* 45: 677-691.

Cresswell, G., John, H. S., Karl, K. T. and Steve, A. T. (2001). East Australian Current. *Encyclopedia of Ocean Sciences.* Academic Press, Oxford, pp. 187-96.

Church, J. A., Freeland, H. J. and Smith, R. L. (1986). Coastal-Trapped Waves on the East Australian Continental Shelf Part I: Propagation of Modes. *Journal of Physical Oceanography* **16**: 1929-43.

Clayton, M.N. (1974). Studies on the development, life history and taxonomy of Ectocarpales (Phaeophyta) in southern Australia. *Australian Journal of Botany* 22: 743-813.

Costanzo, S.D., O'Donohue, M.J., Dennison, W.C., Loneragan, N.R. and Thomas, M. (2001). A new approach for detecting and mapping sewage impacts. *Marine Pollution bulletin*, 42 (2): 149-156.

CSIRO Australia (2001). The East Australian Current: Information Sheet No. 37.

DECCW (2009) CERAT – Coastal Eutrophication Risk Assessment Tool, CD-Rom. Department of Environment Climate Change and Water 2009.

Derse, E., Knee, K.L, Wankel, S.D., Kendall, C., Berg Jr., C.J. and Paytan, A. (2007). Identifying sources of nitrogen to Hanalei By, Kauai, utilizing the nitrogen isotope signature of macroalgae. *Environmental Science and Technology*, 41 (15): 5217-523.

Elgin Associates (2009). Merimbula Bay Deep Water Survey - 2008. Final Report prepared for Bega Valley Shire Council, 7 September 2009, pp. 47.

Elgin Associates (2010-2012). *Environmental monitoring of coastal lakes and lagoons in the BVSC region* – MER digital data (unpubl.), data collection ongoing in 2013.

EPA (2012). Protection of the Environment Operations (POEO) Public Register. URL: http://www.environment.nsw.gov.au/prpoeo/index.htm, accessed June 2012.

Eyre, B. D. and Pepperell, P. (1999). *Budgets for Australian Estuarine Systems: Subtropical Systems.* In: Smith, S. V. and Crossland, C. J. (eds), Australasian Estuarine Systems: Carbon, Nitrogen and Phosphorus Fluxes. pp. 12-18. LOICZ Reports and Studies No. 12. Loicz, Texel, The Netherlands. ISBN: 1383-4304

Gartner, A. Lavery, P. and Smit, A.J. (2002). Use of δ15N signatures of different functional forms of macroalgae and filter-feeders to reveal temporal and spatial patterns in sewage dispersal. *Marine Ecology Progress Series*, 235: 63-73.

Griffen, D. A. and Middleton, J. H. (1991). Local and Remote Wind Forcing of New South Wales Inner Shelf Currents and Sea Level. *Journal of Physical Oceanography* **21**: 304-22.

Harris, G.P. (1999). Biogeochemistry of nitrogen and phosphorus in Australian catchments, rivers and estuaries: effects of land use and flow regulation and comparisons with global patterns. *Mar. Freshwater Res.*, 52: 139–49

Harvey, W.H. (1859). Algae. Part III. Flora Tasmaniae. *In:* The botany of the Antarctic voyage of H.M. discovery ships Erebus and Terror…, Part III. Flora Tasmaniae. Monocotyledones and Acotyledones. (Hooker, J.D. Eds) Vol. II, pp. 282-343. London: Lovell Reeve.

Heaton, T.H.E. (1986). Isotopic studies of nitrogen pollution in the hydrosphere and the atmosphere: a review. *Chem. Geol.* 59: 87-102.

IGGC (2012). Disposal of Effluent from Merimbula Sewage Treatment Plant by Dunal Exfiltration – Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay. Draft Report prepared for BVSC, June 2012.

Kraft, G.T.K. (2009). Algae of Australia: Marine Benthic Alkgae of Lord Howe Island and the Southern Great Barrier Reef, 2: Brown Algae. ABRS, Canberra; CSIRO Publishing, Melbourne (2009).

Kendall, C. (1998). Chapter 16. Tracing nitrogen sources and cycles in catchments *In* Isotope Tracers in Catchment Hydrology, Eds. C. Kendall and J.J. McDonnell. Elsevier Press.

