State of the D’Entrecasteaux Channel and the lower Huon Estuary 2012

Report for the D’Entrecasteaux Channel Project

Dr Karen Parsons, Ecomarine Consulting

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Consulting

The D'Entrecasteaux Channel Project is a collaboration between local and state government agencies, non-government organisations, research institutes and industry to sustainably manage the waterway. This report was funded by Kingborough Council, the Derwent Estuary Program, NRM South, Huon Valley Council and Tassal.

Citation: Parsons, K. E. (2012). State of the D'Entrecasteaux Channel and the lower Huon Estuary 2012. Report for the D'Entrecasteaux Channel Project, prepared by Ecomarine Consulting.

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ISBN 978-0-9874818-2-5

Printed on 100% recycled paper.

Cover photographs by (clockwise from top left): Tassal salmon farms (R. Jupe); Kettering marina (D. Hardie); Feather on local beach (J. Doole); Boathouses at Conningham Beach (D. Hardie); Native pigface at Conningham Beach (D. Hardie)

EXECUTIVE SUMMARY

The D'Entrecasteaux Channel Project has recently been initiated by the Kingborough Council in response to interest being generated within council and the broader community to collaboratively managing the D'Entrecasteaux Channel in a sustainable manner. This project has been developed in partnership with other local government, state government, industry and natural resource management organisations. The first major step for the D'Entrecasteaux Channel Project has been the commissioning of the current review of the State of the D'Entrecasteaux Channel and the lower Huon Estuary to update information previously compiled in 1999. The aim of the review is to develop an understanding of the current environmental status of the region and compile information needed to underpin decisions for sustainable management. Based on data compiled, the report describes the overall status of the environment in the D'Entrecasteaux Channel and lower Huon Estuary and identifies key management issues, data gaps and potential future investigations. The information compiled is intended as a basis for ongoing planning and prioritisation of activities of the D'Entrecasteaux Channel Project.

The D'Entrecasteaux Channel and lower Huon Estuary are located in south-east Tasmania and provide a large area of waterway (446 km^2) that is protected from oceanic swells. While this region has experienced lower levels of urban development than the adjacent Derwent Estuary, its sheltered waters and natural values have encouraged population growth in surrounding areas and increasing pressures from both commercial and recreational activities. The D'Entrecasteaux Channel and lower Huon Estuary receive freshwater inputs from the Derwent Estuary-Bruny and Huon catchments, and fall within the Kingborough and Huon Valley municipalities. The study area for the report included the waterways and coastal zone to 1 km inland of high water mark, incorporating a total coastline of 405 km. The Huon Estuary is a highly stratified salt-wedge estuary, characterised by a freshwater layer overlying a saline wedge, while the D'Entrecasteaux Channel is predominantly marine. The majority of the waterway is >10 m depth, reaching a maximum depth of ~55 m, and experiences a small tidal range averaging 0.5 m. The estimated flushing time for the combined D'Entrecasteaux Channel/Huon Estuary waterway is 26 days, although more rapid individual flushing times have been recorded for the Huon Estuary (2-4-5.6 days) and D'Entrecasteaux Channel (7.5-8.8 days).

The region has experienced a relatively high level of population growth, with primary urban centres concentrated along the coast, while the foreshore includes a very large number of facilities and structures that service recreational and commercial marine activities. Levels of recreational boating and fishing are the highest in Tasmania, and there has been significant growth in finfish and shellfish farm production in the waterways over the past ten years. Secondary industries including a pulp mill and silicone/former carbide plant ceased operations in the early 1990s, however three seafood processing plants and a growing number of tourism operations rely on the waterway.

Anthropogenic (human) inputs

Contaminants enter the D'Entrecasteaux Channel and lower Huon Estuary from a variety of sources. Point sources include 9 wastewater treatment plants (WWTPs), 3 fish processing plants and 20 operational finfish farming leases. Non-point or diffuse sources include stormwater drains, septic and other urban runoff, tips and contaminated sites, quarries, catchment inputs carried by rivers (e.g. forestry and agricultural runoff), marinas and other boating wastes. Available data indicate that catchment inputs via river waters and fish farms are the largest anthropogenic sources of nutrients to the waterways. Smaller inputs occur via sewage and industrial WWTPs, while inputs from stormwater outlets cannot currently be quantified, and septic system leakages in several areas are likely to be contributing locally to pollutant loads. Residual contamination has been recorded at a historic pulp mill site at Port Huon, although a number of potential sources may have contributed to elevated pollutants in the area. There is also evidence of environmental legacy issues at a former carbide works site at Electrona, although measures have been implemented to mitigate potential effects on the waterways. Organic inputs from fish farms have increased since 1999, while a lack of wastewater flow data prior to 2009/2010 prevents temporal comparisons of sewage inputs.

There have been some reductions in pollutant inputs as a result of management initiatives, while additional measures are planned to help further reduce or restrict future inputs. Reticulation and 100% re-use of sewage at Howden has prevented sewage wastes from this location entering North West Bay, while plans to divert effluent from Electrona and Margate may further reduce direct inputs to this bay. Levels of antibiotic use at fish farms have declined to very low levels in recent years, and a phasing-out of the use of copper-based antifoulants on fish cage nets is planned at depositional sites by 2015. Caps have been placed on levels of nutrient inputs from fish farms, and cleanup programs have been instigated by salmon and shellfish growers and community groups to address concerns about marine debris.

Water quality

Water quality has been assessed from recreational water quality surveys performed by local councils during 2000-2011 and system-wide monitoring studies of the ambient environment conducted during 1996-2005. More recent data (2009 to present) have been collected as part of the Broadscale Environmental Monitoring Program (BEMP) and are currently being evaluated, but were not available at the time of preparing this report. Available data suggest that, as of 2005, the water quality of the region remained relatively healthy, with both the D'Entrecasteaux Channel and lower Huon Estuary benefiting from having small regional populations and a lack of heavy processing industries on their shores. Nutrient concentrations frequently exceed national guidelines; however, the primary nutrient source is the neighbouring ocean, highlighting the lack of applicability of national nutrient guidelines to this region. Water quality conditions are generally suitable for primary recreational activities, with occasional periods of localised and short term bacterial contamination associated with high rainfall. Heavy metal concentrations have been investigated in the Huon Estuary and are low in most areas, but have not been extensively surveyed in the D'Entrecasteaux Channel. There is some evidence of environmental degradation determined on the basis of applicable national guidelines (e.g. dissolved oxygen) or comparative assessments, including: localised oxygen depletion and nutrient enrichment in bottom waters of the Huon Estuary, a long-term increase in phytoplankton (microalgal) biomass across the region, and periodic blooms of the introduced and toxic microalga *Gymnodinium catenatum*.

Sediment quality

Marine and estuarine sediments include a mix of sand and fine, silty particles, depending on depth, currents, wind and wave exposure. Areas characterised by fine sediments are particularly vulnerable to accumulation of organic matter and contaminants. The majority of sediments in the region are healthy, as reflected by low organic content and heavy metals, high levels of oxygenation, and relatively diverse communities of benthic infauna. However, localised anoxia (i.e. oxygen depletion) and elevated organic content reflect degradation of some areas, particularly in parts of the lower Huon Estuary and North West Bay. High organic loadings at fish farms are in nearly all cases confined to within farm leases, while sewage is generally a small contributor to organic content except in the immediate vicinity of some urban centres and wastewater discharges. Experiments involving sediments from the Huon Estuary demonstrated that organic loading can potentially trigger the release of nutrients from sediments and increase the risks of eutrophication. This highlights the importance of maintaining healthy sediments and monitoring organic inputs. Examples of contamination issues include residual high pollutant concentrations in the vicinity of a former pulp mill site, elevated metals associated with sewage wastewater and use of copper-based antifoulant paints at fish farms, and localised tributyltin contamination in some marina environments.

Seafood safety

Filter feeding invertebrates such as oysters and mussels tend to accumulate pathogens, toxins and other contaminants at a higher rate than other species and hence are the primary concern for seafood safety. Sanitary surveys performed in the region monitor risks of shellfish contamination and instigate closure of oyster and mussel farms in accordance with specified triggers. During 2000-2011, both biotoxins from toxic microalgae and faecal bacteria indicators were significant causes of shellfish closures. Sites in the lower Huon Estuary, including Port Esperance, are at a particularly high risk from biotoxins associated with the toxic dinoflagellate *G. catenatum*. There are no clear temporal trends in risks to shellfish safety; however, it is clear that risks associated with biotoxins are an ongoing concern, with 2011 recording the highest and most widespread biotoxin-triggered farm closures for the 2000-2011 period. Levels of metals and pesticides in shellfish flesh have been within prescribed guidelines for seafood safety, while a long-term monitoring site has recorded mercury concentrations consistently below the maximum permitted level in flathead.

Nutrient sources and modelled impacts

A coupled model incorporating biogeochemical, hydrodynamic and sediment components has been used to simulate local processes controlling the cycling of nutrients, and predict the interactive effects of anthropogenic and natural inputs of nutrients on water and sediment quality and phytoplankton blooms. Modelling conducted in 2002 indicated that 60% of nitrogen was sourced from marine waters, 23% from the Huon River and 17% from fish farms. Almost all of the fish farm-derived nitrogen was categorised as biologically available to phytoplankton and other organisms, while most of the river-derived nitrogen was found to be biologically unavailable. Additional modelling based on maximum projected farming inputs by 2009 was conducted to determine potential impacts on environmental attributes of the waterway, and to help define fish farming management limits. A separate project is currently reviewing actual changes in nutrient inputs from fish farms and other sources, and performing a concurrent assessment of any changes in water quality.

Foreshore environment

The foreshore of the waterways has considerable scenic and recreational value, and also services marine farming, tourism, commercial fishing vessels, processing and other industries. A large percentage of the foreshore within the region is moderately to highly modified from its natural state. On the basis of mapping for 1.0 ha coastal cells, 34% of the foreshore was categorised as having been completely cleared of native vegetation and 90% was categorised as being under continued pressure from human disturbance. There are no major sites of reclamation; however, the presence of more than 300 foreshore structures reflects a strong focus on marine industries and the popularity of the waterways for recreational fishing, motor boating and yachting. Population growth is also concentrated along the coast, highlighting the need to carefully manage foreshore use to minimise impacts on natural and heritage values.

Values, habitats and species

Many areas of high natural, heritage and geoconservation value occur in the D'Entrecasteaux Channel and lower Huon Estuary, and 45 state reserves have been declared in the waterways and along the coast. Aquatic habitats are dominated by unvegetated soft sediments but also include highly productive seagrass and kelp beds and saltmarshes. The region supports a wide range of fauna due to its diverse marine, estuarine and foreshore habitats, including 150 species of fish and 130 species of birds. Threatened species include 23 fauna and 45 plants, while 7 threatened vegetation communities occur on the foreshore. Threatened fauna species include eight birds, two terrestrial invertebrates, three marine invertebrates, three fish, three terrestrial mammals and four marine mammals. Many threatened and other high conservation value species are endemic (i.e. unique) to Tasmania, south-east Tasmania or even to the Channel and Huon Estuary, including the spotted handfish, seastar species and highly restricted algae (or 'seaweeds'). Research on seagrass beds indicates reductions in their areal extent over the past 60 years, while giant kelp beds have not declined to the same extent observed in more northern parts of Tasmania. Declines in other marine species and overall diversity have occurred in association with historic scallop dredging, siltation of habitats, nutrient inputs and spread of introduced species, while little penguins and other nesting shorebirds have been impacted by habitat degradation and disturbance.

The majority of the foreshore is rated as moderate to high geoconservation value and contains a total of 24 listed sites, including several classified nationally as geological monuments. At least 600 Aboriginal heritage sites have been identified, and are concentrated along the immediate coast. Some have been degraded by erosion, diverted runoff, walking tracks and trampling. Approximately 65 state-listed and numerous additional locally-listed European heritage sites also occur on the coast and at the sites of historic shipwrecks.

Introduced species

There are currently 49 known introduced and cryptogenic (= potentially introduced) marine species in the D'Entrecasteaux Channel and lower Huon Estuary, including six 'target' introduced pest species. This represents a significant increase in the number of identified introduced marine species since 1999, but may largely reflect improved data availability. The toxic microalga *G. catenatum*, New Zealand screwshell *Maoricolpus roseus*, and the northern Pacific seastar *Asterias amurensis* have become dominant members of the community. There is evidence of increasing densities of certain benthic introduced species, with their proportional abundance increasing by 2-3% per annum during 1998-2003 relative to the total benthic community. Foreshore mapping to 100 m from the high water mark has revealed 31 dominant weed species, with weeds present in nearly 60% of foreshore areas surveyed. This mapping, and additional records extending to 1 km inland of the coast, indicate the presence of 27 declared weed species, as listed under the *Tasmanian Weed Management Act 1999*, including 8 Weeds of National Significance.

Climate change

Regional risks associated with climate change include shoreline erosion, flooding and landward recession due to sea level rise, with geomorphological mapping indicating that many areas of the study area are highly vulnerable, particularly around Margate, Snug, Great Bay, Bruny Island Neck and mid-Channel tertiary shores. The frequency and severity of storm surge events relative to current sea level and coastal infrastructure locations are predicted to increase, while saltmarshes and other coastal habitats are at risk where there are no suitable environments for their retreat. Additional impacts are associated with changes to water temperatures and chemical properties that influence the composition of marine and estuarine biological communities. Changes already evident include range expansions of species such as the long-spined sea urchin *Centrostephanus rodgersii* and microalga *Noctiluca scintillans*, while threats to kelp beds and fisheries species have also been identified.

Key management issues and data gaps

There has been a very large improvement in the availability of environmental data for the D'Entrecasteaux Channel and lower Huon Estuary since 1999. In particular, several system-wide studies have contributed greatly to our understanding of the water and sediment dynamics of the waterways. These studies indicate that anthropogenic inputs of organic matter and nutrients are currently the most significant threat to the ecological functioning of the waterway. Catchment runoff and fish farms are the primary sources, but are supplemented by inputs from sewage treatment plants, boat wastes, seafood processing plants, stormwater and leaking septic systems. Additional and, in some cases, related key management issues include recurrent toxic algal blooms, degradation of sediments, foreshore modification, declines in native marine and coastal species, increasing densities of marine pests, and vulnerability to sea level rise and ocean warming. Some of the management issues identified by the report are already being addressed by various government, industry and community initiatives.

The most significant data gap is the absence of a ‘catchment to waterway’ monitoring strategy that effectively measures the major sources of human inputs to the waterways, and provides for long-term monitoring of environmental status using consistent sites and techniques. Examples of other key gaps include a general paucity of data for the broader D’Entrecasteaux Channel compared to the Huon Estuary and North West Bay, incomplete spatial coverage of sediment contaminant surveys, absence of water quality classifications for recreational sites, and lack of data on stormwater outlet locations and discharges. A more detailed assessment of management issues and data gaps, including identification of potential future investigations, is provided to facilitate planning within the D’Entrecasteaux Channel Project.

ACKNOWLEDGEMENTS

This project was jointly funded by the Kingborough Council, NRM South, the Derwent Estuary Program, Huon Valley Council and Tassal.

The following members of the D'Entrecasteaux Channel Project Working Group are thanked for providing comments on an earlier draft of this report and/or for facilitating access to data:

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Jon Doole	Kingborough Council
Christine Coughanowr	Derwent Estuary Program
Catriona Macleod	Institute for Marine and Antarctic Studies, UTAS
Kathryn McLeod	Southern Water
Jocelyn Scopes	Huon Valley Council
Fionna Bourne	Marine Farming Branch, DPIPWE
Fiona Ewing	Tassal
Dom O'Brien	Huon Aquaculture Company
Simon Allen	CSIRO
Jill Pearson	NRM South

Numerous additional individuals within state and local governments, research agencies, natural resource management groups, private companies, and other non-government organisations also contributed general information, data, reports and review comments. Particular thanks go to:

Lois Koehnken (Technical Advice on Water, project subconsultant); Alison Turnbull (Department of Health and Human Services); Abyilene McGuire, Patrick McGuire, Daniel Willsmore, John Devries and Dianne Cowen (Kingborough Council); Nepelle Crane, Scott Edwards, Sue McCarter, Stuart Baldwin and Brett Thompson (Huon Valley Council); Sarah Richards, Andrew Ezzy, Bruce Terry, David Mitchell, Phil Roberts, Liz Canning, Bill Wilson, John Langenberg and Bob Hyde (EPA, DPIPWE); Marty Jack (Water Assessment Branch, DPIPWE); James Gourlay (Crown Land Services, DPIPWE); Graham Woods (Marine Farming Branch, DPIPWE); Alastair Morton (Policy and Conservation Assessment Branch, DPIPWE); Naomi Lawrence and Kris Carlyon (Biodiversity Conservation Branch, DPIPWE); Rolan Eberhard (Landscape Conservation Branch, DPIPWE); Adam Marshall (Aboriginal Heritage Tasmania, DPIPWE); Peter Hopkins (Marine and Safety Tasmania); Lance Stapleton (Southern Water); Jeff Ross, Neville Barrett, Vanessa Lucieer and Justin Hulls (IMAS, University of Tasmania); Sean Riley (Aquenal); Jason Whitehead (Derwent Estuary Program); James Burke (Nyrstar); Dick Shaw and Gunadasa Ginneliya (Department of Infrastrucure, Energy and Resources); Louise Cherrie and Charles Black (Tasmanian Ports Corporation); Eric Woehler (Birdlife Tasmania); Chris Sharples and Vishnu Prahalad (School of Geography and Environmental Studies, University of Tasmania); and Pam Elliot (Woodbridge Marine Discovery Centre).

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ABBREVIATIONS

Abbreviation	Meaning
ABS	Australian Bureau of Statistics
ACE CRC	Antarctic Climate and Ecosystem Cooperative Research Centre
AHD	Australian Height Datum
ANZECC	Australia and New Zealand Environment and Conservation Council
Aquafin CRC	Aquafin Cooperative Research Centre
BEMP	Broadscale Environmental Monitoring Program
BOD	Biochemical Oxygen Demand
BOM	Bureau of Meteorology
CFEV	Conservation of Freshwater Ecosystem Values
CMPI	Conservation Management Priority - Immediate (allocated in CFEV)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEPHA	(former) Department of Environment, Parks, Heritage and the Arts
DHHS	Department of Health and Human Services
DIER	Department of Infrastructure, Energy and Resources
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DPIPWE	Department of Primary Industries, Parks, Water and Environment
DPIW	(former) Department of Primary Industries and Water
DPIWE	(former) Department of Primary Industries, Water and Environment
DTAE	(former) Department of Tourism, Arts and the Environment
EAC	East Australian Current
EPA	Environment Protection Authority
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
FSANZ	Food Standards Australia New Zealand
GEL	Generally Expected Level
HAB	Harmful Algal Bloom
HES	Huon Estuary Study
IBA	Important Bird Area
ICV	Integrated Conservation Value (allocated in CFEV)
IMAS	Institute for Marine and Antarctic Studies
IPCC	Intergovernmental Panel on Climate Change
ISQG	Interim Sediment Quality Guideline
LOI	Loss on Ignition
MAST	Marine and Safety Tasmania
MFDP	Marine Farming Development Plan
ML	Maximum Permitted Level (Seafood Safety); Megalitres (Other Report Sections)
MPA	Marine Protected Area
MRT	Mineral Resources Tasmania
MSAP	Marine Structures Assessment Project
NFR	Non-filterable Residue
NRM	Natural Resource Management

Abbreviation	Meaning
NTU	Nephelometric Turbidity Units
NVA	Natural Values Atlas
NWQMS	National Water Quality Management Strategy
OTC	Oxytetracycline (antibiotic)
PAH	Polycyclic Aromatic Compounds
PSP	Paralytic Shellfish Poisoning
PSU	Practical Salinity Units
PWS	Parks and Wildlife Service
RPDC	Resource Planning and Development Commission
SEWPaC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
SPM	Suspended Particulate Matter
STCA	Southern Tasmanian Councils Authority
TASI	Tasmanian Aboriginal Site Index
TASVEG	Tasmanian vegetation map (Tasmanian Vegetation Monitoring and Mapping Program)
TBT	Tributyltin
THR	Tasmanian Heritage Register
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TPDNO	Total Permissible Dissolved Nitrogen Output
TSIC	Tasmanian Seafood Industry Council
TSPA	*Threatened Species Protection Act 1995*
TSQAP	Tasmanian Shellfish Quality Assurance Program
TSS	Total Suspended Solids
TVS	Tasmanian Visitor Survey
WIST	Water Information System of Tasmania
WoEASF	Whole of Ecosystem Assessment for Salmon Farming
WoNS	Weed of National Significance
WSUD	Water Sensitive Urban Design
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

The D'Entrecasteaux Channel and lower Huon Estuary are located in south-east Tasmania and provide a vast area of waterways protected from oceanic swells. The Channel separates Bruny Island from the Tasmanian mainland, while the Huon Estuary separates the more developed parts of southern Tasmania from the broad south west wildness area. Both waterways are central to the geography and social and economic development of the region. While they have experienced lower levels of urban development than the adjacent Derwent Estuary, their sheltered waters and natural values have encouraged population growth and increasing pressures from both commercial and recreational activities. The need to monitor and better manage changing uses in the region was previously recognised through the D'Entrecasteaux Channel and North West Bay Integrated Land and Marine Planning Project. As part of this project, a Strategic Management Plan and Strategic Action Plan (Phillips 2000) was produced, which was informed by the complementary 1999 State of the D'Entrecasteaux Channel Report (Phillips 1999).

The 1999 report documented natural and cultural resources of the D'Entrecasteaux Channel and described major pressures and environmental impacts evident at that time. However, there have been considerable changes in uses of the waterway since 1999, and also a growing understanding of the important hydrological and other links between the Channel and adjacent Huon Estuary. The D'Entrecasteaux Channel Project has, therefore, been recently initiated by the Kingborough Council in response to interest generated within council and the broader community to collaboratively manage the D'Entrecasteaux Channel in a sustainable manner.

The first major step for D'Entrecasteaux Channel Project has been the commissioning of a review of the State of the D'Entrecasteaux Channel and the lower Huon Estuary to update information previously compiled in 1999. The aim of the review is to develop an understanding of the current environmental status of the region and compile information needed to underpin decisions for sustainable management. The review has been undertaken in two stages: a data inventory was initially compiled to provide a description of available post-1999 data sets for the D'Entrecasteaux Channel and lower Huon Estuary (Parsons 2012); the current State of the D'Entrecasteaux Channel and the lower Huon Estuary 2012 report was then compiled using the major data sets identified. Both stages of the review were supported by input from the D'Entrecasteaux Channel Project Working Group, which includes representatives of various government, industry and regional natural resource management stakeholder groups (refer to acknowledgements section).

The State of the D'Entrecasteaux Channel 1999 report included an assessment of estimated nutrient inputs to North West Bay, but otherwise was largely a qualitative report due to the paucity of environmental data available at that time. Since then, a large number of studies of water quality and other environmental attributes have been undertaken, most notably two studies led by the CSIRO: the Huon Estuary Study published in 2000; and the Whole of Ecosystem Assessment for Salmon Farming completed for the Huon Estuary and D'Entrecasteaux Channel in 2009. Due to the paucity of data available in 1999, assessments of temporal trends through comparisons of the earlier State of the D'Entrecasteaux Channel report and post-1999 data are limited. Some comparisons of records for native and introduced species are possible, although even then the more recent estimates may largely reflect improved data availability rather than changes in the environment. Temporal comparisons are therefore confined primarily to changes documented over the period 2000-2012, with longer term assessments feasible where datasets were readily available or report authors had made comparisons with earlier data. In some cases, the report is only able to establish a recent 'baseline'; this nevertheless has value in facilitating future updates and monitoring changes in the region.

Based on data compiled, the report describes the overall status of the environment in the D'Entrecasteaux Channel and lower Huon Estuary and identifies key management issues. Data gaps are identified, and potential future investigations are described that will help to address these gaps and facilitate sustainable management of the waterways.

2 PHYSICAL SETTING

2.1 Location and climate

The D'Entrecasteaux Channel and lower Huon Estuary are located in Tasmania's south-east between latitudes 43°01' S and 43°42' S. The D'Entrecasteaux Channel is separated from Storm Bay and the Tasman Sea to the east by Bruny Island, while the Huon Estuary joins the D'Entrecasteaux Channel near its southern limit. Bruny Island and land bordering the northern part of the D'Entrecasteaux Channel fall within the Kingborough municipality, while areas adjacent to the Huon Estuary and southern Channel are located in the Huon Valley municipality. At its northern end, the Channel connects via a narrow opening to the lower Derwent Estuary and Storm Bay, while in the south it is connected to the Southern Ocean.

The precise study area for this report is illustrated in Figure 1, and includes the waterways and coastal zone to a distance of 1 km inland from high-water mark; hence this is the region referred to throughout the report as the 'study area'. Note that the broader catchments of the D'Entrecasteaux Channel and lower Huon Estuary are outside the scope of the current report; however, some features are considered where they provide context, or where available data sets extend beyond the coastal zone. In addition, system-wide assessments have included the entire Huon Estuary, and hence results are in some cases reported for both the upper and lower estuary, again to provide context.

The region experiences a maritime climate dominated by zonal westerlies that produce changeable, cool temperate conditions. The primary station for weather observations is located at Dover, although rainfall data are collected at numerous additional sites (e.g. Margate, Snug, Killora, Woodbridge, Middleton, Great Bay, Lunawanna, Alonnah, and Lymington). Temperature data are available since 1990 (Figure 2), and reflect mean minimum and maximum temperatures of 6.8°C and 16.4°C, respectively, although they were slightly higher during 2000-2011, at 6.9°C and 16.5°C (BOM 2012).

Annual rainfall has been measured at Dover since 1901, although data were missing for many years until a more consistent program was established from 1956. The mean annual rainfall between 1901 and 2011 was 879 mm, while in 2000-2011 it was 845 mm (Figure 3). Rainfall data for other sites in the study area have been available from 1908 at some sites, ranging to as recently as 2005 for others. Mean values based on all years of data available range from 650 mm (Great Bay) to 920 mm (Middleton). In 2000-2011, mean annual rainfall ranged from 582 mm (Killora) to 900 mm (Middleton). There was a trend for lowest rainfall at northern Bruny Island, followed by other northern parts of the study area, with increased rainfall in more southern areas. This has also been demonstrated in climate modelling studies, as presented in Figure 4.

Overall, the 2000-2011 period has been characterised by slightly warmer mean temperatures, higher August-September rainfall and lower November-May rainfall, relative to longer term historic data.

North-westerly and westerly winds predominate in the region over most of the year, with south-easterly sea breezes often developing during summer months. Geographic features affect local wind conditions, which in turn have a major influence on currents, water movement and exchange in the waterway. High winds can generate choppy conditions dangerous for small craft, with wind gusts particularly strong near headlands (Phillips 1999).

Figure 1 Study area for the report.

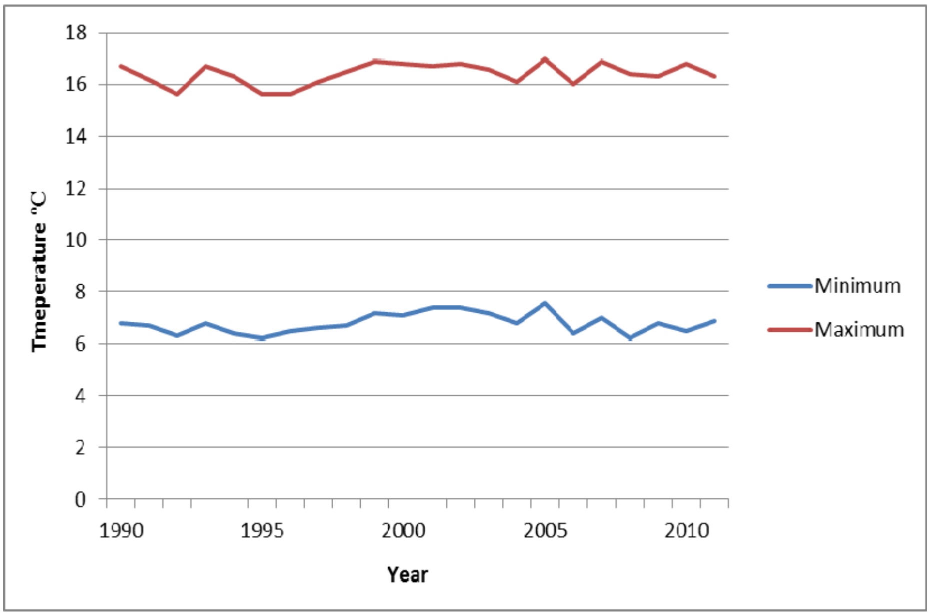


Figure 2 Mean temperatures at Dover (Data source: BOM 2012).