Lapointe, B.E., Bedford, B.J. (2011). Stormwater nutrient inputs favour growth of non-native macroalgae (Rhodophyta) on O'ahu, Hawaiian Islands. *Harmful Algae,* 10: 310-318.

Lapointe, B.E., Barile, P.J., Littler, M.M. and Littler, D.S. (2005). Macroalgal blooms on southeast Florida coral reefs II. Cross-shelf discrimination of nitrogen sources indicates widespread assimilation of sewage nitrogen. *Harmful Algae,* 4: 1106-1122.

Lovelock, C.E., Clegg, E., Hurrey, L., Udy, J. and Moore, K. (2008). Growth and physiology of nuisance alga *Hincksia sordida* during a bloom in south east Queensland, Australia. *J. Exp. Mar. Biol. Ecol.*, 363: 84-88

Lobban, C.S. and Harrison, P.J. (1994). *Seaweed ecology and physiology.* Cambridge University Press, New York, 1994.

Macko, S.A. and Ostrom, N.E. (1994). *Pollution studies using stable isotopes. In:* Stable Isotopes in Ecology, Lajtha, K. and R. Michener, eds. Blackwell Scientific Pub., Oxford, UK, pp 45-62.

Owens, N.P.J. (1987). Natural variations in ^{15}N in the marine environment. *Adv. Mar. Biol.* 24, 389-451.

Phillips, J. (2006). Drifting blooms of the endemic filamentous brown alga *Hincksia sordida* at Noosa on the subtropical east Australian coast. *Marine Pollution Bulletin*, 52: 962-968.

REFERENCES

Pritchard, T.R., Lee, R.S., Ajani, P.A., Rendell, P.S., Black, K. and Koop, K. (2003). Phytoplankton responses to nutrient sources in coastal waters off southeastern Australia. *Aquatic Ecosystem Health and Management*, 6 (2): 105-117.

Savage, C. and Elmgren, R. (2004). Macroalgal (*Fucus vesiculosus*) δ15N values trace decrease in sewage influence. *Ecological Applications*, 14(2): 517-526.

Seitzinger, S.P. (1988). Denitrification in freshwater and coastal marine ecosystems: Ecological and geochemical significance. *Limnol. Oceanogr*. 33: 702-724.

Short, A. D. and Woodroffe, C. D. (2009). *The coasts of Australia.* Cambridge University Press, Melbourne 288 pp.

Silva, P.C., Meñez, E.G. & Moe, R.L. (1987). Catalog of the benthic marine algae of the Philippines. *Smithsonian Contributions to Marine Sciences* 27: [i-ii] iii-iv, 1-179.

Sinclair Knight Merz (1997). Nutrient Discharges from Estuaries. Report to NSW EPA (New South Wales Environment Protection Authority).

Suthers, I.M. *et al.* (2011). The strengthening East Australian Current, its eddies and biological effects: an introduction and overview. *Deep Sea Research Part II: Topical Studies in Oceanography*, 58 (2011): 538-546.

Spies, R.B., Kruger, H., Ireland, R. and Rice, D.W. Jr. (1989). Stable isotope ratios and contaminant concentrations in a sewage-distorted food web. *Mar. Ecol. Prog. Ser.* 54: 157-170.

Teichberg, M. *et al.* (2010). Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with *Ulva* spp. *Global Change Biology*, 16, 2624-2637.

Tranter, D.J., Carpenter, D.J. and Leech, G.S. (1986). The coastal enrichment effect of the East Australian Current eddy field. *Deep-sea Res.* 33: 1705-1728.

Womersley, H.B.S. (1987). The Marine Benthic Flora of Southern Australia, Part II. South Australian Government Printing Division, Adelaide 1987.

Zann, L.P. (2000). The Eastern Australian Region: a Dynamic Tropical/Temperate Biotone. *Marine Pollution Bulletin* **41**: 188-203.

LIMITATIONS

Elgin Associates Pty Ltd has prepared this report for the sole use of Bega Valley Shire Council in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 13 January 2012.

The methodology adopted and sources of information used by Elgin Associates are outlined in this report. Elgin Associates has made no independent verification of this information beyond the agreed scope of works and Elgin Associates assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to Elgin Associates was false.