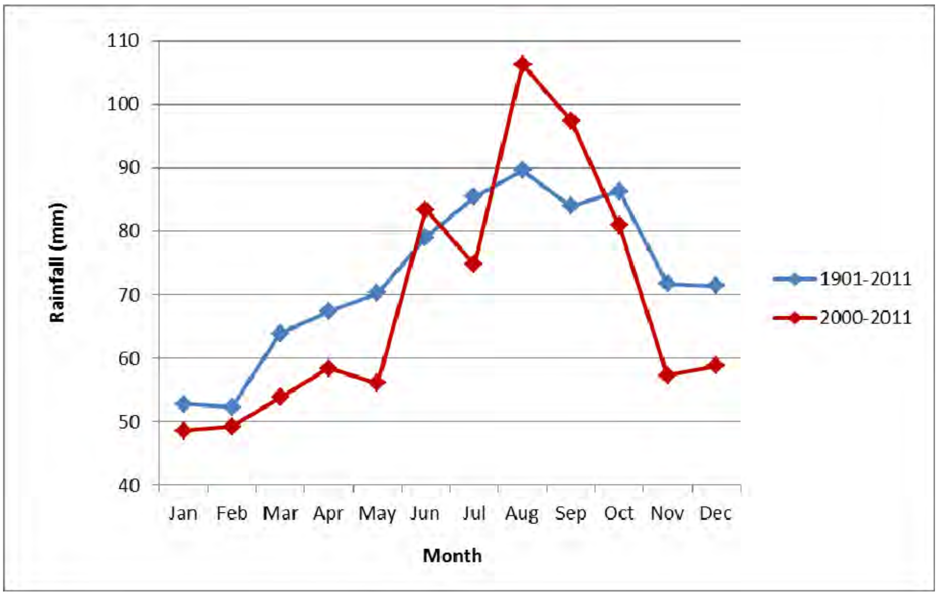


Figure 3 Mean monthly rainfall at Dover (Data source: BOM 2012).

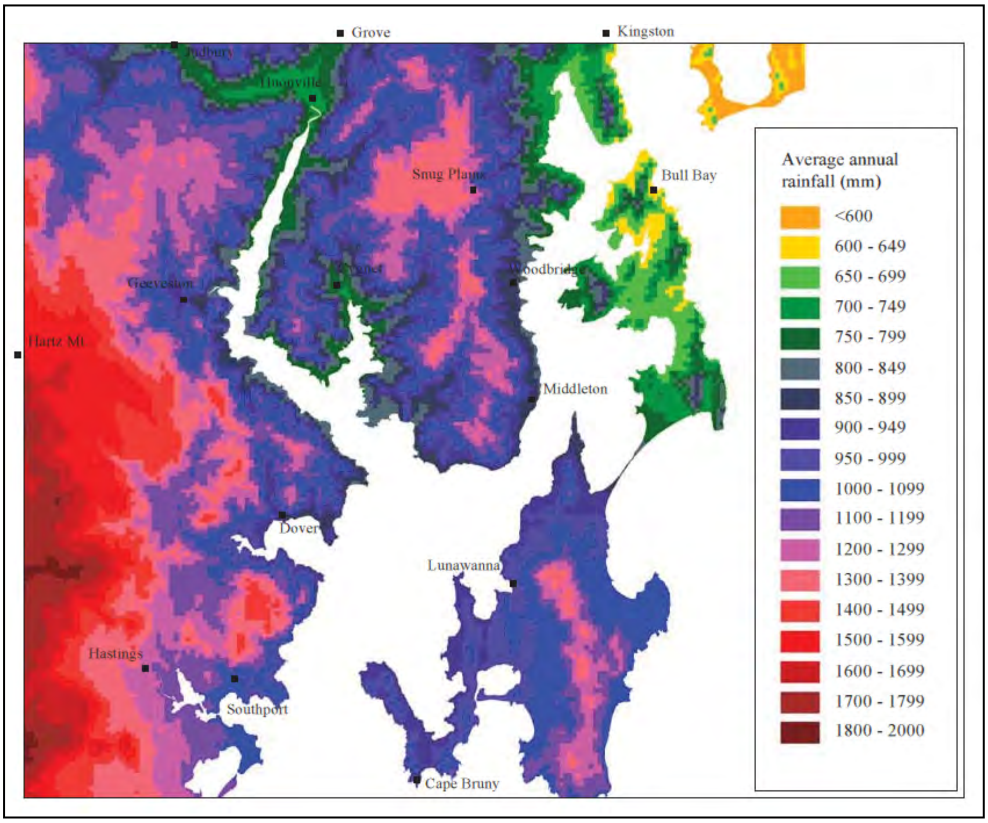


Figure 4 Average annual rainfall (Source: climate modelling data presented in Derose 2001).

2.2 The Huon and D'Entrecasteaux Channel catchments

While the focus of this study is the waterway and coastal zone, the current section briefly describes the catchments for these areas to provide broader context. Catchment boundaries were delineated as part of the Conservation of Freshwater Ecosystem Values (CFEV) Project (DPIW 2008a). This project identified two major catchments in the region, the Huon and Derwent Estuary-Bruny catchments, which contain 71 and 53 sub-catchments, respectively (Figure 5). Of these, 24 in the Huon and 27 in the Derwent Estuary-Bruny catchment fall partially within the coastal study area of this report. The Huon catchment occupies a total area of 3910 km^2, while the Derwent Estuary-Bruny catchment covers 1273 km^2 (DPIW 2008a). Summaries of natural values, conditions and threats in these two catchments have been provided by NRM South (2008a, 2008b).

Average annual rainfall ranges from over 2000 mm in the west of the Huon catchment through to ~600 mm in the eastern part of the Derwent Estuary-Bruny catchment. Land use in the Huon catchment is dominated by conservation management, but with 25% allocated to production forests and a further 9% to grazing. A substantial portion of the western side of this catchment lies within the Tasmanian Wilderness World Heritage Area, and is protected from major land use activities. In the Derwent Estuary-Bruny catchment, conservation management, grazing and 'other' uses each comprise about one quarter of land use, with urban/industry accounting for the majority of the remaining area, supplemented by production forests (Figure 6) (Hydro Tasmania Consulting 2008). Plantation forests, mining and other agricultural uses each account for small percentages of both catchments. Commercial activity in these catchments has typically centred on forestry and agriculture, with these spawning associated industries such as sawmilling, shipbuilding and fruit processing along the banks of the waterways (Butler *et al.* 2000).

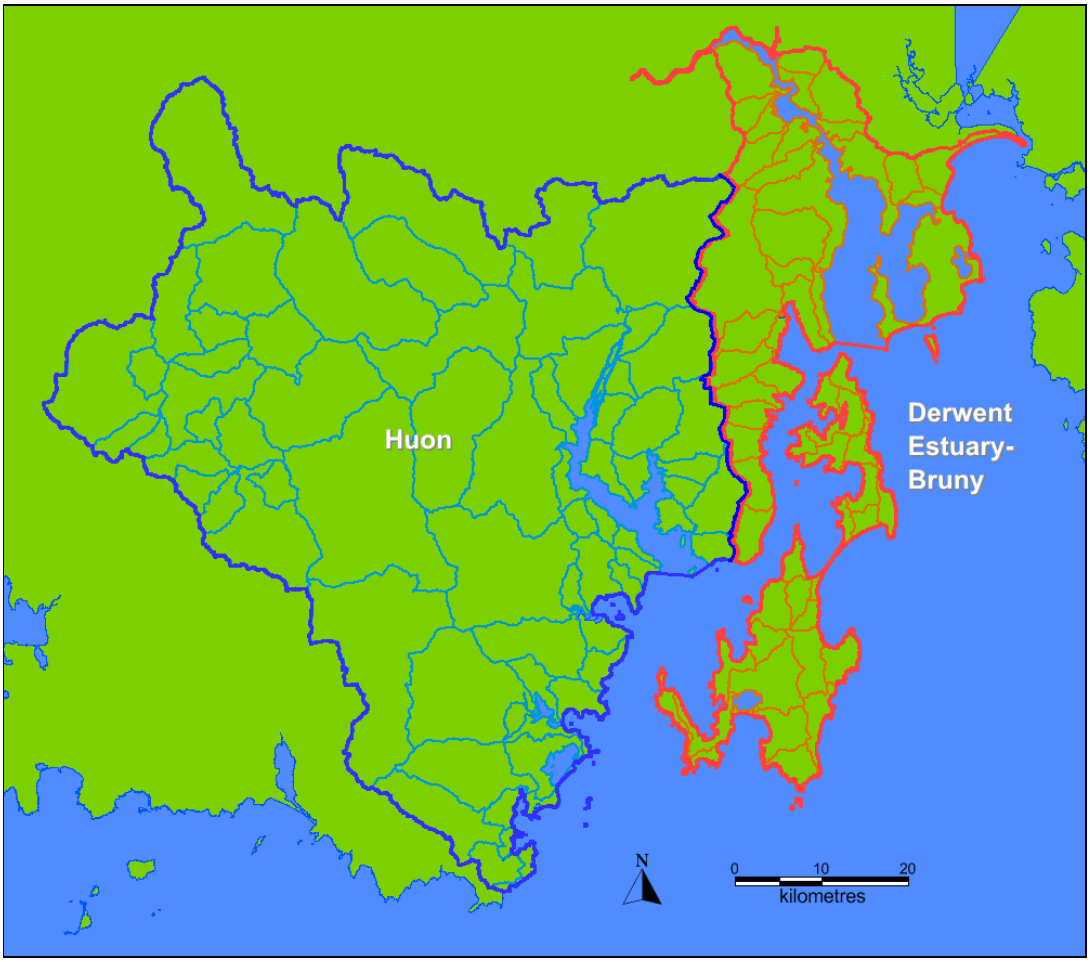
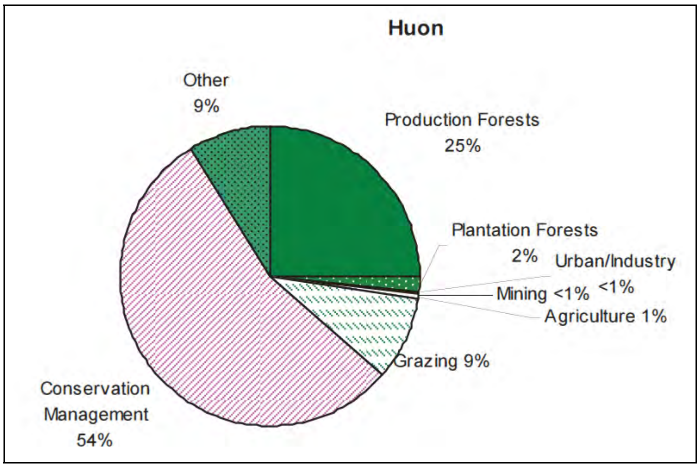


Figure 5 Catchments and sub-catchments (Data source: DPIW 2008a).

The major rivers draining the Huon catchment are the Huon River (104 km), Picton River (52 km), Weld River (44 km), Denison River (30 km) and Mountain River (24 km), all of which flow into the Huon Estuary (DPIW 2009a). The Derwent Estuary-Bruny catchment encompasses numerous small creeks and streams, with the only major river being the North West Bay River (25 km), which flows from the southern side of Mount Wellington into North West Bay at Margate (DPIW 2009b).

Geology and soils influence both the quantity and quality of surface runoff, and hence conditions in streams, estuaries, and coastal waters. The region is dominated by Permo-Triassic sediments (Parmeener Supergroup — mudstone, sandstone and shales) and intrusions of Jurassic dolerite (MRT, undated). Dolerite mountain tops exceed 1200 m in places, and fall away to rolling hills, valleys, undulating plains and river flats. Quaternary deposits (alluvial and estuarine deposits of sand, silt, clay and gravel) are found in coastal wetlands, and the lower reaches and upper estuarine sections of rivers and rivulets. The hills between Cygnet and the Huon Estuary are a local anomaly, with Upper Carboniferous glacio-marine sediments intruded by Cretaceous syenite, a rock type not found elsewhere in southern Tasmania (Seymour *et al.* 2007).



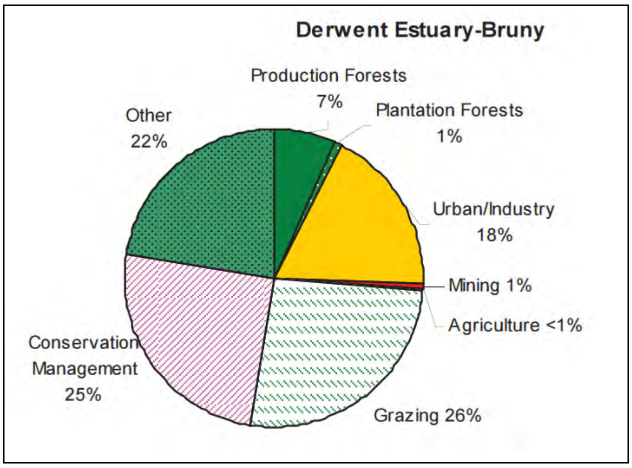


Figure 6 Land use in the Huon and Derwent Estuary-Bruny catchments (Source: Hydro Tasmania Consulting 2008).

The dominant soils are either grey-brown podzolic soils (derived from underlying parent materials) or yellow podzolic soils (formed from siliceous materials) (GHD 2007). Soils vary from acidic to slightly alkaline, with nutrient concentrations ranging from low to medium for total nitrogen, and from low to high for total phosphorus. Runoff from peaty soils in waterlogged sections of the Huon catchment is strongly coloured with dissolved humic material, which can limit light penetration in riverine and estuarine waters (see Section 11.2.2). Soils overlying the Parmeener Supergroup geology are vulnerable to erosion, which may contribute to increased turbidity in streams (Butler *et al.* 2000).

Variable topography produces a complex mosaic of 15 vegetation types in the Huon catchment, including buttongrass moorland, alpine complexes, stringybark eucalypt forests, pockets of rainforest, and wet scrub (Butler *et al.* 2000). The Derwent Estuary-Bruny catchment has open dry forests and grasslands in the north and east, and tall wet forests with shrubby understorey to the south and west (NRM South 2008a). The majority of agricultural land in these catchments occurs within several kilometres of the coast, or follows the major rivers and many smaller rivulets throughout the region (Derose 2001).

2.3 Coastal geomorphology and geology

The D'Entrecasteaux Channel and Huon Estuary are drowned river valleys, which became inundated during the last post-glacial rise in sea level. The upstream reaches of the Huon Estuary deepen to take on the characteristics of a fjord-like estuary, although they were not formed by glacial activity. The D'Entrecasteaux Channel previously formed part of the Derwent River, until a rise in sea level of about 60 m between 6,500-13,000 years ago resulted in waters of the Derwent being diverted to Storm Bay (Phillips 1999).

The D'Entrecasteaux Channel stretches for approximately 50 km in a NNE-SSE direction, while the Huon Estuary is ~40 km in length, detouring in a south-easterly direction at Brabazon Point. The total length of coastline included in the study area is 405 km, while the combined area of the Channel and lower Huon Estuary waterways to high water mark is 446 km^2. Coastal landforms along the foreshore are highly varied and include sandy and muddy intertidal flats, sand and pebble beaches, dunes, rocky shorelines and platforms, steep bluffs and sea cliffs. These landforms have predominantly been shaped by erosional processes associated with fluctuations in sea levels.

Mapping of foreshore geomorphology has been undertaken in the study area in relation to bedrock type, condition, sensitivity to human disturbance, and geoconservation values (DTAE 2007). Mapping of bedrock types indicated that foreshore geology is dominated by dolerite and sedimentary rocks (undifferentiated, sandstones, and siltstones), supplemented by 'unlithified' sediments such as sand, silt and clay and occasional areas of basalt (Table 1). In the case of sedimentary rocks, small cliffs occur in the intertidal and backshore areas, but usually slope gradually underwater. Basalt shores are an unusual feature of the region, and occur primarily along the western shore of North West Bay and the shoreline between Gordon and Kettering. Marine surveys suggest that dolerite reefs tend to extend into deeper waters than the sedimentary reefs, and that most reefs extend little more than 20-50 m offshore and 5 m depth. There are exceptions however, with dolerite reefs reaching ~15 m near the mouth of the Huon Estuary, and up to 25 m off points along the west coast of Bruny Island (Barrett *et al.* 2001).

Table 1 Foreshore bedrock composition (Data source: DTAE 2007).

Bedrock Type	% Study Area Foreshore
Dolerite (mainly Jurassic)	44.8
Parmeener (undifferentiated sedimentary)	33.0
Sandstones (Triassic)	8.2
Unlithified sediments (i.e. loose, non-compacted sediments) mainly Tertiary, some Quaternary terrestrial sediments	7.2
Siltstones (Permian)	6.3
Basalts (mainly Tertiary)	0.4
Unidentified	0.2

Geomorphological condition of the foreshore, which reflects the degree of naturalness of geomorphological features and processes, was rated as partly to significantly disturbed along 80% of the study area coastline, although only 3% was rated as highly modified (DTAE 2007) (Figure 7). Highly natural foreshores were found mainly on small islands, at the southern end of Bruny Island, and at Simpsons Point. Significantly disturbed foreshores were concentrated in North West Bay, Port Cygnet, Port Esperance and Great Bay. Nearly 70% of the coast was attributed a low sensitivity to human disturbance, whereby disturbance can occur without substantially altering natural geomorphic processes, while 15% was rated as highly sensitive (Figure 7). High sensitivity coasts are widely dispersed in the study area, with the longest section encompassing Bruny Island Neck. The majority of the foreshore was rated as moderate to high conservation value, reflecting the presence of a diverse range of significant features, as described in more detail below. This mapping project also identified landform types in the intertidal zone, with results used to describe intertidal habitats in Section 5.1. An earlier geomorphological mapping project assessed coastal vulnerability to flooding and erosion due to predicted rises in sea level (Sharples 2006), as summarised in Section 8.2.1.

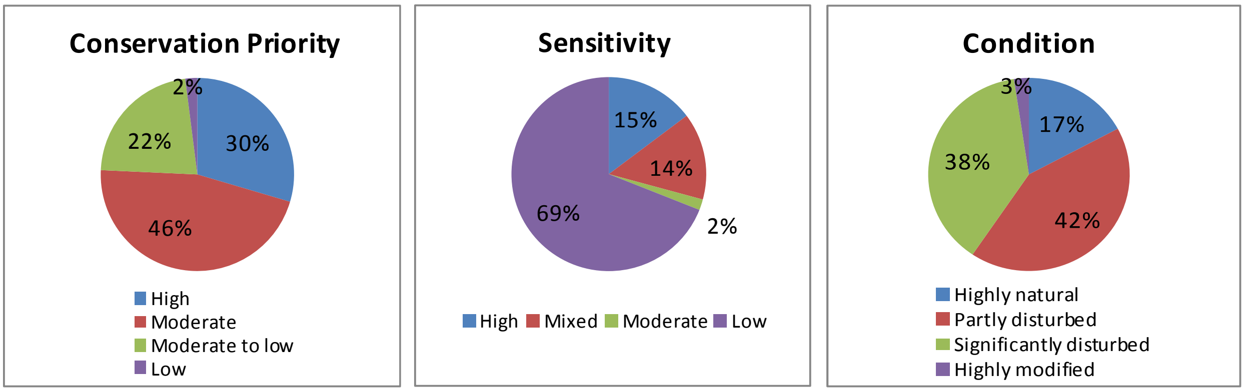


Figure 7 Foreshore geomorphological indices (Data source: DTAE 2007).

A search of the state government geodiversity database available via the Natural Values Atlas (NVA) revealed 24 sites of high geoconservation within the coastal study area. Three of these are classified as 'restricted' which are typically sensitive fossil or mineral localities which could be damaged by inappropriate sampling or collecting, and hence details of locations are not publicly available. The remaining 21 sites included a diverse range of sites considered to provide rare geological references, notable examples of type or only known Tasmanian example, and demonstration of climatic processes during the last glacial maximum. Two structures in the area have previously been classified nationally as geological monuments - Mickeys Bay 'elephant skin' jointing and the Lower Wattle Grove Permian Section, while Conleys Beach includes the only known Tasmanian example of a reasonably intact last interglacial coastal dune occurring at sea level. The most extensive sites of geodiversity value are at Bruny Island Neck (dune field and tombolo – i.e. neck formation connecting two islands) and in Great Bay (Megaripples – i.e. ripple marks with unusually long wavelengths, formed by wind processes) (DPIPWE 2012a). A unique geoconservation site on the boundary of the study area on northern Bruny Island is the Variety Bay coastal karst in which stalactites and flowstone have developed on the roof and walls of sea caves.

Mapping of vulnerability to acid-sulphate soils has identified coastal areas considered to have a high probability of containing these soils, with the largest potentially affected areas occurring in North West Bay, Great Bay, and Simpsons/Isthmus bays (CSIRO 2010). Many smaller bays, wetlands and estuarine habitats may also contain these soils, although ground truthing surveys have not been conducted to confirm their distribution in the study area. Acid-sulphate soils typically occur in low-lying areas such as estuaries, tidal flats and saltmarsh habitats, and have little affect when inundated with water. When exposed to air, they react with oxygen to form sulphuric acid, a compound that has potentially lethal effects on aquatic species (Cook *et al.* 2000).

2.4 Bathymetry, circulation and coastal oceanography

The broadscale bathymetry of the study area is illustrated in Figure 8, and indicates the presence of deeper channels in the lower Huon Estuary, southern Channel and to a lesser extent the very northern end of the Channel. The majority of the Channel is >10 m depth, reaching a maximum depth of ~55 m (Volkman *et al.* 2006). While the northern Channel is very narrow, detailed bathymetry mapping indicates that it still achieves depths >50 m (Figure 8, right). The depth of the lower Huon Estuary ranges from 9 m in the vicinity of Hospital Bay (Port Huon) to 40 m near the estuary mouth (Jones *et al.* 2003). To the south of the estuary, a canyon consistently deeper than 30 m feeds directly to the narrow continental shelf off south-eastern Tasmania (Butler *et al.* 2000). Bathymetry has an important influence on circulation and flushing, with deeper areas vulnerable to contaminant accumulation due to reduced current flows.

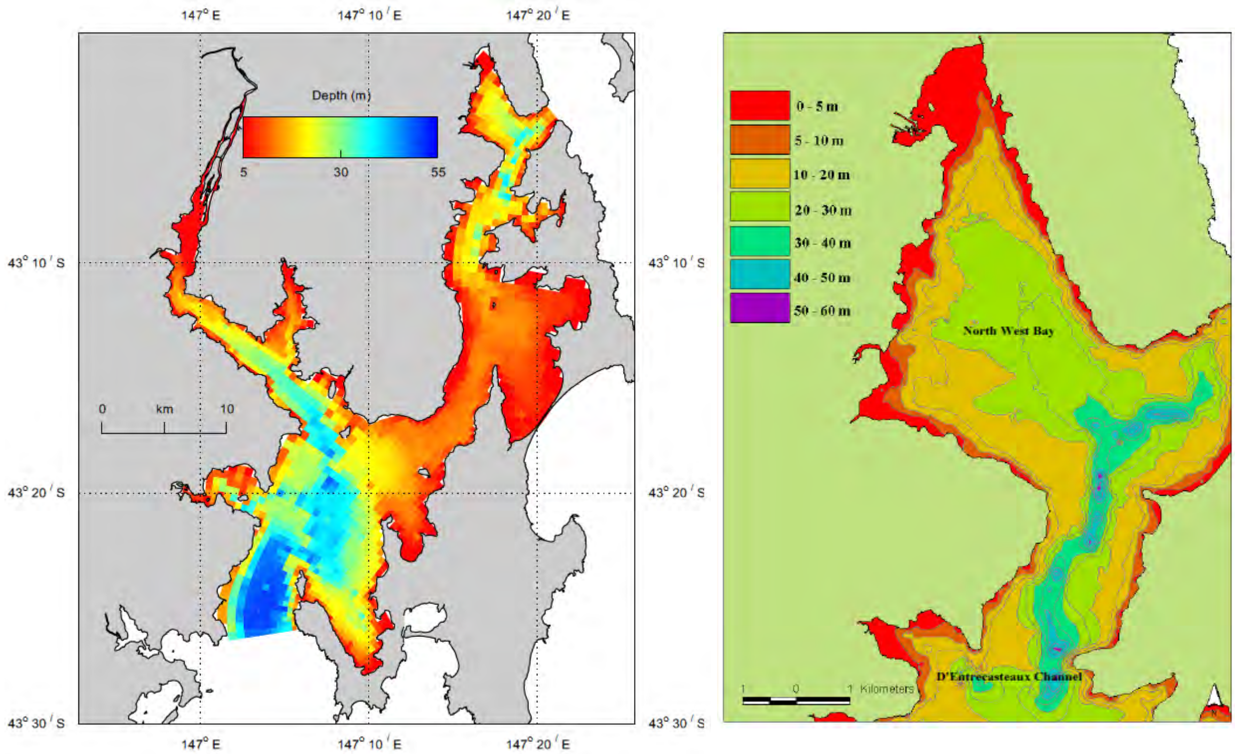


Figure 8 Bathymetry (Source: Herzfeld *et al.* 2005 – left; Jordan *et al.* 2002 – right).

The Huon Estuary, D'Entrecasteaux Channel and side bays are microtidal systems (i.e. having small tidal ranges), with a spring tidal range of about 1 m and average range of 0.5 m. The tide at Port Huon is just one minute in advance of Hobart, and its amplitude is typically 83% of the Hobart reference. Very weak tidal velocities of about 0.02 m/s have been estimated for the Huon Estuary, reflecting the low tidal amplitude and the lack of any large basin in the upper estuary. Current velocities generated by other processes in the estuary are slightly higher, but still generally <0.2 m/s (Butler *et al.* 2000). Maximum current velocities of more than 0.5 m/s have been observed near Gordon in the narrow mid-Channel, and are predominately tidal in nature (Volkman *et al.* 2006). Tides in the region are categorised as having a predominantly diurnal (daily) mixed character, meaning that there is essentially one tidal cycle per day but with some semi-diurnal influences, while the neap-spring cycle occurs over ~14 days (Herzfeld *et al.* 2005). Small variations in tidal height also occur infrequently due to the effects of wind and variations in atmospheric pressure (Jordan *et al.* 2002).

Both the D'Entrecasteaux Channel and Huon Estuary have considerable exchange with offshore waters influenced by three major oceanographic currents. During summer, the East Australian Current (EAC) brings warmer, nutrient-poor water down the east coast and into this region. In winter, nutrient-rich subantarctic waters reach southern Tasmania via the Antarctic Circumpolar Current, while the nutrient-poor Zeehan Current extending from the Leeuwin Current in Western Australia also influences the region. The seasonal interplay and zones of convergence between the two subtropical masses and the nutrient enriched waters from the subantarctic strongly influence the nutrient and algal dynamics of south-east Tasmanian coastal waters (see summary in Parsons 2011).

Long-term water circulation of the D'Entrecasteaux Channel and Huon Estuary has been investigated at a regional level, and is expressed as the 'residual' or mean/net flow. This flow contributes to the flushing of the region and distribution of marine inputs from the above oceanographic sources. The Huon Estuary is a salt-wedge estuary, characterised by a freshwater layer overlying a saline wedge that intrudes up the estuary. Residual flow enters in bottom water at the southern end of the Channel and continues along the bottom and upstream into the Huon Estuary in the salt wedge, favouring the southern bank. Smaller secondary bottom flows continue through the narrowest point of the Channel past Gordon into Isthmus Bay, and a smaller still recirculation heads south into Great Taylors Bay. Subsequent entrainment in the Huon Estuary occurs from the salt wedge into the downstream freshwater flow, the majority of which then turns north upon discharge into the Channel and exits into Storm Bay at the northern end of the Channel. During periods of high flow, this northward flowing discharge is present as a distinct freshwater plume. However, dispersion of freshwater plumes is sensitive to wind direction, with north-easterly winds pushing them southwards to exit via the southern Channel. At the northern end of the D'Entrecasteaux Channel, bottom flow is directed down-Channel and into North West Bay (Herzfeld *et al.* 2005). These patterns of residual flow are illustrated in Figure 9. They suggest that surface water quality in the region may frequently influence the lower Derwent Estuary while, similarly, bottom water quality in the latter estuary could affect conditions within the D'Entrecasteaux Channel.

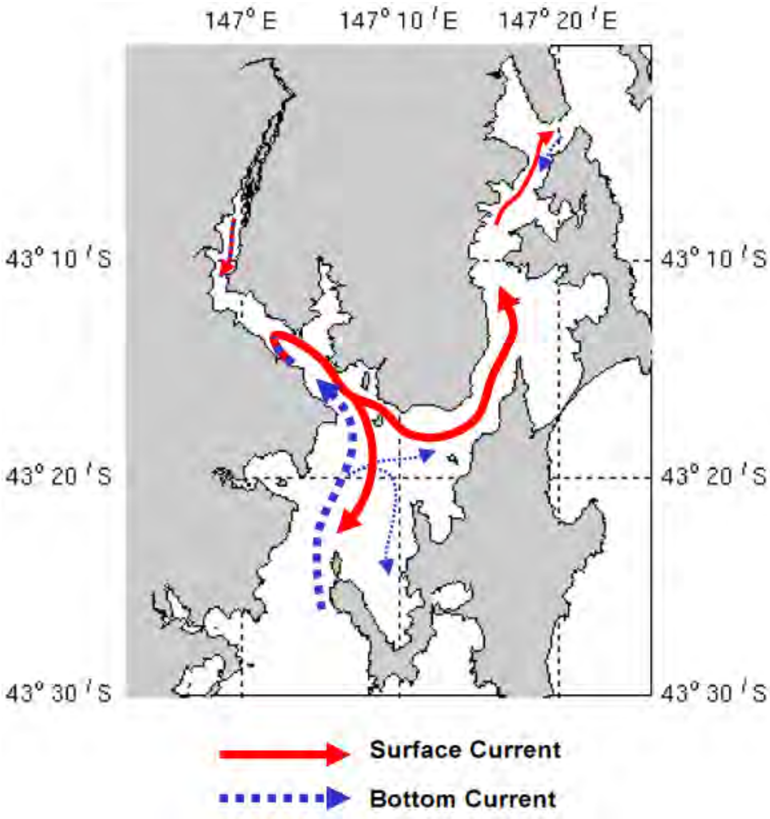


Figure 9 Residual circulation (Source: Herzfeld *et al.* 2005).

Flushing times are frequently estimated for estuaries and coastal embayments and provide a useful indicator of 'residence' time (i.e. the average time dissolved or suspended matter resides in the waterway before it is carried out into the open sea) and the relative importance of physical and biogeochemical processes. However, flushing times must be used cautiously with estuaries such as the Huon Estuary, which has strong downstream and vertical (i.e. surface to bottom) gradients. For example, retention times for particles released from a point source will depend on their circulation throughout the estuary; negatively buoyant particles may be retained more efficiently, as they sink into the bottom layer where the flow is predominantly upstream (Butler *et al.* 2000). Throughout the study area, the instantaneous flushing time may also differ depending on the location of the source and prevalent current speeds (Jordan *et al.* 2002). With these limitations in mind, flushing times for the Huon Estuary have been estimated at 5.6 days during low flow and 2.5 days during high flow. The surface layer within the entire estuary is flushed more rapidly, within 1.3 days during low flow and 0.6 days during high flow (Volkman *et al.* 2009). These fast flushing times have significant implications for nutrient cycling and phytoplankton blooms in the estuary (Butler *et al.* 2000).

Flushing times for the main D'Entrecasteaux Channel have been estimated to range from 7.5 days during February to 8.8 days during October (Herzfeld *et al.* 2005), while estimates for North West Bay specifically have ranged from 5 to 7 days (Jordan *et al.* 2002, Herzfeld *et al.* 2005). A flushing estimate for the combined D'Entreceasteaux Channel/Huon Estuary waterway, based on the average time for neutrally buoyant particles to exit the system, was computed as ~26 days. Dominant drivers of surface flows included river inputs, wind and tides, while vertical and lateral friction were also important in bottom waters. On diurnal timescales, the tidal flow dominated the region, with flow directed up-river and up-Channel during the flood tide, and vice versa during the tidal ebb. Hydrodynamic models suggested that the southern Channel and Huon Estuary are well connected to the broader system, whereas particles released in the northern Channel tended to remain within that area, causing localised effects (Herzfeld *et al.* 2005). These contrasting levels of connectivity are consistent with the residual circulation patterns depicted in Figure 9.

2.5 River inputs

Various rivers and streams drain into the study area, influencing flows, water quality and estuarine dynamics. The Huon River and its tributaries contribute the vast majority of flows to the study area, with other significant contributions including the Kermandie River, Esperance River and North West Bay River. These and additional freshwater sources contribute organic, sediment and nutrient inputs to coastal waterways (see Section 9.3), the levels of which may be altered by changes in flow regimes.

Modifications to flows have been most significant in the Huon River system. The diversion of waters in the upper catchment of the Gordon River for hydro-electric power generation has led to a reduction in annual discharge for the Huon River from approximately 3000 to 2600 million cubic metres (~95 to 82.5 cumecs, i.e. cubic metres per second). Scotts Peak dam is estimated to have caused a 15% reduction in median flows and an 8% reduction in low flows. The environmental impact of these flow reductions is not known; however, it has been suggested that Scotts Peak dam has effectively reduced the frequency and size of flooding in the Huon River (Gallagher 1996, and references therein). Flow diversions have also occurred in the North West Bay River system, with water dammed or diverted for irrigation and domestic water supply for Hobart and the surrounding suburbs and townships (DPIW 2009b). A smaller volume of water is diverted from the Esperance River to provide a water supply for the township of Dover (DPIW 2009a).

River flow data have been recorded at six monitoring stations within catchments providing riverine inputs to the study area, as summarised in Table 2. These stations capture the majority of flows to the study area, although numerous smaller rivulets and creeks are not monitored.

Mean daily flow values recorded for each month at these stations were extrapolated to estimate total monthly and annual flows. The combined annual flow from all river systems was estimated at 92 cumecs based on data averaged for all years. Relative to this long-term dataset, the estimate decreased to 87 cumecs for the 2000-2011 period using the Frying Pan Creek data for the Huon River, although a higher value of 96 cumecs was estimated using the more recent monitoring site established at Judbury. The latter is likely to be a more accurate reflection of flows due to its more downstream position relative to Frying Pan Creek, although limited monitoring at the Judbury site prior to 2000 means that it is less applicable to assessments of long-term temporal trends.

Table 2 River flow monitoring sites (Source: DPIPWE 2012b).

River flow monitoring station	Available flow data
North West Bay River, Margate Water Supply Intake (5201)	1976-1989, 2009-ongoing
Snug River (5202)	1976-ongoing
Huon River at Judbury (635)	1991-1995, 1999-ongoing
Huon River upstream of Frying Pan Creek (119)	1949-ongoing
Mountain River 600 m upstream Huon River (6203)	2008-ongoing
Esperance River at Dover water supply (7200)	1966-1992, 2004-ongoing

Data for 2000-2011 therefore suggest a reduction in water flows of approximately 5 cumecs relative to long-term datasets, which are associated with a decrease in mean annual rainfall (see Section 2.1). Comparisons of 2000-2011 and long-term combined mean monthly flows across the river systems (Figure 10) show seasonal patterns consistent with those observed for rainfall; i.e. higher rainfall and flows during August-September, and lower rainfall and flows in November-May rainfall, during 2000-2011 relative to the long-term data set. Like rainfall, flows peak during winter and early spring, and are lowest during mid-late summer. Other factors that have potentially contributed to temporal changes in total flow estimates include variation in the availability of flow data for different river systems over time, and changes to water extraction in the catchments. Waterway reports published for 2004-2009 did not reflect any major changes in consumptive water allocations over the five year period (Source: DPIPWE).

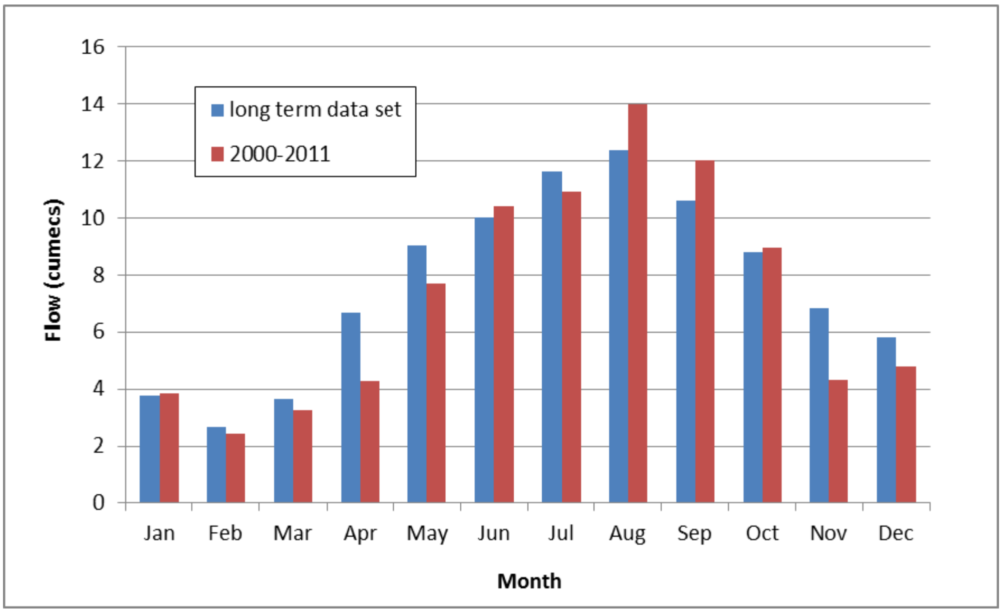


Figure 10 Combined mean monthly flows for all river systems (Data source: DPIPWE 2012b).

Inter-annual and monthly variation in flows over the past five years relative to the long-term data set is depicted for the Huon River in Figure 11, reflecting notably higher flows in 2009 and lower flows in 2008 relative to long-term data. Similar patterns of inter-annual variation were observed in flows of other smaller river systems and largely reflect temporal patterns of rainfall.

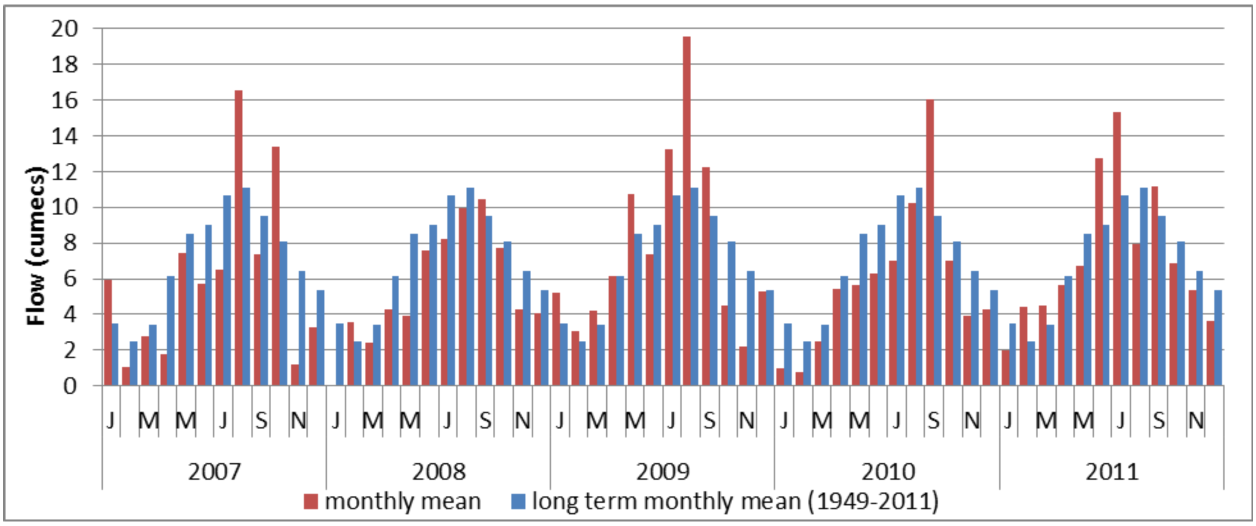


Figure 11 Mean monthly flows in the Huon River (Data source: DPIPWE 2012b).

3 USES

The D'Entrecasteaux Channel and Huon Estuary are bordered by numerous small townships, support growing marine farming and tourism industries, and are widely used for recreation on the water and adjacent coast. Coastal uses previously included several major secondary industries; however, these ceased operation ~20 years ago and the region has instead emerged as the primary salmonid farming area in the state and supports several water-dependent seafood processing facilities. Attractions such as boat tours, galleries and local produce, as well as a growing number of accommodation options, are important features of the Huon tourist trail. Bruny Island, in particular, is a popular retreat for locals as well as visitors to the state, with the connecting ferry service at times struggling to cater to commuter numbers. The region contains several fishing ports and unique marine-based educational facilities, while its waterways are the most popular in the state for recreational boating and fishing. The coastline is dotted with marinas, slipways, jetties and other facilities servicing a wide range of boating and other water-based activities encouraged by the sheltered conditions of the waterways and multitude of suitable anchorages. The majority of uses, whether commercial or recreational, are strongly focussed on the waterways, while a shift away from secondary industry has been accompanied by the realisation that a healthy environment is important for the future of the region.

Further information on the major uses of the waterway and coastal zone is provided in the sections below. The current report does not provide detailed information on uses within the broader Huon and Channel catchments, but clearly agriculture and forestry remain important in these areas. Horticultural practices are diversifying, with orchards continuing to be important but being replaced in some areas by less traditional farming enterprises such as viticulture, hazelnut and olive orchards (Derose 2001).

3.1 Population centres

The D'Entrecasteaux Channel and lower Huon Estuary are sparsely populated, with numerous small settlements and townships. Population centres are located primarily at, from largest to smallest, Margate, Cygnet, Geeveston (on the outskirts of the study area), Kettering, Snug, Dover, Howden, Electrona, and Woodbridge, with additional smaller centres in between. The Australian Bureau of Statistics (ABS) publishes population data for three areas encompassing this region, described as northern Kingborough, Huon, and Channel and Bruny, and indicates a total combined population of approximately 50,000 people in 2011 (Table 3). Note that the northern Kingborough (Taroona to Oyster Bay Rivulet) and Huon areas include several highly populated areas outside the current study area, while all three areas include inland as well as coastal populations. Nevertheless, temporal changes reflected in ABS data are likely to be highly indicative of the coastal study area given that most population centres are located along the coast.

Table 3 Recent population data (Data source: ABS 2012).

Area	2011 Population	Change 2001-2011	% change 2001-2011	Average annual % change 2001-2011
Huon	15,544	1,698	12.3	1.2
Channel and Bruny	2,906	331	12.9	1.3
Northern Kingborough	31,919	5,115	19.1	1.9
TOTAL	**50,369**	**7,144**	**16.5**	**1.7**

All three areas showed positive growth during 2001-2011, with a total increase of 19% over this period in northern Kingborough and ~12-13% in both the Huon and Channel/Bruny areas (ABS 2012). The average annual population increase across the entire region was 1.7%. More than 60% of the population was recorded in northern Kingborough, with 30% in the Huon and less than 10% in the Channel/Bruny area (Figure 12).

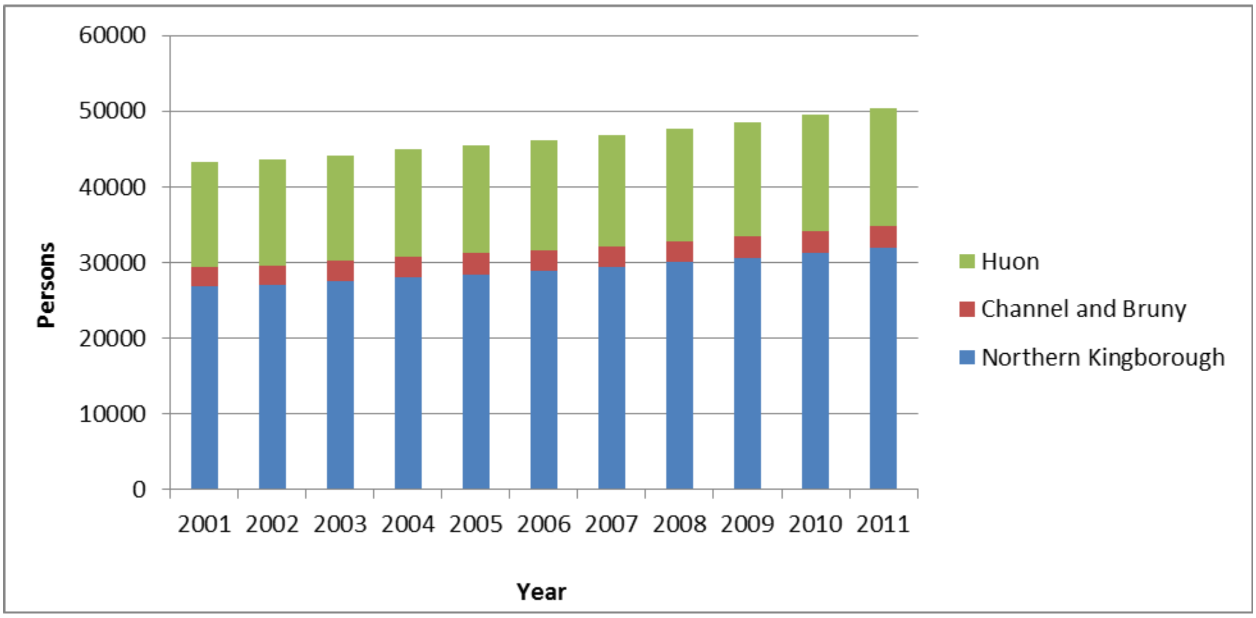


Figure 12 Population numbers during 2001-2011 (Data source: ABS 2012).

Census data are also available for individual population centres, with combined data for coastal centres suggesting a total population of approximately 14,000 within the study area in 2011 (based on data provided by ABS 2012). Margate-Snug is noted as an area of particularly high growth in Tasmania, with its total increase in population second only to Kingston-Huntingfield, and population growth rate second only to Brighton-Pontville, during 2011-2011 (ABS 2012). An analysis of population growth in the Kingborough municipality was made by Wilde (2012), who concluded that since 1986, this municipality has grown at a faster rate than the southern Tasmanian region generally and the metropolitan region. Its fast growth could be compared to that of other 'green-field' housing development areas in Tasmania such as Brighton and Sorell. Kingborough seems likely to experience continuing residential and population growth over at least the next 20 years, although limits on urban fringe development proposed in the Southern Tasmania Regional Land Use Strategy (STCA 2011) are likely to result in slower growth.

3.2 Foreshore land use

The foreshore of the D'Entrecastaux Channel and lower Huon Estuary has been a focal point for development in the region, with numerous projects along the foreshore associated with residential, tourism, recreational, and industrial developments. The majority of land adjacent to the coast is privately owned, although small percentages are state or council owned, and additional areas are occupied by roads and associated corridors. Planning and development controls of foreshore lands are heavily influenced by land tenure; however, all subtidal areas fall within the jurisdiction of state Crown Land. Much of the coastline immediately above high water mark is dedicated as informal Public Reserve and provides a buffer between private uses and the waterways (see Section 4.2).

Compared with the adjacent Derwent Estuary, little of the Channel and Huon Estuary foreshore has been modified by infilling or reclamation, although localised modification has occurred in areas of marinas, and the foreshore around Port Huon has been significantly modified as a result of historical industrial activities (see Section 9.7.2). The foreshore of the region is well-endowed with jetties and other marine structures that support a wide range of recreational activities and also commercial pursuits such as marine farming. Parks, walking tracks and conservation areas located along the coast are owned and managed by state and local governments. Several small land-based industries rely on access to the waterway (Section 9.2.1), but no secondary industrial plants have operated on the foreshore since 1991.

The Kingborough Planning Scheme introduced in 2000 simplified land use zonings in the Kingborough municipality. Under this scheme, the majority of coastal land is zoned for Primary Industries or Environmental Management, while smaller areas zoned for Recreation, Residential, Business and Civic, and Industrial uses are concentrated in or near population centres. A broader suite of land use zones applies to the Huon Valley municipality via three planning schemes, however the Huon Valley Land Use and Development Strategy completed in 2007 provides a basis for developing a unified planning scheme for the municipality (GHD 2007). No quantitative data on the areal extent of land tenure or zonation classes along the foreshore are currently available for the study area.

3.3 Marine facilities and structures

The foreshores of the D'Entrecasteaux Channel and lower Huon Estuary include a very large number of facilities and structures that service recreational and commercial marine activities (Figure 13). These facilities, in conjunction with associated boating activities, may result in inputs to the waterways such as fouling waste, sewage, oil, litter and metals, and also potentially cause issues such as erosion, habitat disturbance and nuisance algal growth. A range of legislation and guidelines have been introduced to reduce inputs and environmental issues; however, deficiencies in waste management practices and facilities remain in some areas, for example in the control of sewage inputs from vessels.

There are four marinas in the region, including Oyster Cove Marina and South Haven marina at Kettering, Margate Marine Park, and the Kermandie Marina. Facilities vary amongst marinas, but collectively they provide berths for recreational and fishing vessels, trailer and boat storage, jetties, boat ramps and slipping facilities. An additional ship building enterprise located near Margate services domestic markets and includes a dedicated vessel launch facility.

Slipways provide facilities for boat repair and maintenance, as well as boat launching, and hence generate biological and other wastes associated with cleaning and construction activities. A review of slipway facilities was performed as part of the Tasmanian Slipways Management Framework (DPIWE 2002). This work identified ten slipways in the study area, including commercial facilities at Margate, Kettering, Kermandie, Dover, Port Cygnet and Strathblane (mouth of the Esperance River), private facilities at Gardners Bay and Kettering, sailing club facilities at Port Cygnet, and a launch slipway associated with boat building facilities (i.e. not used for repairs and maintenance) at Margate (Figure 13). The commercial facilities at Margate, Kermandie and Kettering are associated with the above marinas. At least ten other small private slips are authorised for launching and retrieving boats in the study area (Crown Land Services, unpub. data). The state government has developed environmental guidelines for boat repair and maintenance, aimed at helping to manage environmental risks at slipways and other boat repair and maintenance sites (DEPHA 2009).

Boat ramps providing access to the waterways are widely dispersed in the study area, with a total of 24 boat ramps identified on the basis of records of Marine and Safety Tasmania (MAST) and councils. These ramps are commonly associated with jetty structures, although some of the approximately 20 public jetties in the region are without ramps. Jetties are constructed of timber, concrete or concrete/steel, with available data indicating construction dates ranging from 1980 to 2009. Moorings are regulated by MAST and occur at eight locations in the northern D'Entrecasteaux Channel and also at Port Huon and Port Cygnet, while numerous additional anchorage sites without moorings have been identified around the coastline (DPIW 2006). Numbers of licenced moorings in the D'Entrecasteaux Channel (incorporating the Huon Estuary) exceed those in any other part of Tasmania, although numbers in the adjacent Derwent Estuary are nearly comparable (Figure 14). Note that locations of water-based marine farming structures are described below in Section 3.5.

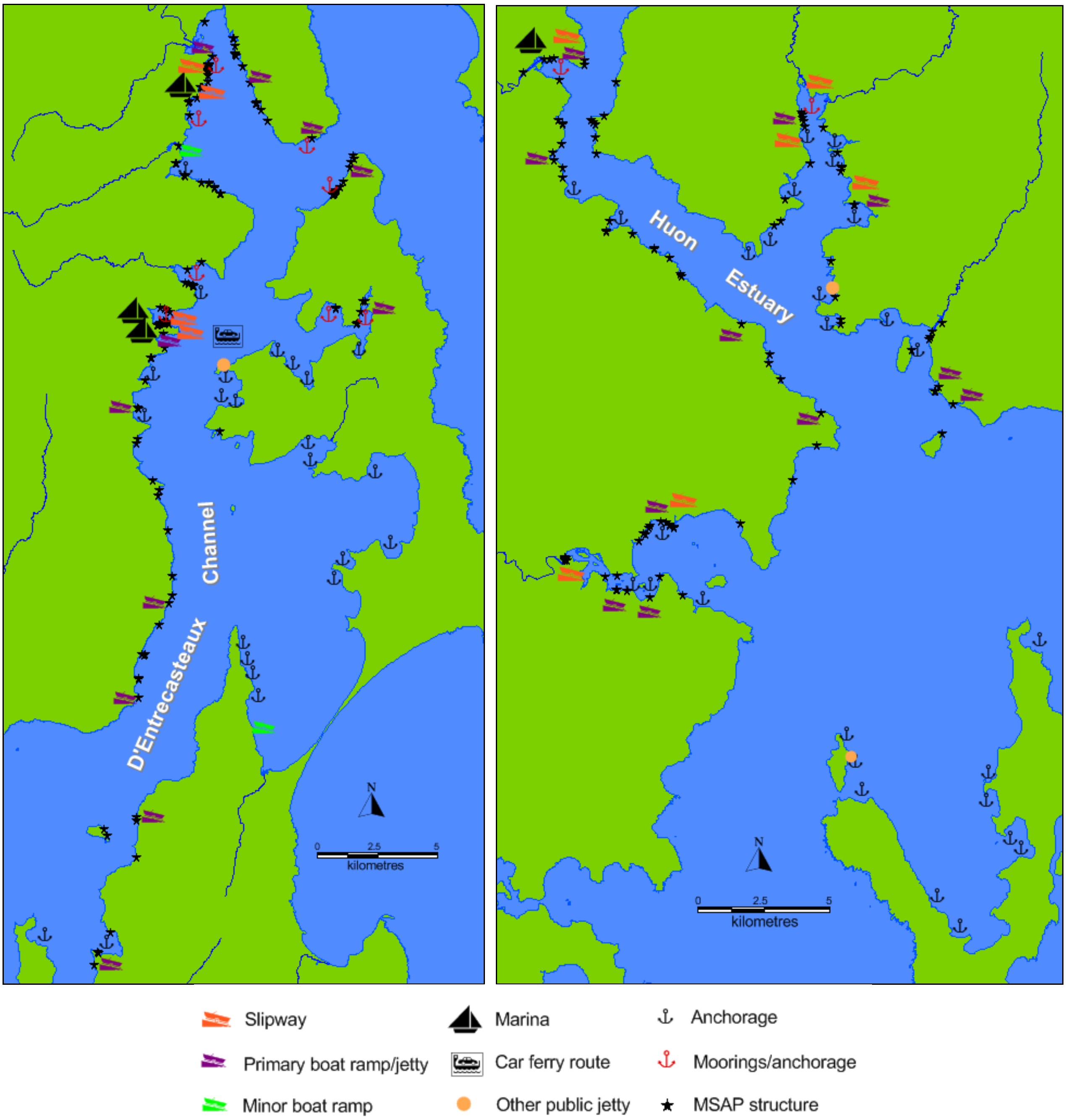


Figure 13 Marine facilities (Data source: DPIWE 2002, MAST 2004, DPIW 2006, DPIW 2008b).

Large numbers of additional structures occur in the region, as identified during the Marine Structures Assessment Project (MSAP) performed by Crown Land Services of the state government during 2006-2008. This project was performed to ascertain the condition of authorised marine structures and also to identify the presence and condition of unauthorised structures. It included assessments of jetties, wharfs, slipways, ramps/skids and boat sheds constructed on waterfront Crown Land or Reserved Land (DPIW 2008b). The assessment identified 332 structures in the study area ('MSAP structures', Figure 13); those that are authorised were dominated numerically by private jetties and boatsheds. Comparisons of MSAP mapping data and lists of authorised structures suggest that approximately 140 unauthorised structures were identified during the project. No data are currently available on numbers of unauthorised structures that were removed or were subsequently licenced (J. Gourlay, Crown Land Services, pers. comm.).