This report was prepared between March and September 2012 (Final Review January 2013) and is based on the conditions encountered and information reviewed during that period up to the time of preparation. Elgin Associates disclaims responsibility for any changes that may have occurred after this time. Opinions and recommendations contained in this report are based upon information gained during desktop study and fieldwork and information provided from government authorities' records and other third parties. The information in this report is considered to be accurate at the date of issue and reflects at the site at the dates sampled. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the fieldwork unless otherwise explicitly stated in a preceding section of this report.

This report should be read in full together with all other reports referenced by this report. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties.

Table 1. Summary of environmental conditions prior to bloom events

Sample						Environmental Conditions					
Sample ID	*Taxon*	Site	State	Collection Date	Collected by	STP Effluent discharge (kL)[1]	Season	Prevailing wind conditions[2]	Regional Offshore Currents[3]	Anticipated Inshore Currents[4]	Approx. SST off Merimbula Bay (°C)[5]
BVSC001	*Hincksia mitchelliae*	Pinic Point	natural	06/04/2008	N. Yee	n/a	Autumn	On day of sampling 6/4/08, calm conditons in morning were followed by light afternoon easterly winds, similar to the preceding 2 days. Earlier in week light morning winds from north-west or south-west shifted to moderate east quadrant (NE to SE) winds in afternoon. An exception was 3/4/08 with moderate winds from the west during the morning and afternoon.	Variable or southerly flowing currents off shelf, with inshore currents flowing north off Sapphire Coast	SE flowing	20-21
BVSC002	*Hincksia mitchelliae*	Cuttagee North	natural	06/04/2008	N. Yee	n/a					
BVSC003	*Hincksia mitchelliae*	Cuttagee South	natural	06/04/2008	N. Yee	n/a					
BVSC004	*Hincksia sordida*	Asling Beach	bloom	02/05/2008	N. Yee	n/a - Twofold Bay	Autumn	On day of sampling, calm conditons in morning were followed by light afternoon easterly winds, similar to the preceding 2 days. Middle of week experienced moderate westerly winds in morning that shifted southwest in the afternoon at similar strength. At the start of the preceding week, calm conditions in morning were followed by moderate afternoon northeasterly winds.	South flowing currents off shelf, with inshore current to the SSE apparent off Sapphire Coast	S-SE flowing	18-20
BVSC006	*Hincksia mitchelliae*	Haycock Point	natural	03/07/2008	N. Yee	n/a	Winter	On day of sampling (3/7/2008), light winds from northwest in morning shifted to the east in the afternoon. In contrast, the preceding three days (from 30/6-2/7/08) experienced mostly moderate-strong W quadrant winds (NW to SW) in the morning and afternoon. Lighter conditions were again experienced at the start of the week, with mostly calm conditions in the morning followed by either light-moderate west or east winds.	North flowing current apparent inshore and off shelf	N flowing	14-16
BVSC007 BVSC008 BVSC009 BVSC010	*Hincksia sordida*	Merimbula main beach	bloom	26/08/2008	N. Yee	10,020 kL	Winter	On day of sampling (26/8/08) and day before (25/8/08), calm or light northwest winds in morning shifted to light-moderate northeast in the afternoon. The middle of the week (22/8-24/8/08) was dominated by moderate to strong south to southwesterly winds which were preceded by three days of mostly north quadrant winds (NW to NE).	South flowing current off southern NSW coast, with inshore components to SSE apparent off Sapphire Coast.	S flowing	13-15
BVSC011 BVSC012 BVSC013	*Hincksia sordida*	Merimbula beach outfall	bloom	29/08/2008	N. Yee	8,584 kL	Winter	On sampling day of 31/8/08 and day before (30/8/08), calm or light west winds in morning shifted to moderate northeast or northwest winds in the afternoon. This was preceded by three days (27-29/8/08) of south quadrant winds, with mostly light SW winds in the morning shifting to stronger southwest or southeast winds in the afternoon, which included winds during the sampling on 29/8/08. Start of the week (25-26/8/08) saw calm or light northwest winds in the morning shifting to light to moderate northeast in the afternoon.			
BVSC014	*Hincksia sordida*	Wallagoot Lake	bloom	31/08/2008	N. Yee	n/a	Winter				
BVSC015 BVSC016 BVSC017	*Hincksia sordida*	Merimbula beach outfall	bloom	05/09/2008	N. Yee	11,049 kL	Spring	On day of sampling (5/9/08) and for most of the preceding week, winds in the morning were either calm or from the west quadrant (NW-SW), shifting to light to moderate E quadrant (NE-SE) winds in the afternoon.	South flowing current off southern NSW coast	S flowing	12-14
BVSC018 BVSC019 BVSC020	*Hincksia sordida*	Pambula rivermouth at Jiguma	bloom	05/09/2008	N. Yee						
BVSC021	*Ectocarpus fasiculatus*	Cuttagee south	natural	15/10/2008	N. Yee	n/a	Spring	Winds on day of sampling (15/10/08) were moderate west shifting southwest in the afternoon. In the preceding two days winds were either from the south and southwest (14/10) or northwest (13/10). Earlier in the week (8/10-12/10/08) experienced light west winds or calm conditions in the morning followed by moderate east quadrant (NE-SE) winds in the afternoon.	South flowing current off southern NSW coast	S flowing	14-16
BVSC022	*Ectocarpus fasiculatus*	Aragunnu	natural	15/10/2008	N. Yee						
BVSC024 BVSC025 BVSC026	*Hincksia sordida*	off STP outfall (surface)	bloom	26/10/2008	N. Yee	1,100 kL	Spring	On day of sampling (26/10/08) and preceding two days (24-25/10/08), winds were calm or light easterly in the morning followed by stronger east quadrant winds (NE-SE) in the afternoon. Earlier in the week (19-23/10/08) was dominated by light to moderate south quadrant winds, mostly from the southwest in the morning shifting southeast in the afternoon.	South flowing current off southern NSW coast	S flowing	15-17
BVSC027 BVSC028 BVSC029	*Hincksia sordida*	off STP outfall (benthic)	bloom	26/10/2008	N. Yee						
BVSC030	*Colpomenia sinuosa*	off STP outfall (surface)	bloom	26/10/2008	N. Yee						