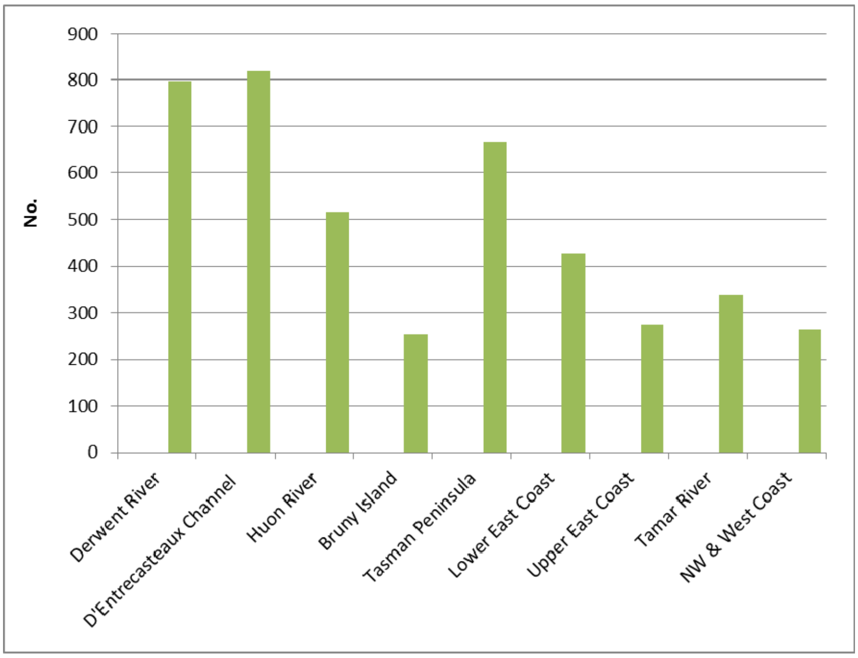


Figure 14 Numbers of moorings at January 2012 (Data source: MAST, unpub. data).

3.4 Navigation and transportation

Land based transportation in the study area is serviced by state-owned roads (Channel Highway, Huon Highway; and Lymington, Nicholls Rivulet, Scotts, Ferry, Bruny, and Lennon roads), as well as roads managed by the Kingborough and Huon Valley councils. There are also numerous small bridges, for example 78 within the Kingborough component of the study area. The total length of state-owned road in the study area is 114 km, with these roads managed by the Department of Infrastrucure, Energy and Resources (DIER). Data are not readily available on the total length of council managed roads within this area; however, total road lengths at a municipal level are provided in Table 4; note that all lengths are approximate only.

Table 4 Total road lengths (km) (Data source: Kingborough Council, Huon Valley Council, DIER).

Road Type	Kingborough mainland	Kingborough Bruny Island	Huon Valley	TOTAL
State-owned - all	94	58	162	314
State-owned - study area	38	32	43	114
Council - sealed	182	84	184	450
Council-unsealed	253	18	522	793
Council- total	435	101	706	1242

Vehicular transport to Bruny Island is via a 15 minute ferry trip operated by the 'Mirambeena' from Kettering to Roberts Point (Figure 13), departing a minimum of ten times daily, while there is also an airstrip on northern Bruny Island which services light planes.

The navigable waters of the D'Entrecasteaux Channel and lower Huon Estuary have had an important place in shaping the development and commerce of the region. Historic shipping activities served both national and international markets, and included visits of bulk carrier vessels to the Port Huon pulp mill wharf up until 1991, and export of fruit via wharf facilities at Port Huon and Port Cygnet (Butler *et al.* 2000). There are currently no regular shipping activities in the region, although a small number of large vessels periodically utilise the D'Entrecasteaux Channel and require pilotage services. A summary of these ships since 1999 is provided in Table 5; note that this list does not include fishing vessels or other small local commercial vessels not requiring pilotage services (C. Black, Tasmanian Ports Corporation, pers. comm.). Ports visited by these vessels prior to them arriving in the Channel have ranged from the nearby Port of Hobart through to international ports in Spain, Japan, and Macau, and island ports at Bermuda, Majuro, and Nassau.

Table 5 Ships recorded in the D'Entrecasteaux Channel since 1999 (Source: Tasmanian Ports Corporation).

Type of Vessel	Number	Home/Last Port
Antarctic	3	San Lorenzo, Vladivostok, Russia
Warship	2	Australia
Fishing	3	Hobart
Passenger liner	8	Hamilton (Bermuda), Nassau, Yokohama, Majuro, Macau, Port of Spain, Australia
Research	1	Hobart

The region contains important fishing ports at Margate and Dover, which provide landing sites for a large percentage of the state's rock lobster and abalone catches. Lobster may also be landed at jetties in Gordon, Kettering and Woodbridge. Marine navigation is integral to a variety of additional recreational activities (Section 3.8), and is facilitated by approximately 50 beacons maintained in the study area by MAST. Additional markers are used to indicate the boundaries of marine farming leases and hence facilitate navigation around associated structures.

3.5 Marine farming

The D'Entrecasteaux Channel and lower Huon Estuary are important waterways for marine farming industries in Tasmania, supporting both finfish and shellfish farming activities. Finfish farming is centred on salmonids (primarily Atlantic salmon), with two thirds of the state's salmonid industry by area based in the region (Volkman *et al.* 2009). Cultured shellfish include Pacific oysters and blue mussels, which are grown on racks and lines, respectively.

Marine Farming Development Plans (MFDP) have been developed for two areas relevant to the current report, including the D'Entrecasteaux Channel, and the Huon River and Port Esperance. Within each of these MFDP areas, there are a number of zones which have been allocated for the culturing of finfish and/or shellfish, and each have a set maximum leasable area. One or multiple leases may be established within each zone, with both zones and leases illustrated in Figure 15. Note that additional zones and leases exist in the D'Entrecasteaux Channel MFDP area, to the south of Port Esperance and in Cloudy Bay Lagoon, however these are outside the study area of the report.

Figure 15 Locations of marine farming zones and leases (Source: Marine Farming Branch, DPIPWE).

Within the study area, there are currently 53 marine farming zones incorporating 20 operational finfish leases and 33 shellfish leases. The total finfish lease area is approximately 931ha, while the total shellfish lease area is approximately 367 ha (Marine Farming Branch, DPIPWE, unpub. data). Production data provide an indicator of industry growth, and reflect increases in both shellfish and finfish farming in the region (see Table 6). Relative to 2000, most recent data suggest a 130% increase in finfish production (to 2010) and an estimated 40% increase in shellfish production.

Table 6 Marine farming production data in the combined D'Entrecasteaux Channel and Huon River/Port Esperance MDFP areas (Source: Marine Farming Branch, DPIPWE).

Product	Year	Production (tonnes)
Finfish	2000	10,351
	2010	23,858
Shellfish	2000	417
	2012 (estimate)	600

MFDPs for these areas include management controls relating to nitrogen outputs (see Section 9.2.2), carrying capacity, environmental monitoring, use of chemicals, waste, disease, visual, access, odour and other controls. A large number of studies have assessed impacts of marine farming at local and system-wide scales, and the effects of finfish farming inputs on water quality has been modelled (see Section 13.3). A study of several shellfish farms suggested that they were having little impact on the benthic environment (Crawford *et al.* 2003), although a broader review identified risks of spreading introduced pests and pathogens via movements of shellfish stock, and also localised habitat alteration (Crawford 2001).

The fish farm industry performs a range of compliance and in-farm survey programs to monitor environmental health. For example, compliance monitoring includes benthic (seabed) surveys within farms and at compliance sites 35 m from lease boundaries, and regional-scale surveys of water quality and benthic health for the Broadscale Environmental Monitoring Program (BEMP). Monitoring data on feed inputs is maintained and provided to state government, while discharges from associated fish processing sites are also monitored, as described in Section 9.2.1. Fish farm operators perform additional monitoring of water quality conditions, including abiotic parameters and phytoplankton counts, as part of their routine site management.

Impacts of finfish farming are considered more significant than those of shellfish farming and may include organic enrichment and oxygen depletion, with the potential to cause changes to nutrient dynamics and algal bloom frequency (Butler *et al.* 2000, Volkman *et al.* 2009). A statewide assessment of marine farm benthic monitoring data, the majority of which were collected in the current study area, indicated localised impacts reflected by depressed sediment redox levels, a dominance of organic enrichment indicator worm species, and low macrofaunal species richness (Edgar *et al.* 2005). These impacts were detected <10 m from fish cages and hence were confined to fish farm lease areas, while more minor impacts were detected at compliance monitoring sites 35 m from lease boundaries. Fish farm effects over regional scales could not be adequately assessed because reference regions without fish farms were not monitored; however, a significant decrease in oxygen availability in sediments, and increases in sediment organic matter and total macrofaunal abundance were commonly associated with fish farm sites (Edgar *et al.* 2010).

Fish farms have been associated with increased cover of opportunistic algae within 100-400 m of the farms (OH 2009), while there are also potential environmental impacts associated with use of copper-based antifoulants on nets and administration of antibiotics (Macleod and Eriksen 2009). Separation of certain impacts of finfish farming from longer term natural changes and inputs via other sources has been problematic. The evaluation and assessment of the BEMP described in Section 10.4 will include an assessment of inputs from various sources and assess water quality data in light of modelled impacts of fish farming expansion.

3.6 Fishing

The D'Entrecasteaux Channel and lower Huon Estuary region supports a primarily recreational fishery for wild-caught species. There is no commercial fishing of rock lobster in the study area, and only very small amounts of commercial abalone fishing occur on the northern and southern fringes of the D'Entrecasteaux Channel (C. Mundy, IMAS, pers. comm.). Commercial scalefishing is not permitted and commercial gillnetting has been phased out due to the region being part of a designated shark refuge area (DPIW 2008c), although limited recreational gillnet fishing is still allowed (DPIPWE 2011a). The commercial fishing ports in the region (Section 3.4 above) are used to land catches taken from adjacent parts of Tasmania's south and south-west coasts.

The Channel region is important for recreational fishing, providing an extensive body of relatively sheltered water with many protected bays, anchorages and launching ramps. Conditions are suited to the use of small vessels favoured by many recreational fishers, while its close proximity to Hobart makes it highly accessible (Phillips 1999). Hotspots for recreational scalefishing include Dover-Port Esperance, Gordon, Woodbridge, Kettering, Alonnah, Barnes Bay and Dennes Point. Major angling species include flathead, cod, Australian salmon, Atlantic salmon (farm escapees), sea-run trout, barracouta, bream, mullet, squid, pike and founder (DPIPWE 2010a).

Quantitative information on recreational fisheries has been compiled through fisher surveys conducted by the Institute of Marine and Antarctic Studies (IMAS). The most recent fishery-wide surveys published were for 2007-2008 and indicated that, based on the number of fishers and total fisher days of effort, the D'Entrecasteaux Channel was the most heavily fished region in Tasmania. The significance of the Channel was clearly evident based not only on the number of fisher days of effort (92,000) but also the number of fishers (31,000) estimated to have utilised the region during 2007-08. The majority of the fishing activity was boat-based, with flathead dominating catches numerically. Large numbers of scallops were also taken, with the Channel representing the focal point for the recreational scallop fishery in Tasmania. Species of secondary importance included rock lobster, Gould's squid, abalone, cod, wrasse and southern calamari (Figure 16). Comparisons with 2000-2001 survey data indicated an increase in fishing effort in the D'Entrecasteaux Channel, which was partially attributed to the scallop fishery that was closed during the earlier surveys (Lyle *et al.* 2009). There is some evidence from a separate monitoring program that the size of flathead in the D'Entrecasteaux Channel has decreased over time (see Section 14.4.1), which could potentially be related to fishing pressure.

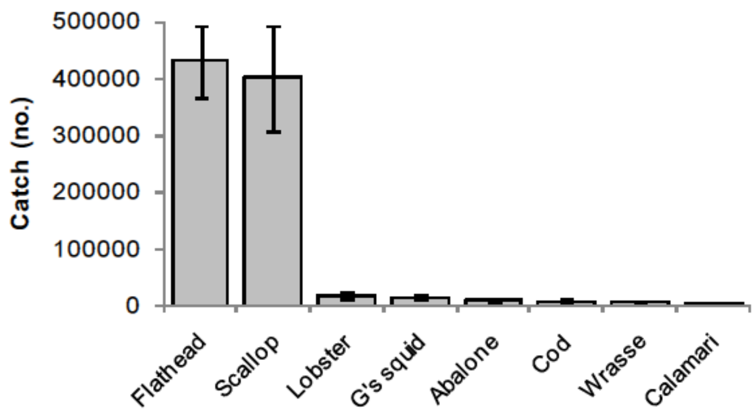


Figure 16 D'Entrecasteaux Channel recreational catch during 2007-08 (Source: Lyle *et al.* 2009).

The D'Entrecasteaux Channel has a history of scallop dredging, with the total catch peaking at 23.9 million in 1947, followed by the collapse and closure of the fishery in 1967 (Edgar and Samson 2004). The recent history of the Channel scallop fishery has involved hand collection only; however, recurrent collapses have continued and resulted in protracted closures of up to 15 years at a time. In 2005, after 12 years of closure, the fishery was re-opened but with reduced bag limits and increased minimum size limits compared with earlier openings. Despite this, scallop stocks assessed through dive surveys and fisher interviews declined markedly, with an 87% reduction between 2006 and 2011. Commercial scallops, which had been the most abundant of the three species in the Channel, declined by 93%, while queen scallops and doughboy scallops declined by 75% and 52%, respectively (Figure 17). The fishery was closed in 2012, since re-opening was considered to pose a significant risk of fishing down the remaining adult stocks to unsustainable levels (Tracey and Lyle 2011a, 2011b).

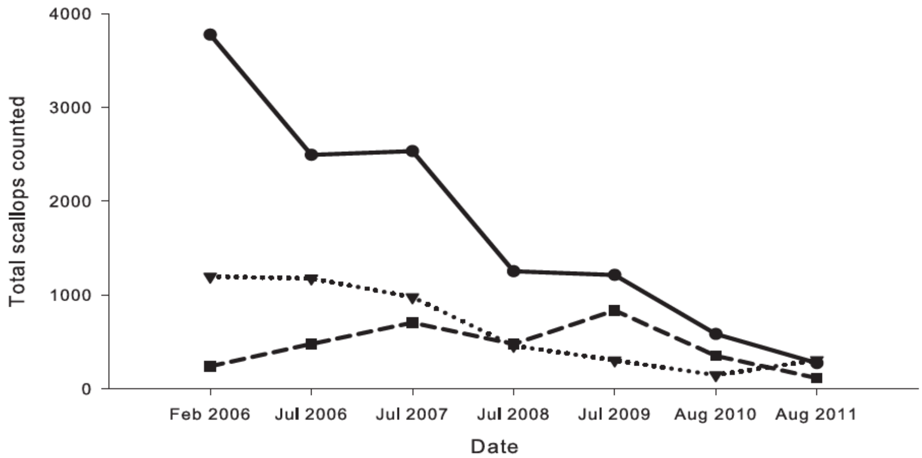


Figure 17 Numbers of scallops, commercial scallop (●), queen scallop (▼) and doughboy scallop (■), in the D'Entrecasteaux Channel during 2006-2011 (Source: Tracey and Lyle 2011a).

Detailed information on recreational lobster and abalone catches was compiled during 2008-2009. Surveys found that the south-east region of Tasmania accounted for ~28% of rock lobster caught recreationally, with 19% of these (i.e. ~5% of the statewide catch) caught in the D'Entrecasteaux Channel. This represented ~5,600 lobsters, with the entire catch collected by diving, since lobster pots are prohibited in the Channel. Recreational effort and harvest of abalone during the same period was concentrated in the south-east of the state, where one third of the harvest and 37% of the effort were reported. Within this area, the D'Entrecasteaux Channel and Bruny Island recorded the third highest catch behind the Tasman Peninsula and Norfolk-Frederick Henry Bay. At a statewide level, the number of people holding recreational licences more than doubled for lobsters and tripled for abalone between 1995 and the 2008/2009 season. There was no evidence of increases in the recreational harvest for rock lobster and abalone since the mid-2000s despite increases in licence numbers (Lyle and Tracey 2010).

3.7 Tourism

The picturesque D' Entrecasteaux Channel and lower Huon Estuary have much to offer tourists in the way of fine local produce, highly rated cool-climate wines, boutique accommodation and spa retreats, galleries, local museums, wilderness adventures and magnificent scenery. The region falls within the 'Huon Trail', one of 11 tourist touring routes (or 'self-drive trails') in Tasmania. The Huon Trail includes the Channel, Bruny Island, Huon Valley and the Far South, and contains 56 registered attractions. Some are located outside the current study area, but all contribute to drawing tourists to the region. Examples include the Tahune Forest

Airwalk, Hastings Caves and Thermal Springs, Bruny Island boat tours and Wooden Boat Centre, while a range of other attractions add to the diversity of experiences on offer, including: berry and mushroom farms, vineyards, cheese tasting, a scenic railway, national parks, bird watching activities, gardens, golf courses, forest drives and walks, craft studios and restaurants. Special events include the Taste of the Huon, Huon Show, Bruny Island Bird Festival and Brookfield Margate Market, while tours on offer include rafting, kayaking, jet boating, fishing, cruising, horse trekking, caving and hang gliding. There has been a growing importance of cruises and water-based tourism, highlighting the importance of the waterways for the local tourism industry. Approximately 120 accommodation options are available, with self-contained cottages being most numerous (ATDW 2012).

The primary source of tourism data is the Tasmanian Visitor Survey (TVS) which was initiated in 1978 and has been conducted annually by Tourism Tasmania since 1988. The survey is based on a sample of more than 9,000 visitors each year, and provides a profile of the characteristics and travel behaviour of international and domestic visitors to Tasmania (Tourism Tasmania 2012). TVS data are available from 2007/2008 to 2011/2012 and indicate a statewide peak of visitors during 2008/2009 and gradual decline since that time. The Huon Trail received 190,500 visitors during 2008/2009, a figure which progressively declined by 21% to 138,100 in 2011/2012, reflecting the third highest decline for a Tasmanian trail. Most recently, a decline of 9.5% in visitor numbers was recorded between 2010/2011 and 2011/2012, representing a smaller decline than experienced in eight of the other ten trails. Numbers of visitors to attractions such as the Tahune Forest Airwalk and Hastings Caves and Thermal Springs displayed similar temporal trends to overall visitor numbers. However, data on overnight stays reflected a different picture, with numbers fluctuating over the past five years but showing no evidence of decline for the Huon Trail. Total nights spent in the region increased by 9.5% in the past year to 238,900 and by 53% since 2007/2008 (total nights at that time: 155,800). At the same time, eight of the other trails experienced declines in the past year and all experienced declines or smaller increases (6 to 31%) since 2007/2008 (Tourism Tasmania 2012).

In summary, numbers of tourists have been declining over the past five years, but visitors are choosing to spend more time in the region, as reflected by a higher number of overnight stays. The downturn in tourist numbers is part of a wider trend being experienced across the state and Australia, and has been attributed in part to the strong performance of the Australian dollar and the emergence of low-cost carriers in south-east Asia (Tourism Tasmania 2010).

3.8 Recreation

The D'Entrecasteaux Channel and lower Huon Estuary region is Tasmania's most popular area for boating, fishing and yachting, and also offers excellent opportunities for bushwalking, scuba diving, surfing, kayaking and swimming.

The waterways of the region provide extensive deep waters, sheltered bays and anchorages suited to cruising and yacht racing. Recreational sailing is an important activity in the region, with yacht clubs located at Port Huon, Kettering, Port Cygnet and Port Esperance all conducting regular race days primarily during summer months. These clubs and also the Royal Yacht Club of Tasmania and Derwent Sailing Squadron in the Derwent Estuary host a number of special sailing events in the region. Examples include the Green Island Race, Channel Race, Pipe Opener Series, Cock of the Huon, Bruny Island Race, Barnes Bay Regatta, Port Cygnet Regatta and Port Esperance Regatta. Some of these events have a very long history; the Bruny Island Race (a circumnavigation of the island) for example has been described as the oldest yacht race in Australia, having operated for 86 out of the past 114 years. Additional boating events are open to motor boats as well as sailing vessels, such as the Kettering Wooden Boat Rally.

As described in Section 3.6, the D'Entrecasteaux Channel is the most intensively used area for recreational fishing in Tasmania. This waterway, incorporating the Channel and lower Huon Estuary, is also the most popular region for motor boating in Tasmania. This is reflected by surveys of recreational boat owners performed by MAST, with recorded boating levels far exceeding those in other areas and demonstrating a slight increase between 2007 and 2010 (Figure 18). There is currently little signage in the study area about recreational fishing and boating, although there are plans to assess how signage and infrastructure in the region could be updated to facilitate use and improve management (D. Willsmore, Kingborough Council, pers. comm.).

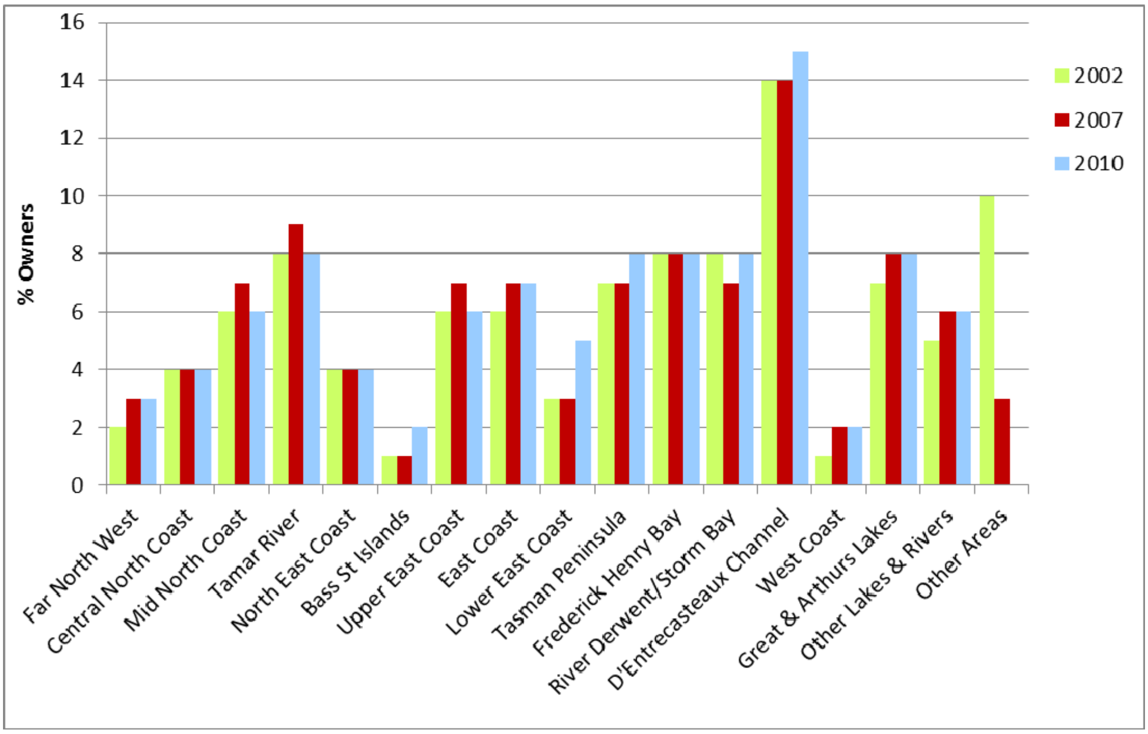


Figure 18 Recreational boating use (Data source: MAST).

Scuba diving activities are frequently associated with recreational fishing of rock lobster, abalone and, prior to fishery closure (Section 3.6), scallops. However diving is also linked to training activities, a recreational dive trail at Tinderbox, wreck diving, and observations of marine species and scenery in marine reserves and numerous additional popular dive sites. Kayaking is also widespread in the study area, with training and tours operated primarily from Kettering. Assessing the needs of kayakers in the area has been identified as a priority, since with improved infrastructure the Channel has the potential to become a 'hub' for kayaking activity (D. Willsmore, Kingborough Council, pers. comm.). Swimming is popular during summer months, with recreational water quality monitoring conducted by councils in key areas (see Section 11.3).

A range of tracks and trails occur in the study area, with those recorded on council mapping systems occupying a total combined length of 34.8 km in the Kingborough municipality and 4.3 km in the Huon Valley municipality. Longest tracks in Kingborough include those at the Peter Murrell Reserve, Wingara Gully, Margate Rivulet, Snug River, Coningham Clifftop, Kettering Point, Alonnah-Sheepwash Bay, and the Labillardiere Peninsula on southern Bruny Island. In the Huon Valley municipality, primary walks are along the Lymington Road, Dover Foreshore, and Kent Beach walking tracks. Permitted activities vary between trails, but collectively they include a wide range of uses such as bushwalking, cycling, cross country mountain bike riding, horse riding and dog walking.

Golf clubs are located at Cygnet, Dover and Margate, with four additional clubs located in neighbouring parts of the Huon Valley and Kingborough municipalities. Irrigation of the North West Bay Golf Club at Margate accounts for 100% of wastewater re-use from the Howden Wastewater Treatement Plant (see Section 9.1.1). Additional sporting grounds in the study area include nine ovals and five tennis court facilities, while numerous additional playgrounds and picnic areas are found in the region. Foreshore reserves and conservation areas also provide important areas for recreation and are described in Section 4.2.

3.9 Research and education

Several unique educational facilities occur within the study area and surrounds that reflect a strong focus on the waterways. The Marine Discovery Centre built over the water at Woodbridge gives students from Kindergarten to Year 12 the opportunity to learn about, discover and care for the marine environment through diverse shore and sea-based programs. The centre was established in 1979 and quickly became an integral part of the Tasmanian education experience. It has its own research vessel and incorporates an aquarium room, marine pond and touch tanks, as well as displays of marine life, human impacts and fishing technology (Department of Education 2012). Long-term monitoring of physical water quality characteristics, sediments and benthic species has been conducted at a standard suite of sites by the centre as part of its educational activities (P. Elliott, pers. comm.).

The Wooden Boat Centre located adjacent to the study area at Franklin is a school and visitor centre dedicated to preserving the traditional craft/trade of wooden boat building, and to stimulating public awareness and understanding of the craft. The Wooden Boat Centre was initially established in 1990 as the Shipwright's Point School of Wooden Boatbuilding, to teach and preserve the skills of traditional wooden boatbuilding. It runs a fully nationally-accredited Certificate course which is the only one of its kind actively operating in Australia, and allows students the opportunity to construct a full-sized, sea-going cruising vessel built in solid timber (Wooden Boat Centre 2012).

The D’Entrecasteaux Channel and Huon Estuary have been the focus of several major, system-wide research projects aimed at better understanding the ecosystem dynamics of the waterways (see Section 10). These studies headed by the CSIRO have been triggered by the need to understand the environmental carrying capacity of the region for fish farming and other anthropogenic inputs, and are unique to Tasmania in their detail and scope. Community education in the region has been key to the development of numerous ‘care’ groups, for example 31 in the Kingborough municipality alone in 2012, comprised of landcare, coastcare, wildcare, bushcare, friends of reserves and other environmental groups. These groups in turn continue to perform activities that engage and educate the community on environmental issues in the waterways and adjacent lands.

4 VALUES

4.1 Heritage

4.1.1 Aboriginal heritage

The region traditionally belonged to the Mellukerdee (Huon River), Mouheneenner (Hobart and to its south) and Nuenonne (Bruny Island) Bands of the South-east Tribe, who were the most maritime of Tasmanian aborigines. The tribe harvested shellfish, seabirds, seals, algae and a range of terrestrial foods, and built bark canoes for frequent voyages to and from Bruny Island and other areas of south-east Tasmania. Small, sharp-edged hand tools were collected from stone quarries for cutting and skinning, and tribe members journeyed hundreds of kilometres along coastal and inland paths to meet with other groups for trade and ritual. The most obvious remaining traces of Aboriginal habitation are the vast areas of shell middens lining the coastline, which contain shells and stone tools marking the locations of former gathering places (Kingborough Council 2011). Today's Tasmanian aborigines maintain some of the traditional hunting and fishing activities of their ancestors in the waterways and catchment.

Oyster Cove is a site of historic significance and special importance to Tasmanian aborigines. Following failures of mission sites established for the Aboriginal population at Bruny Island and Flinders Island, due largely to the impacts of introduced diseases, the surviving 48 Aboriginal people were brought to Oyster Cove in 1847. They occupied the site until 1874, when the last remaining survivor, Trugernanner (or Truganinni), was moved to Hobart. She died in 1876 and her ashes were finally scattered in the D'Entrecasteaux Channel in 1976, honouring wishes she had expressed a century earlier. Trugernanner was a Nuenonne from Bruny Island, which the Aborigines called Lunawanna-Alonnah. The first two European towns built on the island were named Lunawanna and Alonnah, and many of the island's landmarks are named after Nuenonne people.

The Tasmanian Aboriginal Centre resumed occupation of the Oyster Cove site in 1984 and ownership was granted to the Aboriginal community by the state government in 1995 (Phillips 1999). It was formally recognised as the Putalina (Oyster Cove) Indigenous Protected Area in 1999, and a community festival is held each January to celebrate Putalina’s significance to the Aboriginal community.

To date, there has been no single comprehensive survey of Aboriginal heritage sites undertaken for the D’Entrecasteaux Channel or lower Huon Estuary. However, over the past thirty years, snapshots of information have gradually been compiled through scientific research, local area studies and surveys for development proposals, all of which is maintained by Aboriginal Heritage Tasmania. This information is stored on the Tasmanian Aboriginal Site Index (TASI), and provides a permanent record of identified Aboriginal heritage places in Tasmania, with ~600 known sites registered in the study area (Figure 19). Sites located within 1 km of the coast include stone quarries, artefact scatters, shell middens and isolated artefacts (A. Marshall, Aboriginal Heritage Tasmania, pers. comm.). It is important to acknowledge however that Aboriginal cultural heritage value is not restricted to individual relics, but also encompasses collections of significant sites and in some cases entire landscapes (GHD 2007).

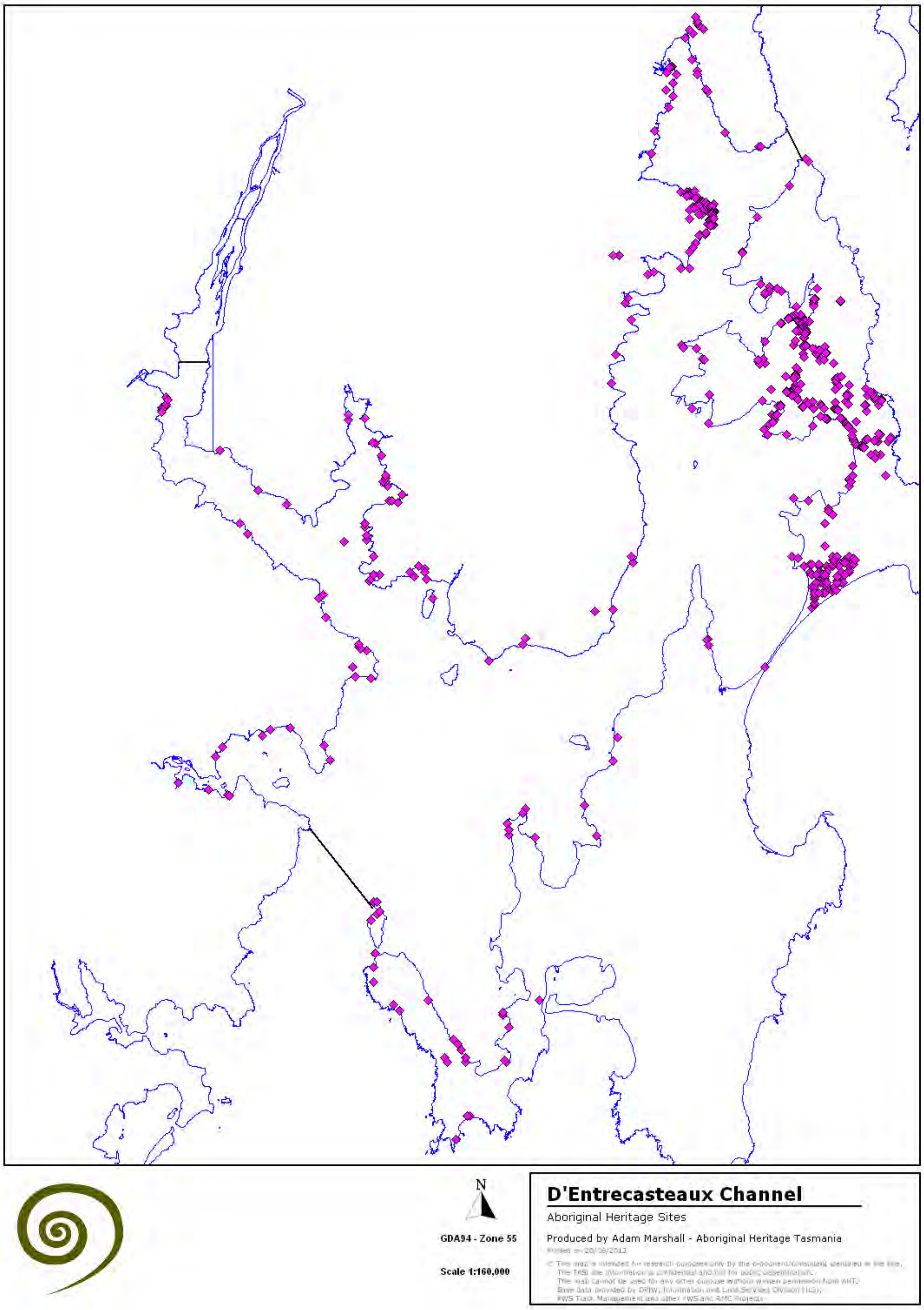


Figure 19 Coastal Aboriginal sites (Source: Aboriginal Heritage Tasmania).

Aboriginal heritage significance is concentrated along the coast in this region, and is therefore an important consideration in coastal development and management. There is evidence of degradation of some heritage sites; for example, in the Coningham Nature Recreation Area, a history of fires has resulted in open heritage sites being subject to increased gully erosion. Some middens are partially exposed and subject to minor runoff, while parts of an Aboriginal cave site are vulnerable to rock-falls and collapse, with erosion exacerbated by a walking track diverting runoff into the cave. The Aboriginal community would prefer that people not visit the cave out of respect for the place and for those who once lived there (DPIPWE 2009a).

4.1.2 European heritage

The European cultural heritage of the region is largely based on the forest, agricultural and maritime industries, which provided much of the economic and social life of the district over the last one hundred and seventy years. Places of heritage value associated with these industries and associated settlements are numerous and include both built heritage as well as landscapes, patterns of subdivision and historic transport routes (GHD 2007). Early historic sites in the study area also include a number of convict probation stations that were established during the 1840s at Oyster Cove, Nichols Rivulet, Huon Island, Dover, Port Esperance, Hope Island, Port Cygnet and Lymington (Phillips 1999).

Within the study area, land-based protected heritage places include sites of state significance listed on the Tasmanian Heritage Register (THR) maintained by Heritage Tasmania, and additional sites of local significance included on Planning Scheme Heritage Schedules of the Kingborough and Huon Valley Councils. The THR includes 160 sites in the Huon Valley municipality and 91 in the Kingborough municipality (Heritage Tasmania 2012). While these sites have not been mapped, 39 sites from the Huon Valley and 26 in Kingborough are potentially within the study area on the basis of general localities. The largest state-listed heritage sites in the study area include the Bruny Island Quarantine Station at Barnes Bay, Mount Royal Signal Station at Gordon, Point Ventenat Quarries on Bruny Island, and Brookfield tobacco drying kiln at Margate. Additional notable sites include some of the above probation stations, Tinderbox pilot station and nearby WWII naval battery at Fort Pierson/Oxley Lookout. Other sites include, for example: churches and cemeteries, apple packing shed and pickers' huts, sawyers camps, hotels and inns, houses and various additional structures and places. Heritage Tasmania is currently undertaking work to map the state-listed heritage places.

The Kingborough Planning Scheme Heritage Schedule includes sites listed on the former Australian Register of the National Estate and National Trust, as well state-listed sites and additional sites of local significance. A total of 87 sites is listed, with 23 of these located within the study area. Locally significant sites include the Oyster Cove Inn at Kettering and the former Barnes Bay Ferry Terminal on northern Bruny Island (~1954-1983) (Kingborough Council 2000). In the Huon Valley, a combined list for planning schemes and the THR recorded 274 sites, including 50 under assessment for the THR (GHD 2007), and ~70 in the study area. Both Kingborough and Huon Valley councils have performed mapping of heritage sites, although the Huon Valley mapping data are potentially outdated (B. Thompson, Huon Valley council, pers. comm.). Mapped council sites are presented in Figure 20 (left), with large sites mapped as regions and small sites as individual points. A very large heritage site located adjacent to the study area is the Kaoota to Margate Tramway, a site significant to the state and local region. In general, there is a need for heritage lists to be reviewed to reflect current national and state heritage listings and mapping data to be updated accordingly.

Maritime heritage is also important in the region, with shipwrecks recorded widely across the waterways. Shipwrecks older than 75 years are protected under Commonwealth and State legislation, while more recent shipwrecks may also be individually protected if they are considered to be significant. The Australian National Shipwreck Database documents 26 protected shipwrecks in the study area, including 21 sailing vessels wrecked primarily between 1831 and 1926, four motor vessels between 1936 and 1969 and one steamer in 1933 (SEWPaC 2009). The more recent wrecks documented comprised vessels constructed as early as 1886. The locations of shipwreck sites are displayed in Figure 20, although note that due to the absence of accurate historical records in most cases, positions are approximate only (M. Nash, Parks and Wildlife Service, pers. comm.). Artefacts remain at some wreck sites, while at others there is no remaining evidence of the vessels. Many of the wrecks involved small coastal transport or fishing vessels, with no major loss of life. However, just south of the D'Entrecasteaux Channel, the convict ship George III wrecked in 1835 with loss of 133 lives, while another large vessel lost in this area was the 248 tonne iron schooner Thuraka in 1929.

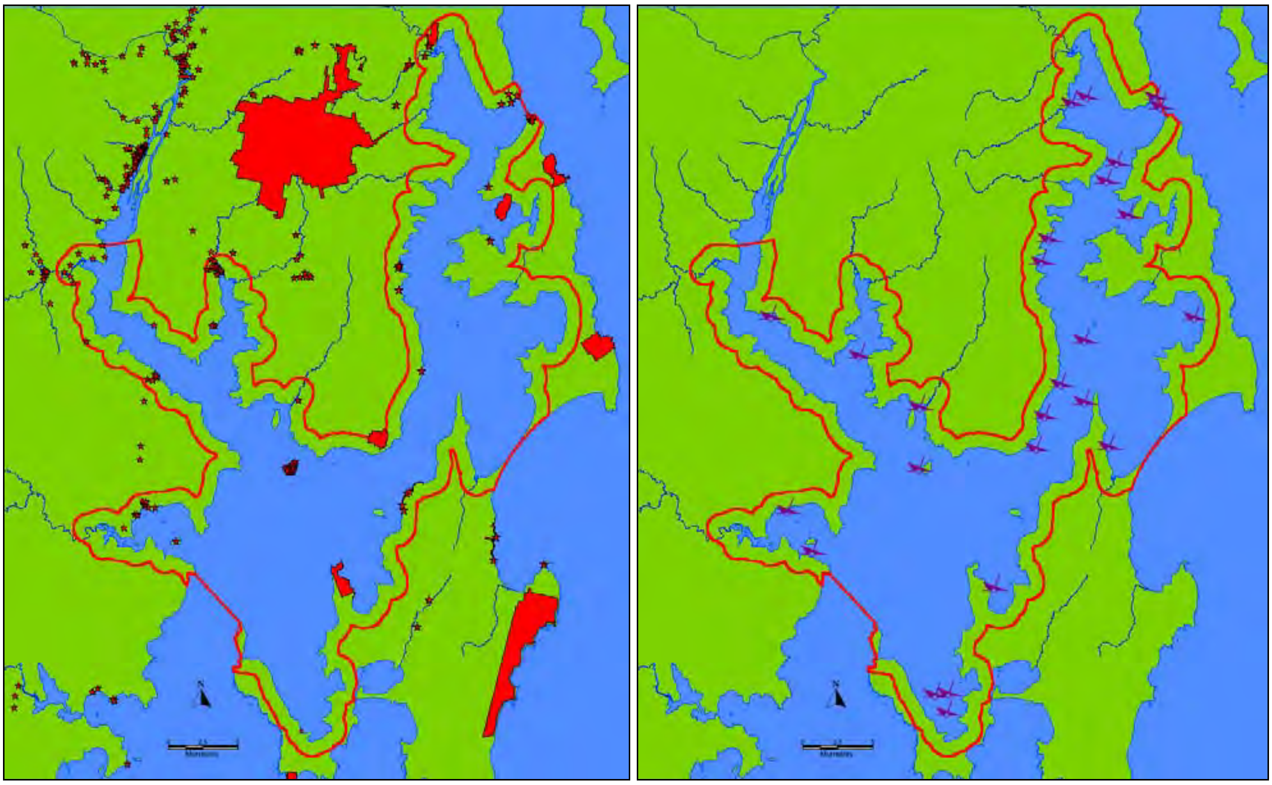


Figure 20 European heritage sites: land-based sites mapped by councils (Data source: Kingborough Council, Huon Valley Council) (left); and protected shipwrecks (Data source: SEWPaC 2009) (right).

4.2 Conservation areas

There are 45 gazetted reserves managed under the state reserve system within the study area, as listed in Table 7 and illustrated in Figure 21 (DPIPWE 2011b). These include the South Bruny National Park, Putalina Indigenous Protected Area, Bruny Island Neck Game Reserve and D'Entrecasteaux Monument Historic Site, as well as 12 conservation areas, six nature reserves, two nature recreation areas, three state reserves and a range of private reserves and informal reserves on public land. In many parts of the study area, a narrow band of informal public reserve forms a buffer between private land and the waterway. In addition to the marine protected areas (MPAs; see below), many of the other reserves also include marine habitats below the high tide mark as well as terrestrial habitats. Note that areas indicated in Table 7 relate to the entire reserve in each case, rather than to the portion occurring in the study area. For example, the largest reserve occurring partly in the study area was an informal public reserve on State Forest or Forestry Tasmania managed land (20,936 ha); however, only a very small portion of this reserve occurs near the coast. Several of the largest reserves within the study area include the Central Channel, Ninepin Point and Simpsons Point MPAs, the Coningham Nature Recreation Area, South Bruny National Park, and Bruny Island Neck Game Reserve.

The D'Entrecasteaux Channel and lower Huon Estuary fall within the Bruny Bioregion, one of nine Tasmanian marine bioregions that have been identified on the basis of distinct biological communities (Commonwealth of Australia 2006). An inquiry into MPAs was conducted for the Bruny Bioregion during 2006-2008, and led to the declaration of four new MPAs in the study area at Roberts Point, Simpsons Point, Central Channel and Port Cygnet, and expansions of two pre-existing reserves at Tinderbox and Ninepin Point (PWS 2012). This increased the total extent of MPAs in the study area from 115 ha as of 1991 to 5,045 ha in 2009. The extent of marine areas totally protected as 'no take' increased from 115 ha to 787 ha, while recreational fishing is permitted in the remaining 4,258 ha of waterway newly reserved in 2009. There has been evidence of poaching at both Ninepin Point and Tinderbox, the two longest standing MPAs in the region, although revised boundaries associated with reserve expansions in 2009 have reduced the potential for some poaching practices (N. Barrett, IMAS, pers. comm.).

Table 7 State reserves in the study area, including terrestrial and marine components (Data source: DPIPWE 2011b).

Name	Classification	Terrestrial (ha)	Marine (ha)
South Bruny National Park	National Park	2436.8	81.2
Port Cygnet Conservation Area	Conservation Area	6.5	-
Randalls Bay Conservation Area	Conservation Area	12.9	6.8
Cape de la Sortie Conservation Area	Conservation Area	19.1	7.8
Marks Point Conservation Area	Conservation Area	21.6	6.9
Surveyors Bay Conservation Area	Conservation Area	28.4	16.3
Chuckle Head Conservation Area	Conservation Area	113.6	76.2
Mount Royal Conservation Area	Conservation Area	128.7	-
Mountain Creek Conservation Area	Conservation Area	325.6	-
Central Channel Marine Conservation Area *	Conservation Area	-	3442.6
Port Cygnet Marine Conservation Area *	Conservation Area	-	103.1
Roberts Point Marine Conservation Area *	Conservation Area	-	138.6
Simpsons Point Marine Conservation Area *	Conservation Area	-	574.0
Peter Murrell Conservation Area	Conservation Area	142.9	-
Ninepin Point Marine Nature Reserve *	Nature Reserve	-	731.8
Tinderbox Marine Nature Reserve *	Nature Reserve	-	144.1
Green Island Nature Reserve	Nature Reserve	4.2	2.4
Tinderbox Nature Reserve	Nature Reserve	71.8	-
Dennes Hill Nature Reserve	Nature Reserve	92.0	-
Green Island Nature Reserve	Nature Reserve	4.2	2.4
Hope Island Nature Recreation Area	Nature Recreation Area	27.5	3.2
Coningham Nature Recreation Area	Nature Recreation Area	487.0	4.8
Putalina Indigenous Protected Area	Indigenous Protected Area	13.4	24.6
Echo Sugarloaf State Reserve	State Reserve	119.4	2.1
Quarantine Station State Reserve	State Reserve	127.3	3.7
Peter Murrell State Reserve	State Reserve	135.0	-
Bruny Island Neck Game Reserve	Game Reserve	1410.7	624.1
D'Entrecasteaux Monument Historic Site	Historic Site	0.4	0.6
14 reserves: 13 Conservation covenants, one Other Private Reserve	Private Reserves	707.8	-
3 reserves: one on State Forest or Forestry Tasmania managed land, two on other public land	Informal Public Reserves	22043.0	1.4

* = MPA

Figure 21 State reserves within the study area (Data source: DPIPWE 2011b).

4.3 Natural values

The D'Entrecasteaux Channel and lower Huon Estuary are partially enclosed bodies of water providing transitional areas between land and sea, and protection from the full force of ocean waves, winds and storms via promontories, islands, reefs and sandy spits. The highly indented coastline of the region combined with diverse geology has produced a myriad of habitats for marine and coastal organisms. These include beaches and dunes, rocky foreshores, saltmarshes and other wetlands, mud and sand flats, seagrass meadows, kelp forests and rocky reefs. Some of the estuarine and marine communities occurring in these areas are amongst the most productive types on earth, such as seagrasses and kelp beds, which may produce more organic matter per area than equivalent areas of forest and grassland. Fringing wetlands also provide valuable services, such as filtering sediments and pollutants from catchment runoff, and protecting the coast from erosion.

Many of the plants and animals are specially adapted for life at the margin of the sea, while fully marine species also find refuge amongst the sheltered habitats. Large numbers of birds, mammals, fish and invertebrates depend on the habitats of the D'Entrecasteaux Channel and lower Huon Estuary as places to live, feed and reproduce. Coastal vegetation provides key habitats for terrestrial fauna as well as marine species that breed on land, and includes threatened native communities that are of high conservation value in Tasmania. The natural values of the D'Entrecasteaux Channel and lower Huon Estuary are closely integrated with the social fabric of the region. People are attracted to the Channel and Huon for the many opportunities they offer, including aesthetics, recreational pursuits such as yachting, kayaking, fishing, scuba diving and bird watching, and simply being able to connect with the natural environment.

Natural values within the study area include aesthetic, geological, biological and habitat features, including many that are of regional, state or national significance and are protected in conservation reserves (Section 4.2) or through other legislation. Further information on these values is provided in various sections of this report; refer to geoconservation values in Section 2.3, habitats in Section 5 and threatened species, communities and other fauna and flora in Section 6.

5 HABITATS

5.1 *Subtidal and intertidal habitats*

The intertidal and subtidal (i.e. area below low water mark) zones in the D'Entrecasteaux Channel and lower Huon Estuary include a diverse range of substrates in areas ranging from high water mark to nearly 60 m depth (see Section 2.4). The open waterways and numerous bays within the region are subject to variable environmental conditions, based on changes in depth, currents and wind and wave exposure. These variables have a major influence on the composition on soft sediments, with high wave exposure and shallow depth favouring coarse sandy sediments, while low wave exposure and greater depth are associated with finer silty sediments. The study area is protected from oceanic swells by Bruny Island, as reflected by an index of wave exposure previously mapped for the region (Figure 22). It indicates that the majority of the Channel can be described as either sheltered or very sheltered, although the southern end and mouth of the Huon Estuary experience low to medium wave exposure (Barrett *et al.* 2001).

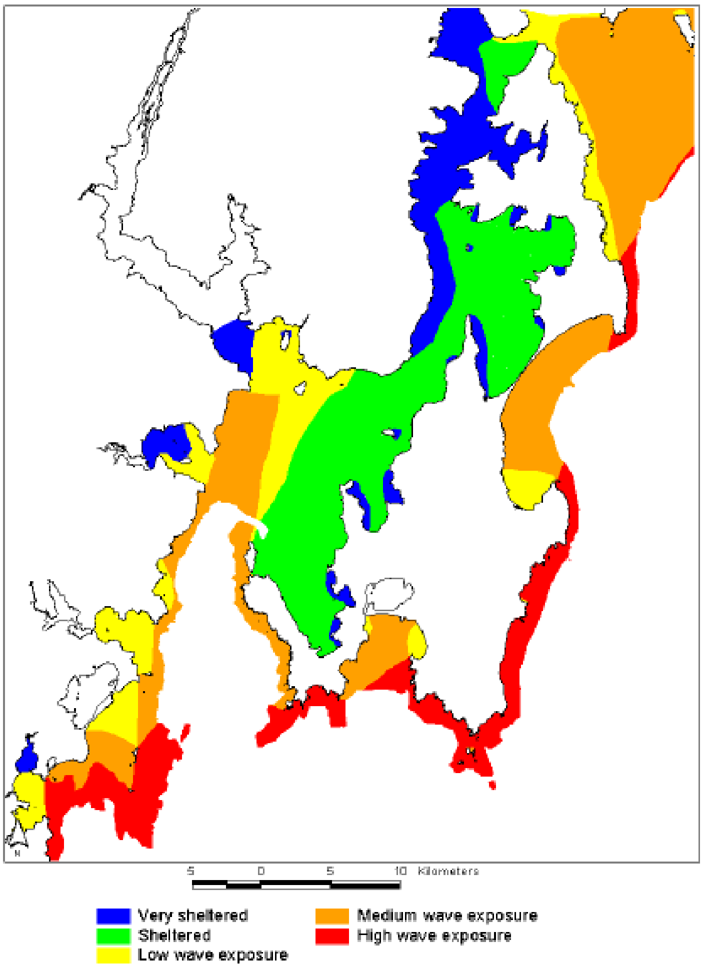


Figure 22 Wave exposure (Source: Barrett *et al.* 2001).

Seabed habitats have been mapped through the Seamap Program of the Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania. The total extent of the seabed mapped in the study area was 434 km^2. Findings indicate that unvegetated silty sand, hard sand, and other sands are the dominant substrate types and together comprise 80% of the seabed (Table 8, Figure 23). The remaining areas consist primarily of silt, with smaller areas of reef and seagrass fringing the coast. In most areas, sand usually extends to depths of 20 m, grading to silty sand between 20 and 30 m and to silt at depths beyond 30 m (Barrett *et al.* 2001). Fine silty sediments occur mainly in the northern part of the Channel, the deeper sections of North West Bay and the Huon Estuary, and an area of deep water in the southern Channel. Largest areas of seagrass were recorded on the coast between Woodbridge and Gordon and in North West Bay, with smaller beds in Port Esperance, Little Taylors Bay and several other areas. Low profile reefs are dispersed widely in the study area, while medium profile reefs occur mainly in the southern part of the Channel, particularly in the area from Port Esperance to the mouth of the Huon Estuary (IMAS 2012).

Table 8 Seabed habitats in the study area (Data source: Seamap, IMAS 2012).

Substrate	Area (km^2)	% of Mapped Area
Medium Profile Reef	3.54	0.8
Low Profile Reef	9.73	2.2
Patchy Reef	0.14	0.0
Hard Sand	120.57	27.8
Sand	97.06	22.4
Silty Sand	128.90	29.7
Silt	69.35	16.0
Seagrass	3.64	0.8
Patchy Seagrass	0.99	0.2
Total area mapped	**433.93**	

Intertidal habitats in the study area have been mapped as part of geomorphic studies included in an assessment of the coastal values of southern Tasmania (DTAE 2007). Mapping of shoreline types was performed for both the upper intertidal and lower intertidal, although for 24% of the coastline in the study area, the shoreline type did not change between these two zones. The results for the study area are presented on the basis of broad substrate categories in Figure 24, and reflect the presence of a diverse range of artificial, rocky, sandy, muddy and mixed substrates. Habitats range from prominent sea cliffs at the southern end of Bruny Island through to mud and sandflats in sheltered bays and estuarine environments. In both the lower and upper intertidal zones, consolidated rocky substrates are the dominant category and account for ~40% of the total shoreline length. Boulder/pebble habitats are also common, particularly in the upper intertidal zone, while they are sometimes replaced with sandflats in the lower part of the shore. Cliffs are prevalent along 11% of the coast, and frequently extend to the lower intertidal zone. Sandy beaches occupy ~12% of the upper shoreline, while muddy substrates contribute <10% of habitats. While there are numerous artificial structures along the foreshore (see Section 3.3), these account for a small total percentage of the coastline. A larger portion of habitats were simply classified as 'intertidal' or 'unknown' on the lower shore, due potentially to greater difficulty of ground truthing these areas during unfavourable tidal conditions.

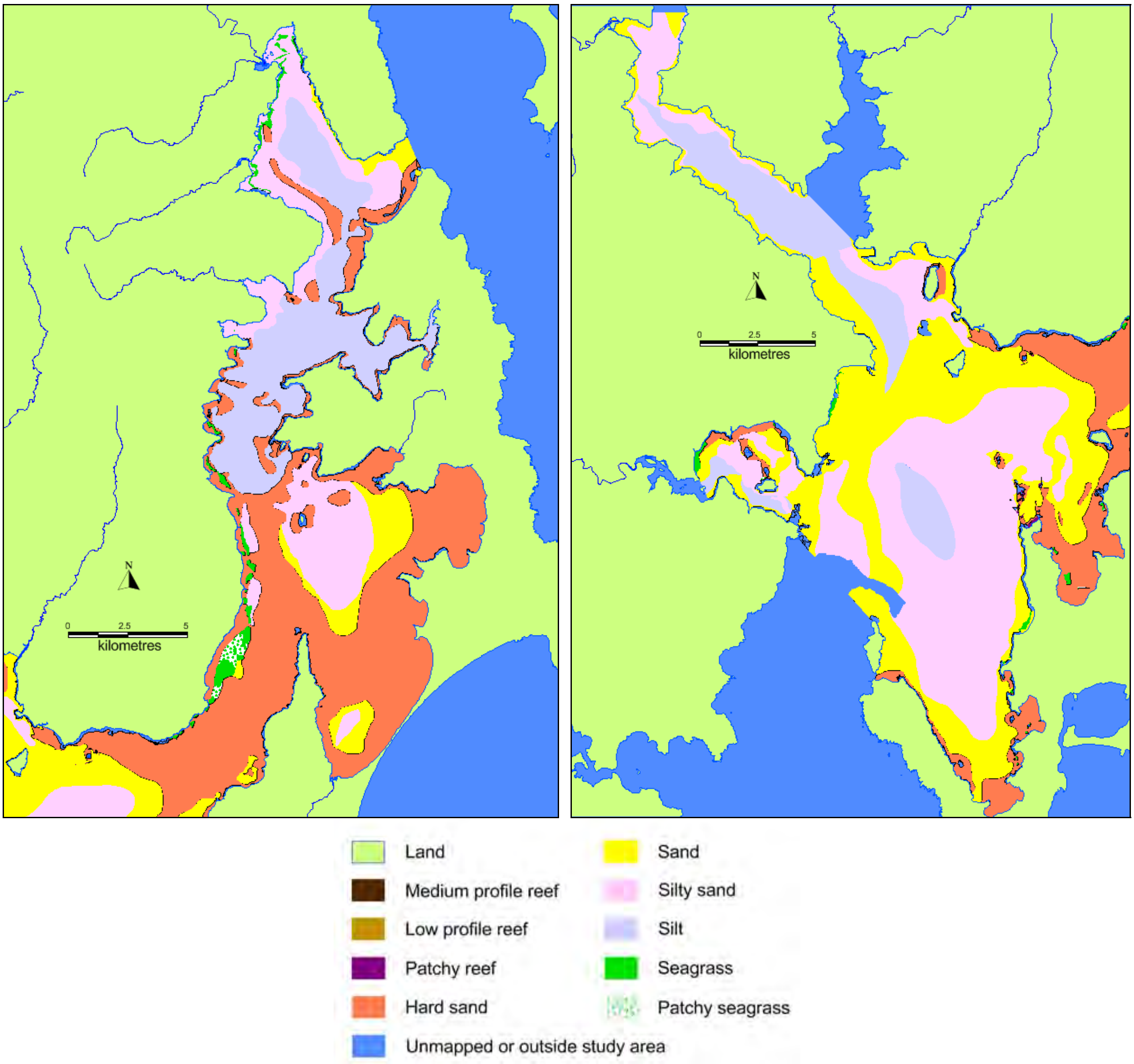


Figure 23 Seabed habitats (Data source: Seamap, IMAS 2012).

Figure 24 Intertidal shoreline types (Data source: DTAE 2007).