Note:

[1] STP effluent discharge based on ocean outfall in 7 day period prior to sample collection date (BVSC effluent flow data)

[2] Prevailing wind conditions based on 7 day period prior to samples collection date with weather data from Merimbula Airport AWS (BOM station 069147)

[3] Regional offshore currents inferred from CSIRO and IMOS data (URL: http://imos.org.au/)

[4] Anticipated local inshore currents inferred from BOM wind data and influence of regional offshore currents

[5] SST - sea surface temperature inferred from CSIRO and IMOS data (URL: http://imos.org.au/)

Table 1. Summary of environmental conditions prior to bloom events

Sample						Environmental Conditions					
Sample ID	***Taxon***	**Site**	**State**	**Collection Date**	**Collected by**	**STP Effluent discharge (kL)[1]**	**Season**	**Prevailing wind conditions[2]**	**Regional Offshore Currents[3]**	**Anticipated Inshore Currents[4]**	**Approx. SST off Merimbula Bay (°C)[5]**
BVSC032 BVSC033 BVSC034	*Hincksia sordida*	Pambula rivermouth at Jiguma	bloom	05/12/2008	N. Yee	7,370 kL	Summer	On day of sampling (5/12/08) and preceding day (4/12/08), calm conditions in the morning were followed by moderate northeast winds in the afternoon. Earlier in the week (1-3/12/08) saw east quadrant winds (NE-SE) in the morning shifting to the S or SE in the afternoon. Start of the week (28/11-30/11) saw calm or light west quadrant winds in the morning, shifting to moderate to	South flowing current off southern NSW coast. Inshore N flowing current on far south coast.	N flowing	17-19
BVSC035 BVSC036 BVSC037	*Hincksia sordida*	Pambula main beach	bloom	12/01/2010	N. Yee & D.Madigan	no pumping to ocean outfall in previous 7 days	Summer	Day of sampling (12/1/10) and day prior (11/1/10) experienced northeast winds in the morning and afternoon, strengthening during the day. Earlier in the week was also dominated by east quadrant winds, with calm to light northeast or southeast winds in the morning strengthening in the afternoon from a similar direction.	South flowing current off southern NSW coast	S flowing	19-21
BVSC038 BVSC039	*Hincksia sordida*	Pambula rivermouth at Jiguma	bloom	16/11/2011	N. Yee	11,884 kL	Spring	On day of sampling (16/11/11), northeast winds in the morning shifted to southeast in the afternoon. In the preceding seven days, generally variable morning winds (ranging from calm to NW to SE) were followed by moderate northeast or southeast winds in the afternoon.	South flowing currents off shelf, with northerly inshore currents apparent off Sapphire Coast	N flowing	18-20
BVSC041 BVSC042	*Hincksia sordida*	Pambula rivermouth at Jiguma	bloom	03/01/2012	N. Yee	no pumping to ocean outfall in previous 7 days	Summer	On day of sampling (3/1/12) and preceding three days (31/12-2/1/12), northeast or southeast winds in the morning strengthened from the northeast in the afternoon. Earlier in the week (27/12-30/12) morning winds were more variable, however afternoon winds on these days were	South flowing current extending down NSW coast before eddying east of Gabo Island	S flowing	17-19
BVSC045 BVSC046	*Hincksia sordida*	Pambula rivermouth at Jiguma	bloom	25/01/2012	N. Yee	no pumping to ocean outfall in previous 7 days	Summer	On day of sampling (25/1/12) and preceding seven days (18-24/1/12), morning winds were light and either from the north or east quadrant, and were followed by moderate northeast or southeast winds in the afternoon.	Southeast flowing current off shelf is apparent, with inshore flow to the north off Sapphire Coast.	N flowing	18-20
BVSC047	*Hincksia sordida*	Merimbula main beach	bloom	22/02/2012	D. Van Bracht	n/a	Summer	Calm conditions in mornings and then NE,E or SE in afternoons.	South flowing current off southern NSW coast.	weak N flowing	21-23

Note:

[1] STP effluent discharge based on ocean outfall in 7 day period prior to sample collection date (BVSC effluent flow data)

[2] Prevailing wind conditions based on 7 day period prior to samples collection date with weather data from Merimbula Airport AWS (BOM station 069147)

[3] Regional offshore currents inferred from CSIRO and IMOS data (URL: http://imos.org.au/)

[4] Anticipated local inshore currents inferred from BOM wind data and influence of regional offshore currents

[5] SST - sea surface temperature inferred from CSIRO and IMOS data (URL: http://imos.org.au/)

Table 5. Summary of algal isotope data

Sample Details						Elemental				Isotopic			Effluent discharged to beach outfall[2] (kL)
Code	Type	Site	State	Date collected	Date processed	% Comp (C)	% Comp (N)	C:N ratio	C:N ratio Mean	$\delta^{13}C$	$\delta^{15}N$	Mean[1] $\delta^{15}N$	
BVSC001	*Hincksia mitchelliae*	Pinic Point	Natural	6/04/2008	7/04/2008	32.7	3.7	10.3		-15.0	7.9		-
BVSC002	*Hincksia mitchelliae*	Cuttagee North	Natural	6/04/2008	7/04/2008	35.0	4.6	8.9		-17.2	7.1		-
BVSC003	*Hincksia mitchelliae*	Cuttagee South	Natural	6/04/2008	7/04/2008	24.0	2.6	10.8		-17.2	6.8		-
BVSC004	*Hincksia sordida*	Aslings Beach	Bloom	2/05/2008	2/05/2008	20.8	1.7	14.3		-16.0	7.5		-
BVSC0006	*Hincksia mitchelliae*	Haycock Point	Natural	3/07/2008	4/07/2008	32.9	3.5	10.9		-15.8	6.9		-
BVSC0007	*Hincksia sordida*	Merimbula Bar	Bloom	26/08/2008	27/08/2008	32.2	3.8	9.9	9.9 ± 0	-16.8	6.0	5.9 ± 0	10,020
BVSC0008	*Hincksia sordida*	Merimbula Bar	Bloom	26/08/2008	27/08/2008	31.1	3.7	9.9		-17.1	5.9		
BVSC0009	*Hincksia sordida*	Merimbula Bar	Bloom	26/08/2008	27/08/2008	32.3	3.8	9.8		-17.1	5.8		
BVSC0010	*Hincksia sordida*	Merimbula Bar	Bloom	26/08/2008	27/08/2008	32.9	3.9	9.8		-17.1	5.8		
BVSC0011	*Hincksia sordida*	Merimbula outfall	Bloom	29/8/2008	31/8/2008	22.7	2.1	12.6	12.4 ± 0.1	-14.5	7.7	8.0 ± 0.1	8,584
BVSC0012	*Hincksia sordida*	Merimbula outfall	Bloom	29/8/2008	31/8/2008	22.4	2.1	12.3		-14.6	8.2		
BVSC0013	*Hincksia sordida*	Merimbula outfall	Bloom	29/8/2008	31/8/2008	23.5	2.2	12.4		-14.8	8.0		
BVSC0014	*Hincksia sordida*	Lake Wallagoot	Bloom	31/8/2008	31/8/2008	32.1	2.3	16.4		-21.0	7.9		-
BVSC0015	*Hincksia sordida*	Merimbula outfall	Bloom	5/9/2008	5/9/2008	21.4	1.8	13.8	14.6 ± 0.5	-14.6	7.5	7.4 ± 0.1	11,049
BVSC0016	*Hincksia sordida*	Merimbula outfall	Bloom	5/9/2008	5/9/2008	19.5	1.6	14.6		-13.8	7.5		
BVSC0017	*Hincksia sordida*	Merimbula outfall	Bloom	5/9/2008	5/9/2008	18.6	1.4	15.4		-13.1	7.2		
BVSC0018	*Hincksia sordida*	Pambula rivermouth	Bloom	5/9/2008	5/9/2008	25.1	1.7	17.6	17.6 ± 0.1	-16.8	8.4	8.4 ± 0	
BVSC0019	*Hincksia sordida*	Pambula rivermouth	Bloom	5/9/2008	5/9/2008	26.8	1.8	17.5		-16.7	8.4		
BVSC0020	*Hincksia sordida*	Pambula rivermouth	Bloom	5/9/2008	5/9/2008	25.5	1.7	17.6		-16.9	8.5		