Assessment and mapping of intertidal zone values, condition and pressures in southern Tasmania, including the D'Entrecasteaux Channel and lower Huon Estuary, were commissioned by NRM South to better inform future management (Migus 2008). Seventeen electronic mapping layers were produced, which were used to grade the intertidal zone based on parameters such as biological values and conditions. Figure 25 provides a summary of the study area intertidal zone assessment for the key indices and indicates that a large portion of the intertidal zone is slightly modified, and has a high natural value. Nearly 90% of intertidal habitat is under slight-moderate pressure from human activities, whilst more than 50% is rated as moderate-very high for human use values.

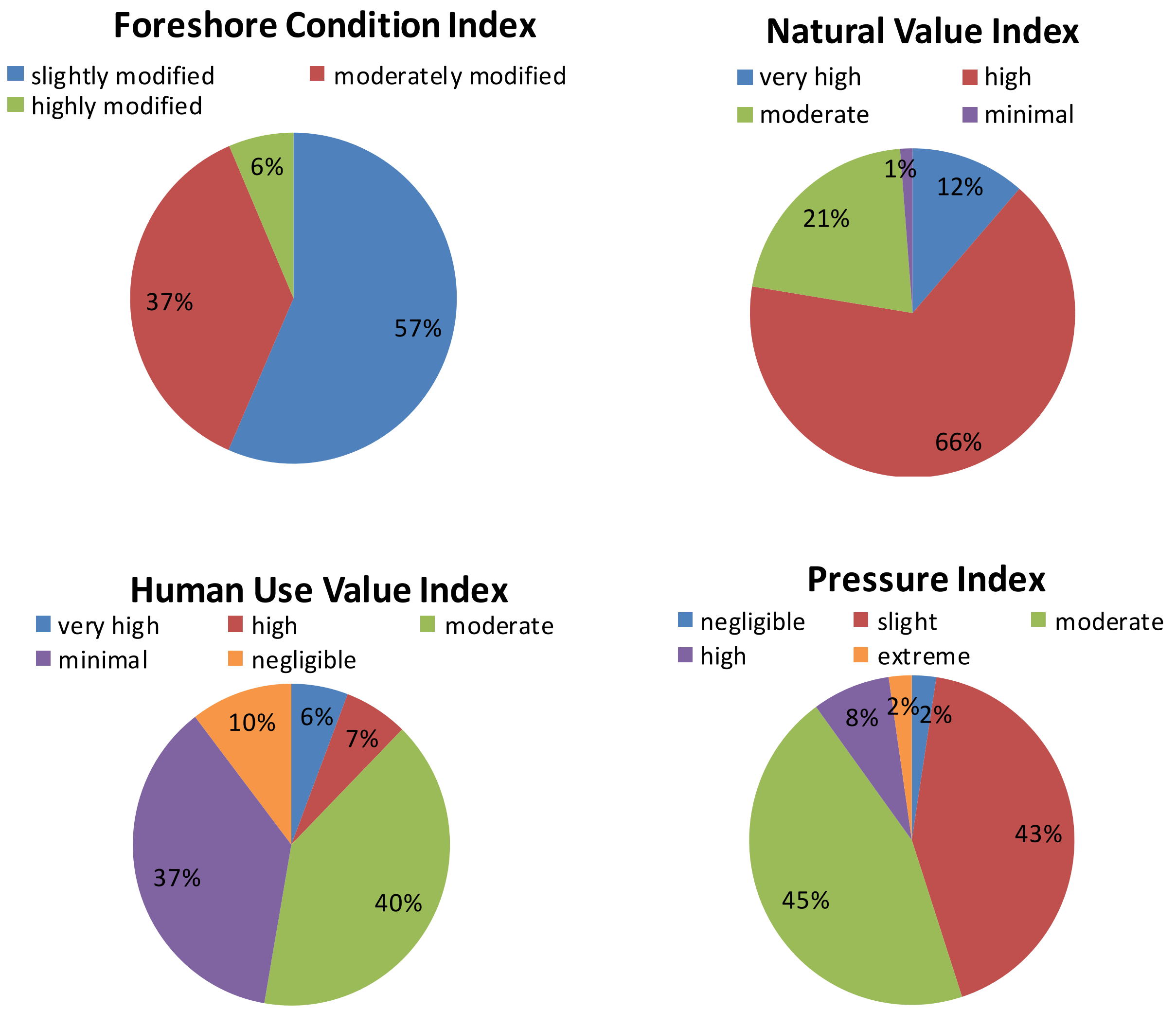


Figure 25 Intertidal habitat indices (Data source: Migus 2008).

Various factors have influenced the health of subtidal and intertidal habitats in the study area, resulting in changes in physical and chemical attributes of sediments and reduced biodiversity of seabed communities. It is likely that anthropogenic activities such as land clearance, forestry and agriculture in the Huon and Channel catchments have contributed to siltation in some parts of the waterway. Accumulation of silt has the potential to impact on public amenity, modify benthic fauna communities and degrade or displace algal and seagrass beds. Intensive scallop dredging in the Channel during 1925-1967 is also likely to have modified seabed habitats, and may have contributed to very high rates of invertebrate extinction in the region (Edgar and Samson 2004). Discharges from a former pulp mill at Port Huon appear to have had long-term consequences for sediment health in that area (Section 9.7.2), whilst inputs from fish farms and wastewater treatment plants may cause localised oxygen depletion and organic enrichment of the seabed. For further information on the health of seabed sediments, refer to Section 12.

The introduction of non-native species is also likely to have caused major changes to habitats, as introduced marine species can significantly alter the structural complexity and integrity of the seabed. A notable example has been the formation of extensive populations of the New Zealand screwshell *Maoricolpus roseus* in the D'Entrecasteaux Channel (see Section 7.2), which has resulted in changes to seabed and native community structure in some areas (Reid 2010). In the intertidal zone, foreshore development and runoff from stormwater outlets and septic systems may have direct impacts on the quality and physical characteristics of habitats.

5.2 Wetlands and saltmarshes

The highly indented coast of the D'Entrecasteaux Channel and lower Huon Estuary creates a range of sheltered environments that contain coastal wetlands, areas that are permanently or seasonally saturated with marine or brackish water. Saltmarshes are a particular type of wetland occurring on saline flats and estuarine areas fringing low energy coasts, and are characterised by a high cover of salt tolerant species. They are variously dominated by succulent shrubs (samphire), grasses, sedges, rushes or herbs. Saltmarshes and other wetlands provide valuable wildlife habitat, fish spawning grounds and nurseries, flood and erosion control, pollution abatement as well as visual and recreational amenities. Many wetland and saltmarsh plants actively regulate hydrology and also act as a natural filter, removing or attenuating silt, nutrients, pathogens, metals, and other pollutants (Whitehead *et al.* 2010).

Several wetlands in the study area are considered to be of particular conservation significance at national or state levels. The tidal flats at Oyster Cover are a listed site on the Directory of Important Wetlands in Australia (Blackhall *et al.* 2001), while the Port Cygnet Conservation Area includes wetland habitat that is significant at a statewide level. Some of the vegetation communities associated with wetlands and saltmarshes are categorised as threatened in Tasmania (see Section 6.2.1). Also, an earlier statewide investigation of saltmarshes suggested that the Lutregala Marsh at the southern end of Bruny Island Neck is of particularly high conservation significance due to species-rich invertebrate communities (Wong *et al.* 1993).

The Conservation of Freshwater Ecosystem Values (CFEV) Project mapped all known saltmarshes and wetlands and also assessed their naturalness and conservation value. Fifty-four wetlands were identified in the study area, occupying a total area of 2.95 km^2, while 43 saltmarshes identified occupy 1.88 km^2 (Table 9). The majority of the wetlands mapped occur at the northern and southern ends of Bruny Island Neck, while saltmarshes are concentrated in these areas and also in North West Bay, Port Cygnet, Port Esperance, and several other sheltered inlets. The condition status of each site was assessed using a naturalness score derived from information on various types of disturbance within and adjacent to the wetland or saltmarsh. The average naturalness scores for wetlands and saltmarshes in the study area were 0.71 and 0.84 respectively, which were rated as moderate within the potential range of 0-1 (poor-good condition), and indicative of significant (but not severe) alteration from natural condition (DPIW 2008a).

The CFEV project assessed the Integrated Conservation Value (ICV) and Immediate Conservation Management Priority (CMPI) of each wetland and saltmarsh. The ICV was based on special values and how representative the site was of a given biophysical class, while the CMPI was determined by integrating ratings for conservation value (ICV applied here), condition status (naturalness score) and land tenure security. Within the study area, nearly 50% of the mapped wetland habitat was rated as having a high ICV, while the remaining area was almost evenly divided between moderate and very high ICV categories (Table 9). At the same time, more than 40% of total wetland habitat was allocated a very high CMPI, with remaining habitat primarily rated as moderate or low. Contrasting results were recorded for saltmarshes, with the majority of habitat in the study area rated as being of moderate conservation value and management priority. On average, each wetland had ~2 special values, which included attributes such as phylogentically distinct fauna species (platypus), priority fauna and flora communities, threatened flora, priority limnological features, and high fauna species richness. None of these special values were identified in saltmarshes, although this may reflect a paucity of knowledge about these habitats.

Table 9 Wetland values and conservation priorities (Data source: DPIW 2008a).

Integrated Conservation Value	Wetlands			Saltmarshes		
	No.	Area		No.	Area	
		km^2	%		km^2	%
Very High	9	0.72	24	0	0	0
High	23	1.36	46	10	0.05	3
Moderate	16	0.85	29	33	1.82	97
Low	6	0.03	1	0	0	0
Conservation Management Priority						
Very High	26	1.24	42	8	0.04	2
High	3	0.02	1	2	0.01	1
Moderate	13	0.73	25	31	1.75	93
Low	12	0.97	33	2	0.07	4
TOTALS	**54**	**2.95**		**43**	**1.88**	

Saltmarsh habitats have been recognised to be particularly vulnerable to the effects of climate change and associated increases in sea-level and coastal erosion. Gradual landward retreat of saltmarshes is predicted, and hence ‘planned retreat’ or providing ‘room to move’ for coastal saltmarshes has been investigated. The likely extent of these habitats in the future, referred to as the ‘future saltmarsh footprint’, has been mapped for the D’Entrecasteaux Channel, Huon Estuary and other parts of the southern NRM region (Prahalad and Pearson 2012). This ‘saltmarsh futures’ mapping study identified four saltmarsh ‘complexes’ in the study region including the D’Entrecasteaux Channel, North West Bay, Huon-Port Cygnet and Port Esperance coastal complexes, with each containing a number of smaller saltmarsh ‘clusters’. Factors that may impede the potential retreat of saltmarshes, or impact in other ways on their long-term sustainability, include agricultural land clearing, construction of adjacent roads and housing areas, weeds and littering, four wheel driving, obstructions to tidal movement, and land filling. The total area of saltmarshes recorded within the study area was 1.2 km^2, which represents a 0.7 km^2 reduction compared with earlier CFEV mapping. However, the CFEV project was essentially a desktop assessment, while the saltmarsh futures mapping project included ground truthing. On the basis of the different techniques employed, it is therefore not possible to make a definitive assessment of temporal changes in the areal extent of saltmarsh communities.

6 NATIVE SPECIES

6.1 *Marine, estuarine and coastal fauna*

6.1.1 Threatened fauna species

Species listed as threatened either at a state level, in accordance with the Tasmanian *Threatened Species Protection Act 1995* (TSPA), and/or at a national level, in accordance with the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC), occur within the study area. As listed in Table 10, 23 threatened fauna species visit or inhabit the study area. Threatened resident species in marine and estuarine habitats include the spotted handfish (Endangered), live-bearing seastar, Gunn's screw shell, fairy tern (all Vulnerable), and the seastar *Smilasterias tasmaniae* (Rare). Seasonal visitors include the humpback and southern right whales (Endangered), while the southern elephant seal (Endangered) and great white shark (Vulnerable) are recorded occasionally, and the Australian grayling (Vulnerable) resides in freshwater habitats but includes a juvenile marine/estuarine phase. The New Zealand fur seal (Rare) is noted as interacting with fish farming activities, but does not have any breeding or major haul out sites within the region.

Table 10 Threatened fauna (Source: DPIPWE 2012a, unpub. data; SEWPaC 2012).

Scientific Name	Common name	Status	
		Tas	Aust
Accipiter novaehollandiae	grey goshawk	E	-
Carcharodon carcharias	great white shark	V	V
Ceyx azureus subsp. *diemenensis*	Tasmanian azure kingfisher	E	E
Antipodia chaostola subsp. *leucophaea*	Tasmanian chaostola skipper	E	E
Aquila audax subsp. *fleayi*	wedge-tailed eagle	E	E
Brachionichthys hirsutus	spotted handfish	E	E
Dasyurus maculatus subsp. *maculatus*	spotted-tailed quoll	R	V
Eubalaena australis	southern right whale	E	E
Haliaeetus leucogaster	white-bellied sea-eagle	V	-
Lathamus discolor	swift parrot	E	E
Lissotes menalcas	Mt Mangana stag beetle	V	-
Megaptera novaeangliae	humpback whale	E	V
Mirounga leonina	southern elephant seal	E	V
Arctocephalus forsteri	New Zealand fur seal	R	-
Pardalotus quadragintus	forty-spotted pardalote	E	E
Parvulastra vivipara	live–bearing seastar	V	-
Perameles gunnii subsp. *gunnii*	eastern-barred bandicoot	-	V
Prototroctes maraena	Australian grayling	V	V
Sarcophilus harrisii	Tasmanian devil	E	E
Smilasterias tasmaniae	seastar	R	-
Sterna nereis subsp. nereis	fairy tern	V	V
Tyto novaehollandiae subsp. *castanops*	masked owl	E	V
Gazameda gunnii	Gunn's screwshell	V	-

E=Endangered; V=Vulnerable, R=Rare

Some of the threatened species in this region are endemic (i.e. unique) to Tasmania, or to small regions of the state. The Bruny Bioregion (see Section 4.2) is characterised by a very high level of endemic marine species, and this is demonstrated in the D'Entrecasteaux Channel by the presence of three marine benthic species found only in south-east Tasmania: the spotted handfish, live-bearing seastar and seastar *S. tasmaniae*. The spotted handfish occurs primarily in the Derwent Estuary, but has recently been recorded in North West Bay (DPIPWE 2012a) and is also reported near the northern entrance of the Channel (Cochran 2003). This species is believed to have once been more widespread in the D'Entrecasteaux Channel, and may have been impacted by historic scallop dredging (Spotted Handfish Recovery Team 2002). Local extinction of the live-bearing seastar has also been reported in the vicinity of Howden and attributed to coastal development (Rowland 2000). Declines of another threatened marine benthic species, Gunn's screwshell, are thought to be associated with the spread of the introduced New Zealand screwshell *Maoricolpus roseus* (Bax *et al.* 2003).

Terrestrial threatened endemic species include the forty-spotted pardalote, chaostola skipper, Tasmanian devil, Tasmanian subspecies of the wedge-tailed eagle, masked owl and azure kingfisher (all Endangered) and the Mt Mangana stag beetle (Vulnerable). More detailed information on these species and other threatened fauna listed in Table 10 is provided, for example, in the Tasmanian threatened fauna handbook (Bryant and Jackson 1999) and a publication on managing threatened species and communities on Bruny Island (Cochran 2003).

Several studies have been recently conducted to assess the status of Endangered animal species in the D'Entrecasteaux Channel region. Populations of the forty-spotted pardalote were surveyed in 2009, with counts indicating major declines in numbers since the 1990s (refer to Section 6.1.3). At the present rate of decline, there is a risk that this species could be extinct within 10 years (Bryant 2010). A separate study mapped habitats and populations of the chaostola skipper, an Endangered butterfly species reliant on the sedge plant *Gahnia radula* for food, and found largely in the threatened vegetation community '*Eucalyptus amygdalina* forest and woodland on sandstone' (refer to Section 6.2.2). Within the D'Entrecasteaux Channel region, the project extended the known range of the skipper in the Peter Murrell State Reserve; however, this species could not be relocated at some previously known sites at Coningham. The study raised concerns about the long-term viability of the Coningham population and suggested that a destructive fire in 2008 may account for recent population losses (Threatened Species Section 2012). Surveys of the Endangered swift parrot have also been undertaken and, within the study area, recorded the highest numbers of parrots in the lower Huon Estuary and southern part of Bruny Island (Webb 2008). There have been few recent investigations of threatened marine species in the study area, although some baseline data have been collected for the live-bearing seastar (Rowland 2000). An additional study incorporating rare marine species has been initiated, however data analysis and the intertidal component of the survey work are currently incomplete (N. Barrett, IMAS, pers. comm.).

A coastal values study for southern Tasmania assessed the significance of fauna in the coastal strip between mean high water mark and 100 m inland. Mapping was performed by creating polygons within this strip and allocating values to each polygon based on the conservation status of recorded threatened species, the presence of potential habitat for these species, and also migratory birds listed under the EPBC Act. Ratings of 1 to 4 from highest through to lowest significance were applied, although even '4' was indicative of sensitive breeding habitat for non-threatened species or foraging habitat of listed species (DTAE 2007). As illustrated in Figure 26, more than 80% of the mapped coastline was allocated the highest rating possible for fauna significance, reflecting the importance of the region's coast for the swift parrot and other Endangered species.

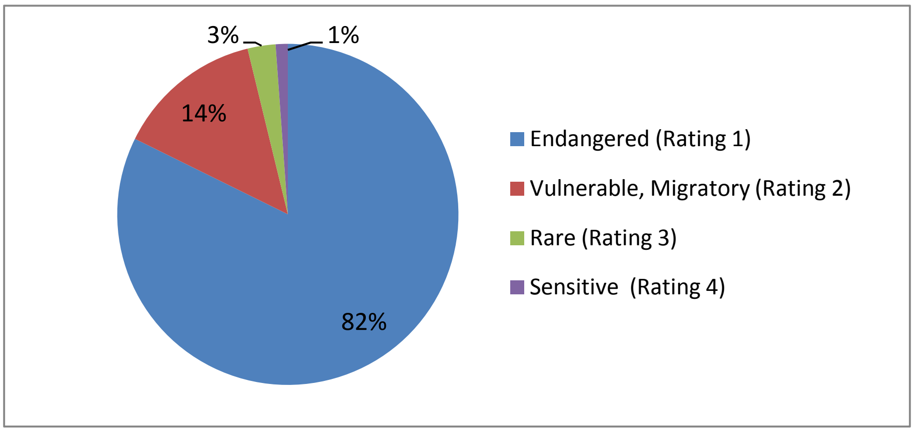


Figure 26 Foreshore habitat fauna significance (Data source: DTAE 2007).

6.1.2 Fish

Approximately 150 native fish species have been documented in the D'Entrecasteaux Channel and lower Huon Estuary, and adjacent coastal streams, as listed inTable 11. This updated list includes 31 additional species not listed in the previous 1999 State of the D'Entrecasteaux Channel report, but this may simply reflect greater availability of data rather than temporal changes. Note that several introduced fish species also occur in the area, including the Atlantic salmon *Salmo salar* (farm escapees), the many-rayed threefin *Forsterygion varium* believed to be introduced from New Zealand, and the brown trout *Salmo trutta* in coastal streams. The distribution of fish species depends primarily on their tolerance to salinity changes and available habitat. The fish communities in the region can be broadly classified as i) pelagic (living in the mid water column), ii) demersal (bottom dwelling on soft sediments), and iii) reef species. Some species, such as flathead (typically associated with soft sediments) and wrasse (reef dwellers) are permanent residents, while others are transitory or seasonal migrants. Some species perform seasonal migratory 'runs' between marine, estuarine and freshwater environments, such as the threatened Australian grayling and also brown trout, *Galaxias* species, black bream, yellow eyed mullet, Tasmanian whitebait, shortfinned eel and short-headed lamprey. For migratory fish, environmental conditions in all parts of their habitat range are critical for sustaining populations.

Common reef fish include the blue throated wrasse, bastard trumpeter, senator wrasse, toothbrush leatherjacket, barber perch, blotch-tail hulafish, common bullseye and blue warehou. Quantitative surveys of reef fish during 1992-2002 compared protected sites at the Tinderbox and Ninepin Point MPAs with adjacent fished sites. Over the duration of the study, the total abundance of large fishes (≥300 mm length) increased approximately 10-fold within the Tinderbox reserve while remaining stable at fished sites. The bastard trumpeter accounted largely for the upward trend at protected sites, but increases in other species such as the blue throated wrasse were also recorded. The species richness of large fishes displayed a similar trend, with the number of species showing a significantly greater increase within the reserve than at fished sites (Figure 27). When all sizes of fish were considered, little change was detected in the overall species richness of fish assemblages at Tinderbox (Barrett *et al.* 2007). These results indicate that fishing was impacting on the abundance of larger fishes, most notably bastard trumpeter, on inshore coastal reefs in this region.

Table 11 Native fish species (Source: Phillips 1999, Krasnicki and Graham 2001, Allen *et al*. 2002, Jordan *et al*. 2002).

Scientific Name	Common Name	Scientific Name	Common Name
Acanthaluteres spilomelanurus	bridled leatherjacket	*Leptatherina presbyteroides*	small-mouthed hardyhead
Acanthaluteres vittiger	toothbrush leatherjacket	*Lesueurina platycephala*	common sandfish
Acanthopagrus butcheri	black bream	*Lophonectes gallus*	crested flounder
Afurcagobius tamarensis	Tamar goby	*Lotella rhacina*	beardie
Alabes dorsalis	common shore-eel	*Lovettia sealii*	Tasmanian whitebait
Aldrichetta forsteri	yellow eyed mullet	*Meuschenia australis*	brown striped leatherjacket
Allomycterus pilatus	porcupine fish	*Meuschenia freycineti*	six-spined leatherjacket
Ammotretis lituratus	spotted flounder	*Meuschenia scaber*	velvet leatherjacket
Ammotretis rostratus	long snouted flounder	*Mitotichthys mollisoni*	Mollison's pipefish
Anguilla australis	shortfinned eel	*Mitotichthys semistriatus*	halfbanded pipefish
Anguilla reinhardtii	long finned-eel	*Mordacia mordax*	short headed lamprey
Aplodactylus arctidens	marble fish	*Mustelus antarcticus*	gummy shark
Aracana aurita	Shaw's cowfish	*Myliobatis australis*	eagle ray
Arenigobius bifrenatus	bridled goby	*Nemadactylus macropterus*	jackass morwong
Argentia australiae	silverside	*Neochanna cleaveri*	Australian mudfish
Arripis trutta	eastern Australian salmon	*Neoodax balteatus*	little rock whiting
Asymbolus sp.d	orange spotted catshark	*Neosebastes scorpaenoides*	ruddy gurnard perch
Atherinosoma microstoma	hardyhead	*Neosebastes thetidis*	theitis fish
Atypichthys strigatus	mado sweep	*Neosgobius* sp.1	goby
Bovichtus angustifrons	dragonet	*Neosgobius* sp.3	goby
Brachaluteres jacksonianus	southern pygmy leatherjacket	*Neosgobius* sp.6	goby
Brachionichthys hirsutus	spotted handfish	*Nesogobius hinsbyi*	orange-spotted goby
Caesioperca lepidoptera	butterfly perch	*Nesogobius pulchellus*	girdled goby
Caesioperca rasor	barber perch	*Notolabrus fucicola*	purple wrasse
Callorhinchus milii	elephant fish	*Notolabrus tetricus*	blue throated wrasse
Carcharodon carcharias	great white shark	*Notopogon lilliei*	crested bellows fish
Cephaloscyllium laticeps	draughtboard shark	*Notorynchus cepedianus*	seven gilled shark
Cheilodactylus nigripes	magpie perch	*Odax cyanomelas*	herring cale
Chelidonichthys kumu	red gurnard	*Omegophora armilla*	ringed toadfish
Conger verreauxi	southern conger eel	*Parablennius tasmanianus*	blenny
Contusus brevicaudus	prickly toadfish	*Parapercis allporti*	barred grubfish
Contusus richei	barred toadfish	*Parascyllium ferrugineum*	rusty catshark
Crapalatus munroi	pink sandfish	*Parequula melbournensis*	silverbelly
Cristiceps australis	silver dory	*Pavoraja nitida*	peacock skate
Cyttus novaezealandiae	New Zealand dory	*Pempheris multiradiata*	common bullseye
Dasyatis thetidis	black stingray	*Pentaceropsis recurvirostris*	long snouted boarfish
Dinolestes lewini	long-finned pike	*Phyllopteryx taeniolatus*	common seadragon
Diodon nicthemerus	globe fish	*Pictilabrus laticlavius*	senator wrasse
Dipturus cerva	white spotted skate	*Platycephalus bassensis*	sand flathead
Dipturus sp. A	long nosed skate	*Platycephalus richardsoni*	tiger flathead
Dipturus whitleyi	Whitley's skate	*Pristiophorus nudipinnis*	southern sawshark
Dotalabrus aurantiacus	castlenau's wrasse	*Prototroctes maraena*	Australian grayling
Emmelichthys nitidus	redbait	*Pseudaphritis urvillii*	freshwater flathead
Engraulis australis	Australian anchovy	*Pseudocaranx dentex*	silver travally
Eubalichthys gunnii	Gunn's leatherjacket	*Pseudogobius olorum*	blue-spotted goby
Eubalichthys mosaicus	mosaic leatherjacket	*Pseudolabrus rubicundus*	rosy wrasse
Foetorepus calauropomus	common stinkfish	*Pseudophycis bachus*	red cod
Galaxias maculatus	common jollytail	*Pseudophycis barbatus*	bearded red cod
Galaxias truttaceus	spotted mountain galaxias	*Pterygotrigla polyommata*	latchet
Galeorhinus galeus	school shark	*Rhombosolea tapirina*	greenback flounder
Genypterus tigerinus	rock ling	*Sardinops neopilchardus*	pilchard
Gnathagnus innotabilis	bulldog stargazer	*Scorpaena papillosa*	southern red scorpioncod
Gnathanacanthus goetzeei	red velvet fish	*Scorpis lineolata*	sweep
Goniistius spectabilis	banded morwong	*Seriolella brama*	blue warehou
Gymnapistes marmoratus	soldierfish	*Sillago flindersi*	eastern school whiting
Haletta semifasciata	blue rock whiting	*Siphonognathus beddomei*	pigmy rock whiting
Helicolenus percoides	red gurnard perch	*Sphyraena novaehollandiae*	short-finned seaspike
Heptranchias perlo	seven-gilled shark	*Squalus acanthias*	white spotted dogfish
Heteroclinus adelaidae	Adelaide weedfish	*Squalus megalops*	piked dogfish
Heteroclinus perspicillatus	common weedfish	*Stigmatopora nigra*	widebody pipefish
Heteroclinus puellarum	the girls' weedfish	*Taratretis derwentensis*	Derwent flounder
Heterodontus portusjacksoni	Port Jackson shark	*Tasmanogobius lasti*	lagoon goby
Hippocampus abdominalis	pot bellied seahorse	*Tetractenos glaber*	smooth toadfish
Hydrolagus ogilbyi	Ogilby's ghost shark	*Thyrsites atun*	barracouta
Hyporhamphus melanochir	southern sea garfish	*Torpedo macneilli*	torpedo ray
Kathetostoma canaster	speckled stargazer	*Trachinops caudimaculatus*	blotch-tail hulafish
Kathetostoma laeve	common stargazer	*Trachurus declivis*	jack mackerel
Kestratherina esox	pikehead hardyhead	*Trinorfolkia clarkei*	Clarke's threefin
Latridopsis forsteri	bastard trumpeter	*Upeneichthys vlamingii*	blue-spotted goatfish
Latris lineata	striped trumpeter	*Urolophus cruciatus*	banded stingaree
Lepidotrigla modesta	grooved gurnard	*Urolophus paucimaculatus*	sparslely spotted stingaree
Lepidotrigla mulhalli	round-snouted gurnard	*Vanacampus phillipi*	Port Phillip pipefish
Lepidotrigla papilio	round snouted gurnard	*Vanacampus poecilolaemus*	long-snouted pipefish
Lepidotrigla vanessa	butterfly gurnard	*Vincentia conspersa*	southern cardinal fish

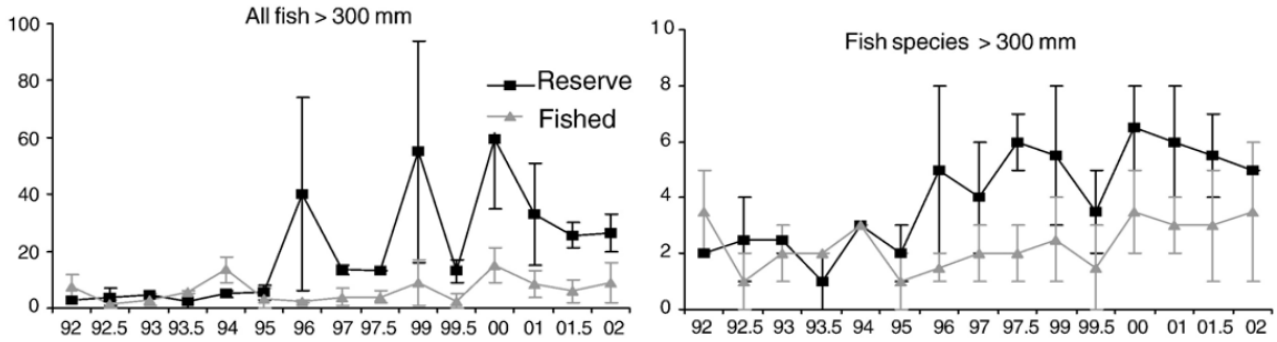


Figure 27 Mean abundance (left) and species richness (right) of large fishes at Tinderbox (Source: Barrett *et al.* 2007).