BVSC0021	*Ectocarpus fasiculatus*	Cuttagee S	Natural	15/10/2008	16/10/2008	27.4	2.7	11.8		-16.8	6.6		-
BVSC0022	*Ectocarpus fasiculatus*	Aragunnu	Natural	15/10/2008	16/10/2008	37.3	3.3	13.0		-17.5	7.2		-
BVSC0024	*Hincksia sordida*	off STP outfall (surface)	Bloom	26/10/2008	26/10/2008	25.8	2.1	14.2	14.1 ± 0.1	-18.5	7.7	7.8 ± 0	1,100
BVSC0025	*Hincksia sordida*	off STP outfall (surface)	Bloom	26/10/2008	26/10/2008	27.1	2.3	14.0		-18.6	7.8		
BVSC0026	*Hincksia sordida*	off STP outfall (surface)	Bloom	26/10/2008	26/10/2008	23.8	2.0	14.2		-18.2	7.8		
BVSC0027	*Hincksia sordida*	off STP outfall (benthic)	Bloom	26/10/2008	26/10/2008	15.5	1.0	17.4	17.4 ± 0.2	-14.0	7.9	7.7 ± 0.1	
BVSC0028	*Hincksia sordida*	off STP outfall (benthic)	Bloom	26/10/2008	26/10/2008	16.3	1.1	17.1		-14.3	7.8		
BVSC0029	*Hincksia sordida*	off STP outfall (benthic)	Bloom	26/10/2008	26/10/2008	14.6	0.9	17.9		-13.5	7.5		
BVSC0030	*Colpomenia sinuosa*	off STP outfall (surface)	Bloom	26/10/2008	26/10/2008	20.8	1.0	24.7		-15.6	7.9		
BVSC0032	*Hincksia sordida*	Pambula Rivermouth	Bloom	5/12/2008	5/12/2008	23.2	1.1	23.8	23.6 ± 0.1	-18.3	7.1	7.2 ± 0	7,370
BVSC0033	*Hincksia sordida*	Pambula Rivermouth	Bloom	5/12/2008	5/12/2008	22.7	1.1	23.7		-18.3	7.1		
BVSC0034	*Hincksia sordida*	Pambula Rivermouth	Bloom	5/12/2008	5/12/2008	22.8	1.1	23.4		-18.4	7.2		
BVSC_037	*Hincksia sordida*	Pambula main beach	Bloom	12/01/2010	12/01/2010	7.9	0.4	20.5		-14.3	13.1		-
BVSC_038	*Hincksia sordida*	Pambula Rivermouth	Bloom	16/11/2011	16/11/2011	12.5	0.9	15.9	16.0 ± 0.1	-15.3	8.7	8.7 ± 0.1	11,884
BVSC_039	*Hincksia sordida*	Pambula Rivermouth	Bloom	16/11/2011	16/11/2011	12.6	0.9	16.1		-15.1	8.6		
BVSC_041	*Hincksia sordida*	Pambula Rivermouth	Bloom	3/01/2012	3/01/2012	8.4	0.8	12.8	12.8 ± 0.1	-16.0	11.6	11.6 ± 0.1	-
BVSC_042	*Hincksia sordida*	Pambula Rivermouth	Bloom	3/01/2012	3/01/2012	8.1	0.7	12.9		-16.1	11.5		
BVSC_045	*Hincksia sordida*	Pambula Rivermouth	Bloom	25/01/2012	25/01/2012	7.5	0.6	15.3	14.6 ± 0.7	-17.3	11.9	13.8 ± 1.9	-
BVSC_046	*Hincksia sordida*	Pambula Rivermouth	Bloom	25/01/2012	25/01/2012	6.8	0.6	13.9		-16.7	15.8		
BVSC_047	*Hincksia sordida*	Merimbula main beach	Bloom	22/02/2012	22/02/2012	13.9	0.8	19.3		-16.9	9.9		-

Note:

[1] Mean values ± standard error (SE) calculated for replicate samples representing same collection event.

[2] Volume of effluent discharged to beach outfall in 7 days prior to sampling date.

Table 6. Summary of effluent isotope data

Sample Details				Elemental			Isotopic Delta	
Sample ID	Sample Date	Letter Date	Sample wt., mg	TDS (mg/L)	% Comp		Delta	
					(C)	(N)	^{13}C	^{15}N
Paul Clayson 1/1	Oct-08	-	-	431	7.5	0.6	-15.6	16.8
T Candatti 1/2	Oct-08	-	-	426	7.2	0.4	-15.9	13.2
T Candatti 2/2	Oct-08	-	-	453	7.1	0.4	-14.2	14.6
MSTP_2/11/2011	2/11/2011	13/12/2011	10.25	468	5.4	0.6	-13.6	16.7
MSTP_10/11/2011	10/11/2011	13/12/2011	10.38	468	7.5	0.8	-17.3	20.1
MSTP_16/11/2011	16/11/2011	13/12/2011	10.42	454	5.8	0.5	-15.0	19.4
MSTP_23/11/2011	23/11/2011	13/12/2011	10.25	496	6.4	0.9	-15.7	21.5
MSTP_30/11/2011	30/11/2011	13/12/2011	10.17	379	5.1	1.3	-16.7	27.9
MSTP_7/12/2011	7/12/2011	13/12/2011	10.32	393	4.9	0.9	-15.7	19.1
MSTP_3/1/2012	3/01/2012	2/02/2012	10.36	453	5.3	0.8	-15.4	21.1
MSTP_10/1/2012	10/01/2012	2/02/2012	10.71	452	5.1	0.7	-13.8	22.4
MSTP_18/1/2012	18/01/2012	2/02/2012	10.24	509	5.4	0.7	-15.4	17.6
MSTP_25/1/2012	25/01/2012	2/02/2012	10.34	487	4.7	0.5	-12.3	19.3
MSTP_2/2/2012	2/02/2012	2/02/2012	10.43	491	4.2	0.9	-15.7	29.4
MSTP_8/2/2012	8/02/2012	2/02/2012	10.04	509	3.8	1.1	-16.0	32.0

Note:

All effluent samples collected from EPA identification point 4 - STP pump-out drain