Changes at Ninepin Point were less noticeable, although the overall abundance of the blue throated wrasse declined by 50% at fished sites during the study while remaining stable within the reserve. This change did not appear to be related to changes in the abundance of larger fishes subject to fishing. The blotch-tail hulafish was the only other species to display a notable pattern in abundance over this period, undergoing a 10-fold increase at both reserve and reference locations between 1992 and 2002. The failure of bastard trumpeter to recover within the reserve was attributed to the small size of the reserve (note: the reserve has now increased in size; see Section 4.2) and heavy recreational gillnet fishing at reserve boundaries (Barrett *et al.* 2007). Note that the D'Entrecasteaux Channel and Huon Estuary are now part of a shark refuge area and hence various restrictions on fishing apply, although recreational gillnetting over a reduced duration of two hours (i.e. instead of the standard six hours) is permitted in most of the region (DPIPWE 2011a).

Seagrass beds are an important habitat for many fish, particularly small resident species such as the bridled leatherjacket and pipefishes. Seagrass is generally not an important nursery habitat for major commercial and recreational fish species, but is important for the overall diversity of fish communities. Unvegetated areas are important habitat for many demersal fish species in the region, although the community present often differs between sand and silt habitats. Dominant fish species are likely to include flounders, leatherjackets, atherinids, mullets and eastern Australian salmon. Both adults and juveniles occur in these habitats indicating that they serve a nursery function as well as feeding ground for later life stages. Based on results for deep (>10 m) unvegetated habitats in adjacent parts of southern Tasmania, leatherjackets, gurnards, skates and stingarees are likely to be dominant species (Jordan *et al.* 2002).

6.1.3 Birds

A wide variety of birds depend upon the diverse environments of the D'Entrecasteaux Channel and lower Huon Estuary, including birds categorised broadly as waders, waterfowl, seabirds, woodland/forest birds and raptors. Estuarine and coastal habitats of particular importance to birds in the study area include dunes, sandy beaches, rocky intertidal outcrops, wetlands and tidal flats in sheltered embayments. The area is primarily of significance for resident species, and provides important breeding habitat for a range of endemic, threatened and other high conservation value species. It has not been identified as an important area for migratory shorebirds; however, several species have been recorded in the area, including the whimbrel, grey-tailed tattler, bar-tailed godwit, red-necked stint, ruddy turnstone and double-banded plover (DPIWE 2000, Bryant 2002).

A native bird list for the study area and adjacent environs is provided in Table 12 and includes 127 species, while eight introduced species have also been recorded. This list is an update of a version provided for the D'Entrecasteaux Channel in 1999, with supplementary information obtained primarily from the Tasmanian Natural Values Atlas (DPIPWE 2012a), a conservation assessment for Tasmanian shorebirds (Bryant 2002), and a management plan covering Green Island, Waterfall Creek and the South Bruny National Park (DPIWE 2000). While the latter plan includes some areas outside the immediate study area, it is likely that species included will occur at least as visitors to the adjacent D'Entrecasteaux Channel. The revised list greatly expands the 1999 list of 34 species, although increased numbers are a likely reflection of improved data resources rather than changes in species richness. Additional species are likely to occur periodically in the study area; for example the total number of species recorded on Bruny Island is 150 (Cochran 2009).

All twelve endemic Tasmanian bird species are found in the region (Table 12), while three out of four additional endemic subspecies have also been recorded. The endemic forty-spotted pardalote *Pardalotus quadragintus* is of special significance in the D'Entrecasteaux Channel, with the majority of known breeding areas occurring on Bruny Island and around Coningham, Howden and Tinderbox (Bryant 2010). A national project conducted during 2005-2009 to identify Important Bird Areas (IBAs) containing sites of global bird conservation importance identified two IBAs of relevance to the study area (Dutson *et al.* 2009). The Bruny Island IBA was recognised as containing the world's largest population of the Endangered forty-spotted pardalote *P. quadragintus*, up to one third of the world population of the Endangered swift parrot *Lathamus discolour*, and nearly all of Tasmania's endemic bird species. The Huon Estuary and mainland coast of the D'Entrecasteaux Channel formed part of the South-east Tasmania IBA, an area also identified as having a large proportion of the populations of threatened and restricted range species.

In addition to endemic fauna and seven threatened bird species (see Section 6.1.1), a number of coastal bird species not formally recognised as threatened are nevertheless considered to be of high conservation value (Table 12, Bryant 2002). These include non-breeding migratory species as well as 13 resident/migratory breeding species recorded in the region. Sites of particular importance include Great Bay and Bruny Island Neck, which each support a high diversity of resident shorebirds, and Green Island which supports a high diversity of breeding species (Bryant 2002). Green Island contains breeding habitat for five high conservation value species, including the caspian tern, crested tern, Pacific gull, pied oystercatcher and sooty oystercatcher, as well as breeding populations of the kelp gull and silver gull (DPIWE 2000). Other islands supporting populations of breeding shorebirds include Arch Rock, Curlew Island and Snake Island (Bryant 2002). Some islands have been severely degraded; for example, much of the native vegetation of Green Island has been lost as a result of previous agricultural uses, and the island is now treeless and infested with weeds (DPIWE 2000).

The region is particularly important for the pied oystercatcher *Haemotopus longirostris*, with high numbers contributing to the identification of the above two IBAs, and for another beach nesting species, the hooded plover *Thinornis rubricollis*. Mapping of the presence or absence of breeding habitat within 100 m segments of the shoreline throughout the study area identified a total of ~38 km of breeding coastline for each of these species (Birds Tasmania 2008). All breeding habitat was identified on the western shores of Bruny Island, highlighting this coast as having a lower level of disturbance. Additional important species are the little penguin *Eudyptula minor*, which breeds around several islands, Bruny Island Neck, and northern shores around Tinderbox, Howden and Coningham (see below), and the muttonbird or short-tailed shearwater *Puffinus tenuirostris* which breeds on Huon Island and at Bruny Island Neck (Birds Tasmania 2008).

Table 12 Native bird species (Source: DPIWE 2000, Bryant 2002, DPIPWE 2012a).

Scientific Name	Common Name	Status	*Scientific Name*	Common Name	Status
Acanthiza chrysorrhoa	yellow-rumped thornbill		*Lathamus discolor*	swift parrot	T
Acanthiza ewingii	Tasmanian thornbill	En	*Lichenostomus flavicollis*	yellow-throated honeyeater	En
Acanthiza pusilla	brown thornbill		*Limosa lapponica*	bar-tailed godwit	C, M
Acanthorhynchus tenuirostris	eastern spinebill		*Malurus cyaneus*	superb fairy-wren	
Acanthornis magnus	scrubtit	En	*Manorina melanocephala*	noisy miner	
Accipiter cirrhocephalus	collared sparrowhawk		*Megalurus gramineus*	little grassbird	
Accipiter fasciatus	brown goshawk		*Melanodryas vittata*	dusky robin	En
Accipiter novaehollandiae	grey goshawk	T	*Melithreptus affinis*	black-headed honeyeater	En
Aegotheles cristatus	Australian owlet-nightjar		*Melithreptus validirostris*	strong-billed honeyeater	En
Anas castanea	chestnut teal		*Morus serrator*	Australasian gannet	C
Anas gracilis	grey teal		*Myiagra cyanoleuca*	satin flycatcher	
Anas rhynchotis	Australasian shoveler		*Neophema chrysostoma*	blue-winged parrot	
Anas superciliosa	pacific black duck		*Ninox novaeseelandiae*	southern boobook	
Anthochaera chrysoptera	little wattlebird		*Numenius phaeopus*	whimbrel	C, M
Anthochaera paradoxa	yellow wattlebird	En	*Oceanites oceanicus*	Wilson's storm-petrel	
Anthus novaeseelandiae	Richard's pipit		*Pachycephala olivacea*	olive whistler	
Apus pacificus	fork-tailed swift		*Pachycephala pectoralis*	golden whistler	
Aquila audax	wedge-tailed eagle	T	*Pardalotus punctatus*	spotted pardalote	
Ardea alba	great egret		*Pardalotus quadragintus*	forty-spotted pardalote	En, T
Ardea ibis	cattle egret		*Pardalotus striatus*	striated pardalote	
Arenaria interpres	ruddy turnstone	C, M	*Pelecanoides urinatrix*	common diving-petrel	
Artamus cyanopterus	dusky woodswallow		*Pelecanus conspicillatus*	Australian pelican	C
Biziura lobata	musk duck		*Petroica multicolor*	scarlet robin	
Cacatua roseicapilla	galah		*Petroica phoenicea*	flame robin	
Cacomantis flabelliformis	fan-tailed cuckoo		*Petroica rodinogaster*	pink robin	
Calamanthus fuliginosus	striated fieldwren		*Pezoporus wallicus*	ground parrot	
Calidris ruficollis	red-necked stint	C, M	*Phalacrocorax carbo*	great cormorant	
Calyptorhynchus funereus	yellow-tailed black-cockatoo		*Phalacrocorax fuscescens*	black-faced cormorant	C
Ceyx azureus subsp. *diemenensis*	Tasmanian azure kingfisher	T	*Phalacrocorax melanoleucos*	little pied cormorant	
Charadrius bicinctus	double-banded plover	C, M	*Phalacrocorax sulcirostris*	little black cormorant	
Charadrius ruficapillus	red-capped plover	C	*Phaps chalcoptera*	common bronzewing	
Chenonetta jubata	Australian wood duck		*Phaps elegans*	brush bronzewing	
Chrysococcyx basalis	horsfield's bronze-cuckoo		*Phylidonyris melanops*	tawny-crowned honeyeater	
Chrysococcyx lucidus	shining bronze-cuckoo		*Phylidonyris novaehollandiae*	new holland honeyeater	
Circus approximans	swamp harrier		*Phylidonyris pyrrhoptera*	crescent honeyeater	
Colluricincla harmonica	grey shrike-thrush		*Platycercus caledonicus*	green rosella	En
Columba livia	rock dove		*Platycercus eximius*	eastern rosella	
Coracina novaehollandiae	black-faced cuckoo-shrike		*Podargus strigoides*	tawny frogmouth	
Corvus tasmanicus	forest raven		*Poliocephalus poliocephalus*	hoary-headed grebe	
Coturnix ypsilophora	brown quail		*Porphyrio phorphyrio*	purple swamphen	
Cracticus torquatus	grey butcherbird		*Porzana tabuensis*	spotless crake	
Cuculus pallidus	pallid cuckoo		*Puffinus griseus*	sooty shearwater	C
Cygnus atratus	black swan		*Puffinus tenuirostris*	short-tailed shearwater	C
Diomedea cauta	shy albatross		*Rallus pectoralis*	Lewin's rail	
Egretta novaehollandiae	white-faced heron		*Rhipidura fuliginosa*	grey fantail	
Elseyornis melanops	black-fronted dotterel		*Sericornis humilis*	Tasmanian scrubwren	En
Eudyptula minor	little penguin	C	*Stagonopleura bella*	beautiful firetail	
Falco berigora	brown falcon		*Stercorarius parasiticus*	Arctic jaeger	
Falco peregrinus	peregrine falcon		*Sterna bergii*	crested tern	C
Fulica atra	eurasian coot		*Sterna caspia*	caspian tern	C
Gallinago hardwickii	Latham's snipe		*Sterna nereis* subsp. *nereis*	fairy tern	T
Gallinula mortierii	Tasmanian native-hen	En	*Sterna striata*	white-fronted tern	
Glossopsitta pusilla	little lorikeet		*Strepera fuliginosa*	black currawong	En
Gymnorhina tibicen	Australian magpie		*Strepera versicolor*	grey currawong	
Haematopus fuliginosus	sooty oystercatcher	C	*Streptopelia chinensis*	spotted turtle-dove	
Haematopus longirostris	pied oystercatcher	C	*Tachybaptus novaehollandiae*	Australasian grebe	
Haliaeetus leucogaster	white-bellied sea-eagle	T	*Tadorna tadornoides*	Australian shelduck	
Heteroscelus brevipes	grey-tailed tattler	C, M	*Thinornis rubricollis*	hooded plover	C
Hirundapus caudacutus	white-throated needletail		*Trichoglossus haematodus*	rainbow lorikeet	
Hirundo neoxena	welcome swallow		*Tyto novaehollandiae* subsp. *castanops*	masked owl	T
Hirundo nigricans	tree martin		*Vanellus miles*	masked lapwing	
Larus dominicanus	kelp gull		*Zoothera lunulata*	bassian thrush	
Larus novaehollandiae	silver gull		*Zosterops lateralis*	silvereye	
Larus pacificus	Pacific gull	C			

Status: T = threatened, En = endemic, C = non-threatened high conservation value coastal bird, M = migratory shorebird.

There have been some notable declines in woodland bird numbers within the D'Entrecasteaux Channel region during recent surveys. Counts of the forty-spotted pardalote in 2009 found that of 33 colonies on Bruny Island, 28 colonies (85%) showed a decline in bird numbers since the 1990s, some by as much as 60 to 95% (Bryant 2010). This was most likely the result of primary environmental changes such as prolonged drought, resulting in deterioration of white gum *Eucalyptus viminalis* vegetation, the primary habitat of this species. However, several colonies were also increasingly being encroached and fragmented by residential development, subdivision, and increased human usage, most notably at Howden, Tinderbox Peninsula, Apollo Bay and Nebraska Beach on Bruny Island (Bryant 2010).

Surveys of little penguins in south-east Tasmania have indicated declines at a range of sites over the past 50 years, with anecdotal evidence suggesting decreased breeding numbers at Bruny Island Neck. The most recent estimate of breeding pair numbers at this site is 400, while 500–600 breeding pairs were estimated during the 1960s/1970s. Similarly, nightly counts of penguins during December and February, the peak reproductive period, declined by ~20% during 2000-2003 (Stevenson and Woehler 2006). Recent surveys of penguin sites in the northern D'Entrecasteaux Channel (North West Bay, Coningham and Dennes Point) failed to locate breeding birds, suggesting declines or potential losses of breeding populations (Vertigan and Woehler 2012). Causes of little penguin declines are likely to include predation by introduced vertebrates, habitat modification and destruction, and incidental drowning in recreational gillnets (Stevenson and Woehler 2006). Birds in both muttonbird and penguin colonies are vulnerable to attacks by dogs or to burrows being trampled by visitors (DPIWE 2000).

In contrast, numbers of silver gulls *Larus novaehollandiae*, and also potentially kelp gulls *Larus dominicanus*, are presently believed to be artificially high in south-east Tasmania following decades of the birds using tips as supplementary food sources. This, combined with degradation and loss of some island breeding habitats, has resulted in management issues associated with breeding colonies occurring in built up areas. Tip sites within the D'Entrecasteaux Channel and lower Huon Estuary have all been converted to waste transfer stations over the last ~10 years (see Section 9.7.1) and landfills covered, hence reducing food availability to gulls. However, food pellets used in the fish farming industry are an additional artificial food source, with bird nets used in most cases and having variable success in preventing feeding by gulls. Restoration of natural breeding habitats and preventing access to artificial food sources are considered to be important long-term management strategies (Woehler unpub. data, BirdLife Tasmania).

6.1.4 Marine mammals

Several species of marine mammals visit the D'Entrecasteaux Channel and lower Huon Estuary, including dolphins, whales and seals. Both bottle-nosed dolphins *Tursiops truncatus* and common dolphins *Delphinius delphis* are sighted frequently in region, and are resident species around Tasmania. Southern right whales *Eubalaena australis* and humpback whales *Megaptera novaeangliae* (both Endangered) are migratory, visiting Tasmania on their way from the Southern Ocean starting in mid-May, with numbers peaking in June and July (Whitehead *et al.* 2010). Resident seals consist primarily of Australian fur seals *Arctocephalus pusillus*, but also include New Zealand fur seals *A. forsteri* (Rare) and occasional southern elephant seals *Mirounga leonina* (Endangered).

The south-east coast provides an important migration path for humpback and southern right whales as they move between their summer subantarctic feeding grounds and winter birthing grounds along Australia's east coast. Based on records contained within the Whalebase database of the DPIPWE Biodiversity Conservation Branch, there were ~20 reported sightings each for these two species in the study area during 2001-2011 (DPIPWE 2011c) (Figure 28). Humpback whale sightings were largely in the northern and central parts of the D'Entrecasteaux Channel, while southern right whale sightings were more widely dispersed and extended as far upstream as Cairns Bay (opposite Brabazon Point) in the Huon Estuary. It should be noted that these data have not been derived from methodical survey programs but represent opportunistic sightings data, and hence may be biased in association with human population density. Southern right whales and humpback whales were hunted close to extinction in the 19th century, with numerous whaling stations operating in south-east Tasmania. Prior to this whaling activity, the Channel provided important calving grounds for the southern right whale, and only in recent years have mother and calf sightings suggested that populations may be slowly starting to recover in Tasmania (RPDC 2006).

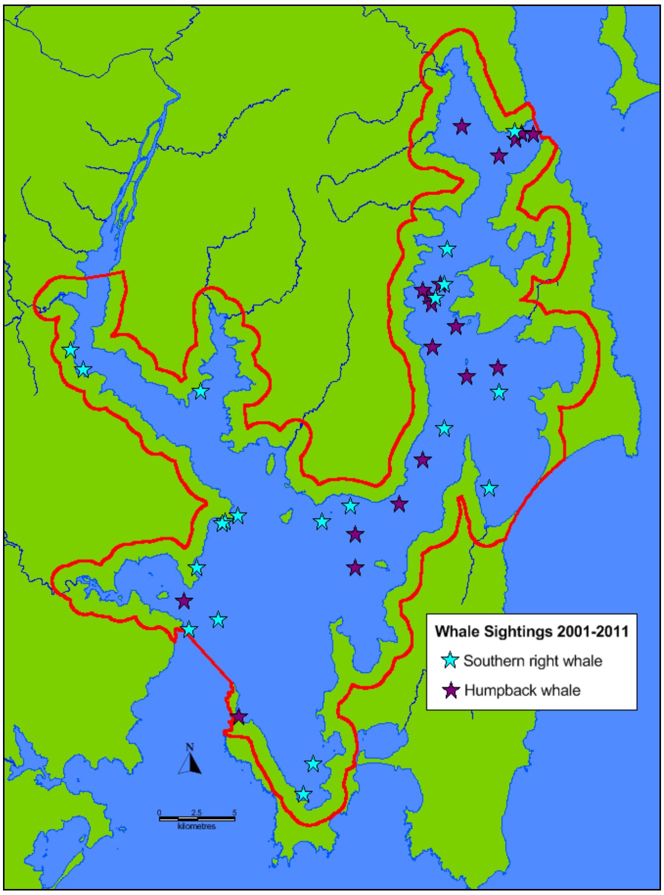


Figure 28 Whale sightings (Data source: DPIPWE 2011c).

While most sightings of cetaceans are either migrating southern right or humpback whales, stranding records since the early 1800s indicate that a large number of other species occur within south-east Tasmania. Stranding records are not currently available for the immediate study area; however, whales and dolphins of 23 species have been found stranded within the broader Bruny Bioregion (see Section 4.2) and represent more than 70% of all marine mammal species known to have stranded within Tasmania (RPDC 2006). Sightings of the orca (*Orcinus orca*) and pygmy right whale (*Caperea marginata*) have previously been recorded for the D'Entrecasteaux Channel (Phillips 1999).

Seals occur in the D'Entrecasteaux Channel and lower Huon Estuary and occasionally haul out on the foreshore; however, no regular haul out or breeding sites occur within the study area. Nearest haul out sites for the primary species, the Australian fur seal, occur at the Friars rocks off southern Bruny Island and remote capes of the Tasman Peninsula (RPDC 2006). Both Australian and New Zealand fur seals have established breeding sites in other parts of Tasmania, while the southern elephant seal is essentially a subantarctic species but produces small numbers of pups at Maatsuyker Island off Tasmania's south coast (DPIPWE 2011d). Occasional visitors or 'vagrants' to Tasmania, including the study area, include several other species which breed in the Southern Ocean or parts of mainland Australia, including the leopard seal, subantarctic fur seal and Australian sea lion (Phillips 1999, DPIPWE 2011d).

Due to the lack of established colonies in the study area, no regular monitoring of seal populations takes place. However observations of interactions with fish farming activities indicate increases in numbers of Australian fur seals visiting the region (D. O'Brien, Huon Aquaculture Company, pers. comm.). Seals are attracted to salmon farms because of the concentration of fish, and commonly interact with farms by chewing through nets, jumping over handrails and entering the sea cages. Interactions with gill-netters have also been recorded, and there has been an increased incidence of seals posing threats to the safety of fishers and salmon farm workers. A seal/fishery interaction management strategy developed for Tasmania has recommended a number potential mitigation measures. These include improved design of salmon farms, modifications of fishing practices, continued relocation programs, and possible use of non-lethal deterrents (e.g. non-lethal explosives, projectiles and irritant chemicals) (Marine and Marine Industries Council 2002). To date, seal control methods have had variable success, and no one solution to this issue has been identified.

Other marine mammal management issues relate primarily to the intensive use of the waterways for boating and fishing activities, and the large amount of infrastructure both within the water and along the coast. It has been suggested that these types of disturbances and structures can interfere with marine mammals, and may hinder the recovery of historic calving grounds (Phillips 1999).

6.1.5 Benthic invertebrates

Benthic macroinvertebrates are organisms that live in or on seafloor sediments and are visible to the naked eye, including crustaceans (e.g. crabs and amphipods), molluscs (e.g. gastropods, bivalves, slugs and snails), polychaetes (worms) and a diverse range of other species. Both infaunal (within the sediments) and epifaunal (surface dwelling) invertebrates are a critical component of a healthy ecosystem and occur in all D'Entrecasteaux Channel and lower Huon Estuary habitats. They can be used to assess the condition of biological communities, with certain components being used as indicators of environmental stress.

Benthic infauna are particularly useful as an environmental indicator because these species are relatively immobile and hence are unable to evade impacts such as nutrient enrichment and toxicant loading. As a consequence, their community structure as measured through indices such as species composition, diversity and dominance, reflect the cumulative impacts of environmental conditions. Benthic infauna have been investigated in several recent major studies of the D'Entrecasteaux Channel and lower Huon Estuary, and have primarily been assessed as an indicator of sediment health. Further information on these studies is therefore provided in conjunction with other sediment health indicators (see Section 12.2.3).

No long-term data are available to assess broadscale, temporal changes in overall benthic infauna community health; however, a study of shell fragments in dated sediment cores has indicated a major decline in mollusc species diversity and abundance in the region over the last 120 years (Edgar and Samson 2004). Based on 5 cm sediment core intervals, the mean shell number and species diversity were 230 and 24, respectively in 1890, but had declined to 20 and 6 by 1990 (Figure 29). This indicates a loss of 75% of the mollusc diversity of the region over 100 years, with declines most pronounced since 1950. Declines in mollusc abundance and diversity were linked to historic dredging of scallops and native oysters, while the arrival of introduced species, siltation and effluent outfalls may also have contributed to reduced diversity. As noted in Section 7.2, the relative abundance of introduced species in benthic invertebrate communities is increasing over time, potentially threatening further native species.

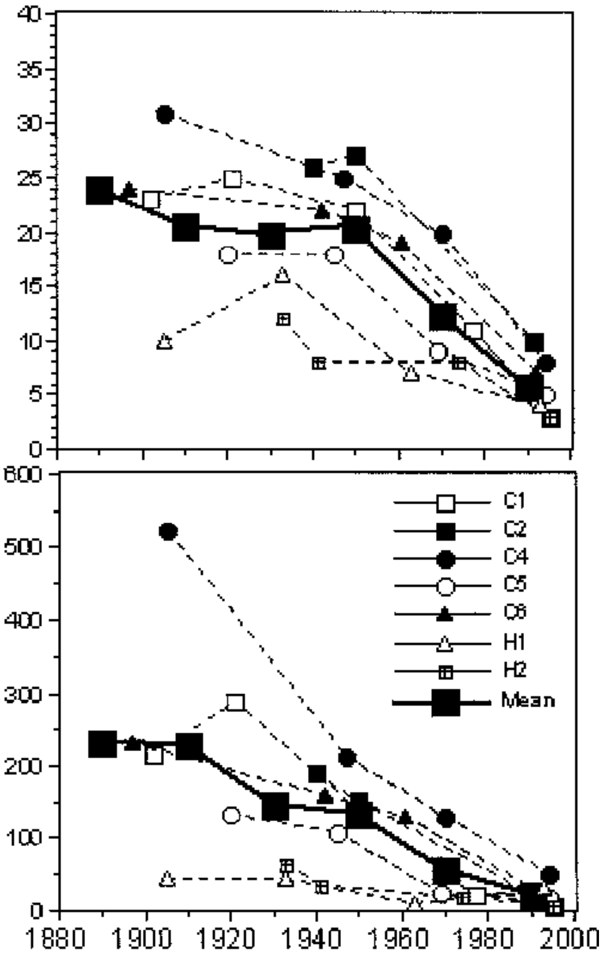


Figure 29 Mean number of mollusc species (top) and shells (bottom) at individual sites (dashed lines) and for the region (solid line) (Source: Edgar and Samson 2004).

Epifauna communities include both mobile and sessile (i.e. attached) invertebrates, which vary in their species composition between reef, seagrass, and unvegetated soft sediment habitats, and with other environmental factors. Studies of mobile reef fauna have occurred primarily through monitoring of marine protected areas (MPAs) at Tinderbox and Ninepin Point, where surveys between 1992 and 2002 recorded 40 and 31 mobile macroinvertebrate species, respectively (Barrett *et al.* 2009). Common species included the southern rock lobster *Jasus edwardsii*, purple urchin *Heliocidaris erythrogramma*, and feather star *Cenolia trichoptera*, and an additional range of urchins and seastars. At Tinderbox, lobster abundances increased twofold within the reserve during the 10 year study, while numbers at fished sites remained relatively constant (Figure 30). This difference was primarily due to a marked increase in the number of large lobsters within the reserve relative to the fished sites. The generally low abundance of the blacklip abalone *Haliotis rubra* at Tinderbox made it difficult to determine temporal or spatial trends, but there was some evidence of increasing numbers at the fished sites relative to the protected area. No protection-related differences in lobster or abalone abundances were detected at Ninepin Point, a finding that was attributed to the small size of the reserve and hence poaching and boundary effects (note: the size of this reserve was subsequently increased in 2009; see Section 4.2).

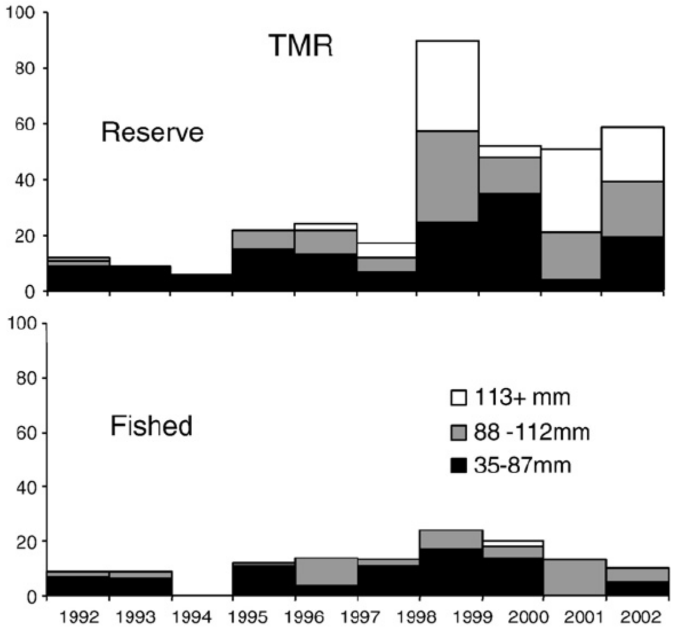


Figure 30 Abundance of the southern rock lobster by size class at Tinderbox (Source: Barrett *et al.* 2009).

The abundances of many of the common reef invertebrates encountered were relatively stable through time, although numbers of *H. erythrogramma* and the pencil urchin *Goniocidaris tubaria* declined within the Tinderbox reserve over time whilst remaining relatively constant at adjacent fished sites. Similarly, numbers of the magnificent biscuit seastar *Tosia magnifica* and inflated egg urchin *Holopneustes inflatus* also decreased. These results were reflected in a small decrease in invertebrate richness at reserve sites relative to fished sites at Tinderbox, while species richness remained relatively stable at the Ninepin Point sites. The reduced numbers of some invertebrate species at Tinderbox were attributed to greater predation pressure as a result of increasing numbers of large fish (see Section 6.1.2) and lobsters. The results suggest that significant changes to benthic invertebrate communities had occurred as a result of fishing, but that biodiversity does not necessarily respond positively at all trophic levels following protection from fishing (Barrett *et al.* 2009). The long-spined sea urchin *Centrostephanus rodgersii* is a species that has spread from mainland Australia to the Tasmanian east coast via the increasing southerly penetration of the East Australian Current (Johnson *et al.* 2005). It has been recorded from sightings at the entrances to Port Esperance and the northern D'Entrecasteaux Channel, but is not common in the region at this stage. In more northern parts of the Tasmanian east coast, this species has caused large urchin barrens in some areas and impacted on numbers of abalone and rock lobster (Johnson *et al.* 2005). Note that additional reef associated invertebrates in the D'Entrecasteaux region have also been documented by Jordan *et al.* (2002).

Mobile epifaunal invertebrates living on soft sediments have not been quantified to the same detailed level, but video surveys and some diver counts show that introduced species such as the New Zealand screw shell *Maoricolpus roseus* and northern Pacific seastar *Asterias amurenis* have become dominant members of the community (Tracey and Lyle 2008, Reid 2010) (see Section 7.2). Native species prominent in surveys include squat lobsters (Nichol *et al.* 2009) and scallops, including the commercial scallop *Pecten fumatus*, doughboy scallop *Chlamys asperrimus* and queen scallop *Equichlamys bifrons* (Reid 2010). The scallop species have experienced major historical (Edgar and Samson 2004) and recent declines (see Section 3.6) and may potentially be impacted by both of the above introduced species. Where soft sediment habitats support seagrass beds, a different invertebrate community arises and includes numerous crustaceans, worms and molluscs (e.g. Jordan *et al.* 2002).

Sessile benthic invertebrates are also a very important component of the fauna in the region. Where there is moderate to strong current flow and reefs or shell beds extend below 5 m, diverse communities of filter feeding sponges, seafans and seawhips become increasingly dominant (Barrett *et al.* 2001). These communities are particularly well developed near Simpsons Point, on the ends of northern points of the Bruny Island west coast, Arch Rock, Butts Reef and Zuidpool Rock, and occur mainly at depths of 6-15 m in high current areas (Barrett *et al.* 2001, Nichol *et al.* 2009). These fragile and diverse communities of filter feeding invertebrates are unique in occurring at much shallower depths than usual. This phenomenon is due to high levels of particulate food associated with elevated flow rates, and also the heavily stained tannin waters of the Huon Estuary which act to 'compress' the typical depth zones for marine organisms (Barrett *et al.* 2001).

There have been few recent investigations of intertidal invertebrates. Nevertheless, an earlier study of numerous sandy standline (= upper intertidal zone) fauna communities around the east, north and west coasts of Tasmania identified those in the southern part of Simpsons Bay to be of high conservation value due to their relatively undisturbed state (Richardson *et al*. 1997a). In an investigation of rocky intertidal communities of Tasmania's east coast, Ventenat Point and Ninepin Point were also identified to be of high conservation value on the basis of being good examples of sheltered to semi-sheltered sites (Richardson *et al*. 1997b). A survey of rocky intertidal species near Electrona in North West Bay in 2000 identified 32 species, dominated by molluscs but also including crabs, seastars and several other species (Aquenal 2000).

6.1.6 Zooplankton

Plankton refers to microscopic organisms in the water column that are generally incapable of swimming against currents, although some perform regular vertical migrations. The animals within these communities are referred to as zooplankton and include the larval phases of many larger animal species, such as fish, molluscs, lobsters and sea urchins, as well as animal species that are only found in the plankton such as tiny crustaceans called copepods and cladocerans (Swadling *et al.* 2008a). Zooplankton play important roles in estuarine and coastal environments by transferring organic matter from phytoplankton to higher-order consumers such as fish and seabirds. Understanding the abundance, distribution and community composition of zooplankton is, therefore, fundamental to interpreting ecosystem dynamics (Swadling *et al.* 2008b).

A major study of zooplankton community composition and structure was performed during 2004-2005 as part of the Whole of Ecosystem Assessment for Salmon Farming (WoEASF) in the D'Entrecasteaux Channel and Huon Estuary (Swadling *et al*. 2008b). The composition of the mesozooplankton (i.e. zooplankton 200 µm – 2 mm) community was typical of inshore, temperate marine habitats, with seasonally higher abundance in summer and early autumn and lower numbers in winter and spring. Total abundance ranged between 675 and 7800 individuals per m^3. Copepods were the largest contributors (>80%) to abundance across all seasons, while cladocerans and appendicularians (small solitary tunicates, related to ascidians) were proportionally more abundant in spring and summer. Larvae of larger benthic animals exhibited short-term peaks and were often absent from the water column for extended periods. North West Bay and the Channel had a higher representation of typically marine species, while truly estuarine species were more common in the Huon Estuary (Swadling *et al.* 2008b).

The microzooplankton (i.e. zooplankton <200 µm) community was also assessed during the WoEASF and, ranked by density, was dominated by ciliates (unicellular organisms with hair-like structures called cilia) (42% of the community), followed by heterotrophic dinoflagellates (these are microalgae which feed on organic matter – rather than obtaining energy from light like other algae and plants – and hence are assessed as part of the zooplankton community) (33%) and tintinnids (a particular group of ciliates) (16%), with less than 10% attributed to other categories. Experiments performed as part of nutrient cycling studies found that the tiny microzooplankton exerted a much stronger grazing pressure on phytoplankton (i.e. microscopic algae in the water column; see Section 6.2.4) than the mesozooplankton, however both are important in the food webs of the Huon Estuary and D'Entrecasteaux Channel and provide a crucial link between primary production and fish (Volkman *et al.* 2009).

6.2 Foreshore, marine and estuarine flora

6.2.1 Threatened flora species

Some plant species are formally listed as threatened in accordance with legislation described in Section 6.1.1. A search of the study area on the DPIPWE Natural Values Atlas (NVA) database indicates that there are 45 threatened plant species within the region, as indicated in Table 13.

The majority of these species are entirely terrestrial, although there are several exceptions. The tall blowngrass *Lachnagrostis robusta* is found in marshy, estuarine habitats, and within the study area has been recorded in wetlands at the northern end of Bruny Island Neck. Similarly, the spreading saltmarshgrass *Puccinellia perlaxa* is found in saline herbfields and has been recorded at the head of Port Cygnet. Additional species, such as *Juncus* spp. are found along the margins of streams and dams, or in permanent wet soakage areas. No threatened algae have been recorded in the study area, which is primarily due to a paucity of baseline data and lack of formal assessments for these species. Research has indicated the presence of a number of algal species that have highly restricted distributions, including some that are endemic to the D'Entrecasteaux Channel (see Section 6.2.3).

Eight of the threatened species recorded are endemic to Tasmania, including the Tasmanian smokebush *Conospermum hookeri*, pretty heath *Epacris virgata*, and six orchid species. The region is widely known and valued for its orchid diversity, with 37 species identified in the Peter Murrell State Reserve for example. However, orchid diversity and abundance is believed to have recently declined in some areas, due potentially to slashing of firebreaks during the key flowering period, lack of rain following some prescribed burns and other factors (PWS 2006). The total number of flora within the study is not known, but for example, ~260 plant species have been recorded in both the Coningham Nature Recreation Area (DPIPWE 2009a), and the South Bruny National Park/Waterfall Creek and Green Island reserves (DPIWE 2000).

6.2.2 Foreshore vegetation and threatened communities

Vegetation along the entire study area foreshore (within 100 m of mean high water) was mapped in detail and categorised according to community type, condition, conservation significance and long-term viability by North Barker Ecosystem Services (DTAE 2007). The major foreshore vegetation groups as defined by TASVEG codes (DPIPWE 2009b) are listed in Table 14, with the relative proportions of the major vegetation groups illustrated in Figure 31. The native vegetation groups can be broadly categorised as: 1) saltmarsh and wetland, 2) dry eucalypt forest and woodland, 3) wet eucalypt forest and woodland, 4) non-eucalypt forest and woodland (e.g. she-oak forests), 5) scrub, heath and coastal complexes and 6) native grassland. Seven vegetation community types recorded in the study area are listed as threatened in the *Nature Conservation Act 2002*, including five types of dry eucalypt forest and woodland, one category of wetland vegetation and the seabird rookery coastal complex (see Table 14). Threatened communities occupied 31% of the total area of foreshore vegetation, with the majority of this contributed by threatened dry eucalypt forests and woodlands.

Table 13 Threatened plant species (Data source: DPIPWE 2012a).

Scientific name	Common name	No. NVA records	Status (Tas.)	Status (Nat.)
Acacia uncifolia	coast wirilda	2	R	
Acacia ulicifolia	juniper wattle	1	R	
Lachnagrostis punicea	bristle blowngrass	2	R	
Lachnagrostis robusta	tall blowngrass	1	R	
Argentipallium spiceri	Spicers everlasting	1		CR
Asperula scoparia subsp. *scoparia*	prickly woodruff	32	R	
Austrostipa blackii	crested spear grass	1	R	
Austrostipa nodosa	knotty speargrass	1	R	
Austrostipa scabra subsp. *falcata*	rough speargrass	7	R	
*Caladenia caudata**	tailed spider-orchid	4	V	V
Caladenia pusilla	tiny fingers	2	R	
Carex gunniana	mountain sedge	1	R	
Carex tasmanica	curly sedge	1	V	
*Conospermum hookeri**	Tasmanian smokebush	4	V	V
Corunastylis morrisii	bearded midge-orchid	1	E	
*Corunastylis nudiscapa**	bare midge-orchid	2	E	
Cyrtostylis robusta	large gnat-orchid	7	R	
Deyeuxia densa	heath bentgrass	2	R	
Dryopoa dives	giant mountaingrass	1	R	
Epacris virgata 'Kettering'*	pretty heath	37	V	E
Juncus amabilis	gentle rush	6	R	
Juncus vaginatus	clustered rush	1	R	
Lepidium hyssopifolium	soft peppercress	1	E	E
Lepidium pseudotasmanicum	shade peppercress	10	R	
Lepidosperma tortuosum	twisting rapiersedge	3	R	
Lepidosperma viscidum	sticky swordsedge	1	R	
Leucopogon virgatus	shortleaf beardheath	16	R	
Lythrum salicaria	purple loosestrife	1	V	
Microtidium atratum	yellow onion-orchid	2	R	
Phyllangium divergens	wiry mitrewort	2	V	
Poa poiformis var. *ramifer*	island purplegrass	29	R	
*Prasophyllum apoxychilum**	tapered leek-orchid	3	E	E
*Prasophyllum castaneum**	chestnut leek-orchid	3	E	CR
*Prasophyllum pulchellum**	pretty leek-orchid	1	E	CR
Pterostylis squamata	ruddy greenhood	5	R	
Puccinellia perlaxa	spreading saltmarshgrass	1	R	
Scleranthus brockiei	mountain knawel	1	R	
Scleranthus fasciculatus	spreading knawel	1	V	
Senecio squarrosus	leafy fireweed	1	R	
Stellaria multiflora	rayless starwort	1	R	
Thelymitra holmesii	bluestar sun-orchid	4	R	
*Thelymitra jonesii**	skyblue sun-orchid	1	E	E
Velleia paradoxa	spur velleia	1	V	
Viola cunninghamii	alpine violet	2	R	
Vittadinia muelleri	narrowleaf new-holland-daisy	1	R	

Status: CR = Critically Endangered; E = Endangered; V = Vulnerable, R = Rare; * = Tasmanian endemic.

Table 14 Vegetation communities (Data source: DTAE 2007).

TASVEG code	Vegetation Type	Area (km²)
Agricultural, urban and exotic vegetation		**12.01**
FAG	Agricultural land	7.36
FPE	Permanent easements	0.01
FPF	*Pteridium esculentum* fernland	0.03
FPL	Plantations for silviculture	0.01
FRG	Regenerating cleared land	0.16
FUM	Extra-urban miscellaneous	2.18
FUR	Urban areas	2.10
FWU	Weed infestation	0.17
Other natural environments		**0.29**
OAQ	Water, sea	0.07
ORO	Rock (cryptogamic lithosere)	0.07
OSM	Sand, mud	0.15
Scrub, heath and coastal complexes		**1.50**
SAC	*Acacia longifolia* coastal scrub	0.02
SBR	Broadleaf scrub	0.05
SCH	Coastal heathland	0.38
SDU	Dry scrub	0.02
SHW	Wet heathland	0.10
SLW	*Leptospermum* scrub	0.15
SMR	*Melaleuca squarrosa* scrub	0.11
SRC*	Seabird rookery complex	0.40
SSC	Coastal scrub	0.27
Dry eucalypt forest and woodland		**18.91**
DAC	*Eucalyptus amygdalina* coastal forest and woodland	0.56
DAD	*Eucalyptus amygdalina* forest and woodland on dolerite	0.10
DAM	*Eucalyptus amygdalina* forest and woodland on mudstone	0.05
DAS*	*Eucalyptus amygdalina* forest and woodland on sandstone	0.95
DGL*	*Eucalyptus globulus* dry forest and woodland	3.49
DNI	*Eucalyptus nitida* dry forest and woodland	0.38
DOB	*Eucalyptus obliqua* dry forest and woodland	4.02
DOV*	*Eucalyptus ovata* forest and woodland	3.92
DPU	*Eucalyptus pulchella* forest and woodland	2.17
DTD	*Eucalyptus tenuiramis* forest and woodland on dolerite	0.38
DTO*	*Eucalyptus tenuiramis* forest and woodland on sediments	1.61
DVC*	*Eucalyptus viminalis - Eucalyptus globulus* coastal forest and woodland	0.65
DVG	*Eucalyptus viminalis* grassy forest and woodland	0.56
DVS	*Eucalyptus viminalis* shrubby/heathy woodland	0.07
Wet eucalypt forest and woodland		**0.50**
WGL	*Eucalyptus globulus* wet forest	0.28
WOB	*Eucalyptus obliqua* forest with broadleaf shrubs	0.21
WOL	*Eucalyptus obliqua* forest over *Leptospermum*	0.01
Non-eucalypt forest and woodland		**0.65**
NAD	*Acacia dealbata* forest	0.04
NAV	*Allocasuarina verticillata* forest	0.60
NBA	*Bursaria - Acacia* woodland and scrub	0.01
Native grassland		**0.31**
GHC	Coastal grass and herbfield	0.23
GTL	Lowland *Themeda* grassland	0.08
Saltmarsh and wetland		**0.99**
ARS	Saline sedgeland/rushland	0.65
ASF*	Fresh water aquatic sedgeland and rushland	0.03
ASS	Succulent saline herbland	0.31

* = Threatened communities

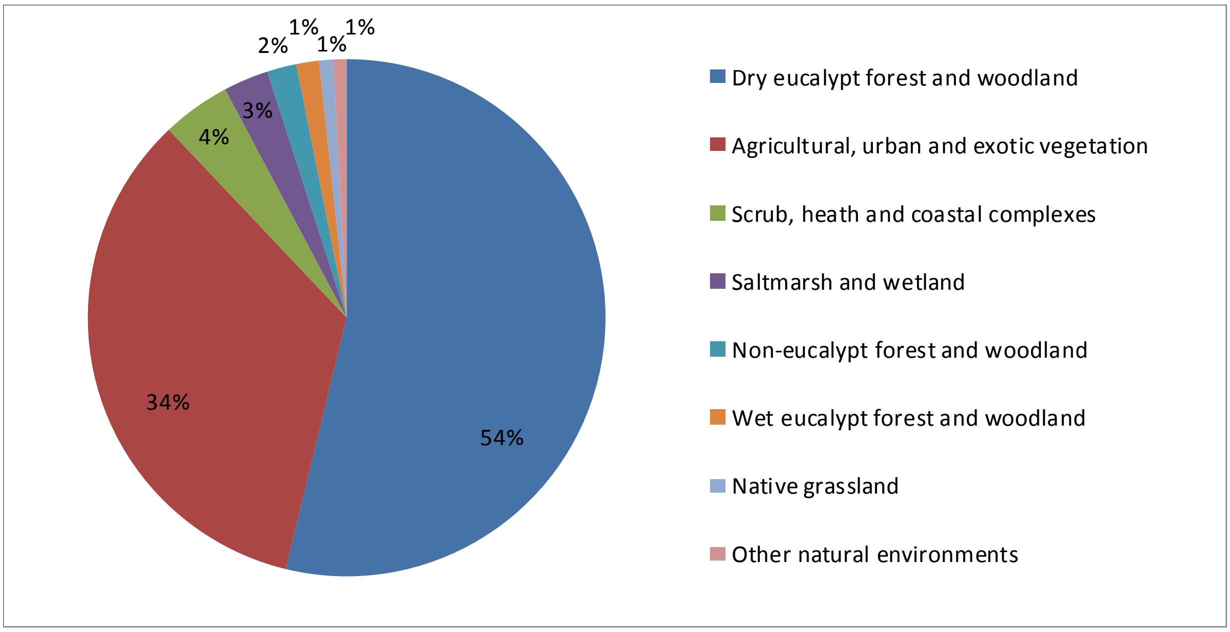
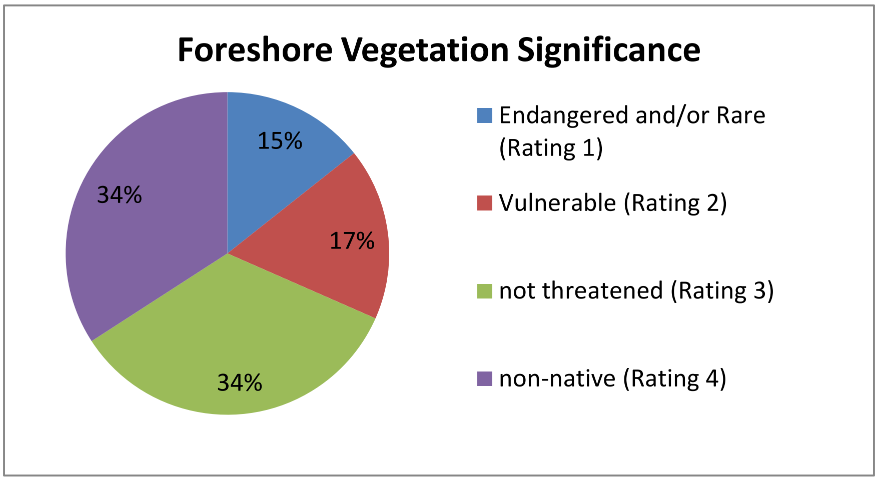
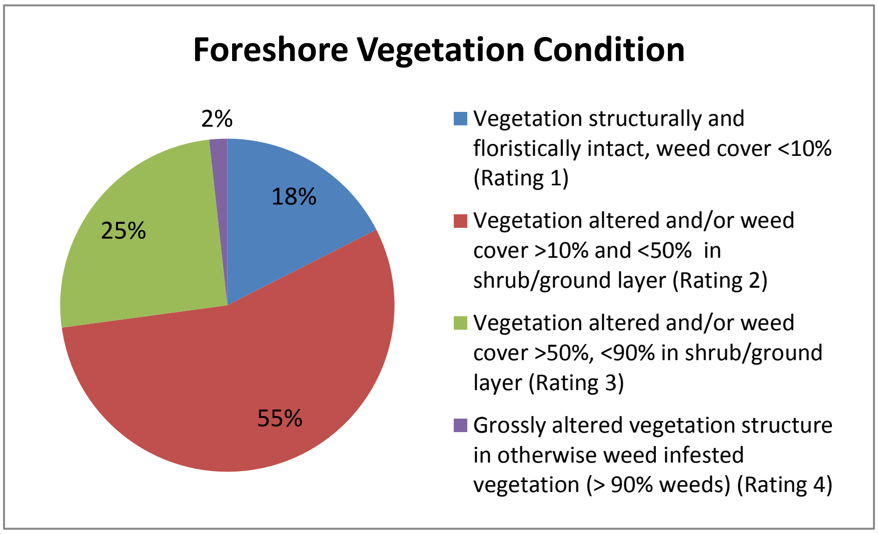


Figure 31 Foreshore vegetation type (Data source: DTAE 2007).

Further analysis of data by area indicates that 34% of the foreshore has been cleared of native vegetation and consists predominantly of urban and rural land or exotic vegetation (Figure 31). The retained native vegetation elsewhere consists primarily of dry eucalypt communities, with *Eucalyptus obliqua*, *E. ovata* and dry *E. globulus* forests and woodlands occupying the largest areas. The conservation significance of vegetation in the coastal strip was rated in accordance with four categories from highest (1) to lowest (4) significance based on threatened community status. Results indicated that lower significance non-native and non-threatened communities dominated the coastal zone across the study area, while the higher significance vegetation included a relatively even mix of Endangered/Rare and Vulnerable communities (Figure 32). Subsequent categorisation of condition and long-term viability of vegetation within 1.0 ha coastal cells indicated that only ~20% of vegetation is intact and self-sustaining (Figure 32) (DTAE 2007).

Several projects have recently been conducted to assess and prioritise native vegetation values in the region. The Biolinks project used satellite imagery and natural values spatial data to identify priority areas for improving biodiversity values at the landscape scale in the Huon Valley and D'Entrecasteaux Channel. Closely adjoining vegetation remnants were identified for the path of notional 'spines' or corridor lines, aimed at large-scale connectivity of larger remnants. Several high priority corridors overlapped with the study area on northern parts of Bruny Island, near Tinderbox, and adjacent to the lower Huon Estuary between Randalls Bay and Deep Bay (Rowland 2008). A separate project developed a regional ecosystem model to determine the significance of remnant vegetation, and reported that 50% of the Kingborough municipality is of very high immediate concern for biodiversity management. This figure increased to 100% when the model was applied specifically to '*Eucalyptus amygdalina* forest and woodland on sandstone', a threatened community which is at risk of fragmentation through development (Knight 2012).





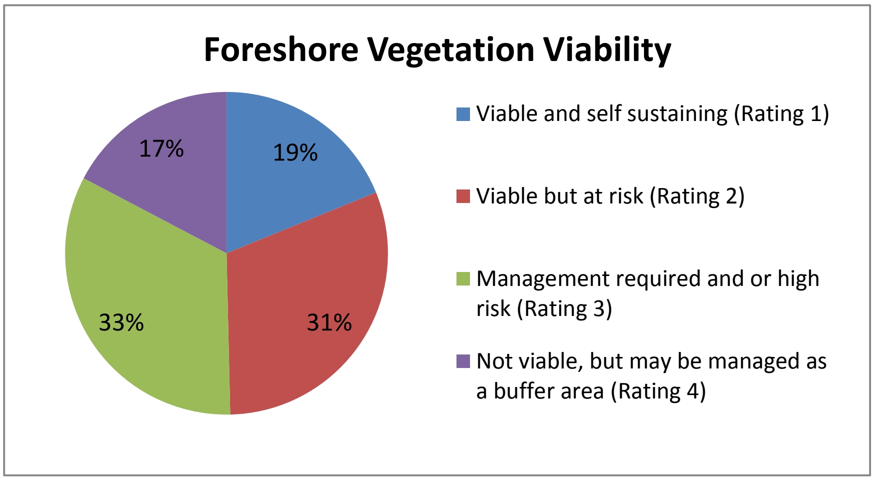


Figure 32 Foreshore vegetation indices (Data source: DTAE 2007).

6.2.3 Algae and seagrasses

The marine flora of the D'Entrecasteaux Channel and lower Huon Estuary include macroalgae (or 'seaweeds') which are non-flowering and use spores to reproduce much like ferns and mosses, as well as seagrasses which produce flowers and are classified as angiosperms like terrestrial flowering plants. Both algae and seagrasses obtain their energy from photosynthesis, a process that uses sunlight and carbon dioxide to produce sugars with the help of photosensitive pigments in their tissues, such as chlorophyll. This reliance on light means that they are limited to relatively shallow depths where there is sufficient light penetration, and hence tend to occur in close proximity to the coast. This means that they are vulnerable to inputs of nutrients and other coastal activities that affect water quality or the seabed environment.

Macroalgae

The rocky reefs of the region provide habitat for a large number of macroalgae, including green, brown and red algal species, with some entirely unique to the study area. At the northern and southern ends of the Channel, the coastal reefs are subject to some swells and the algal communities are dominated by the crayweed *Phyllospora comosa*, with the common kelp *Ecklonia radiata* and other brown algae extending into deeper waters (Barrett *et al.* 2001). Most of the Channel is protected from swells, and reefs in these more sheltered waters have macroalgal communities dominated by *Caulocystis*, *Cystophora* and *Acrocarpia* species and the daggerweed *Xiphophora gladiata* in the shallows, grading to *Sargassum* spp. at ~10 m. Adjacent to the lower margins of rocky reefs there is usually a sandy to shelly strip that is inhabited by *Caulerpa* spp., which extends into the sand or silt (Barrett *et al.* 2001). Silt deposition on the reefs often limits algal growth, particularly on the deeper reefs in areas with limited water motion. Moderately exposed areas, for example around Dover, are dominated by the bull kelp *Durvillaea potatorum* to between 2-5 m, with crayweed below to 10 m and common kelp at greater depth. The giant kelp *Macrocystis pyifera* occurs between 5-8 m in areas subject to some current, while red algae are particularly common in the southern part of the study area, where they occur at most depths and are dominant at depths exceeding 10 m (Barrett *et al.* 2001). Variations of these species combinations and depth ranges occur within the region, depending largely on the level of wave exposure and water clarity.

Quantitative assessments of macroalgal diversity and cover have been conducted at the Tinderbox and Ninepin Point MPAs, where 77 and 84 macroalgal species were recorded respectively during 1992-2002 surveys (Barrett *et al.* 2009). Total levels of diversity may be much higher; for example 208 macroalgal species are documented at Ninepin Point, making it one of the most diverse algal sites in Tasmania (F. Scott, IMAS, pers. comm.). In comparison, just 35 reef species were identified in North West Bay (Jordan *et al.* 2002) (although more species were associated with the seagrass beds found there; see the 'seagrass' section below), but many algal species are difficult to detect and diversity estimates may vary widely depending on survey intensity. Algal species richness and total cover varied little over time at the two MPAs, suggesting declining numbers of grazers such as urchins at Tinderbox (see Section 6.1.5) had not yet affected algal assemblages. The development of a giant kelp stand during 2000-2002 and altered cover of common kelp and *Phacelocarpus* species did however result in a major community shift at Tinderbox (Barrett *et al.* 2009). Additional changes at Tinderbox were associated with the spread of the introduced Japanese seaweed *Undaria pinnitifida*, which increased in abundance over the ten year period (Crawford *et al.* 2006). Other than the latter change, temporal variation in algal species composition appeared to be primarily due to natural variability within the system. Ongoing autumn monitoring at the Tinderbox and Ninepin Point MPAs has been performed annually during 2002-2012 (N. Barrett, IMAS, pers. comm.), and hence future reporting of these data will assist in determining longer-term trends.

There are some particularly unique aspects of the macoalgal community in the study area. The heavily tannin stained waters discharging from the Huon River lead to substantial modification of communities, particularly on reefs closest to the mouth of the Huon River. The tannin limits light penetration, reducing the maximum depth to which algae can grow, so that few brown algae are found at depths greater than 7-10 m, and the red algae occurring in deeper waters are rapidly replaced with communities of sessile filter feeding invertebrates (see Section 6.1.5) (Barrett *et al.* 2001). These unique light limited environments support a particularly high diversity of red algae and represent a hotspot for endemic algal species. Of seven known endemic Tasmanian algae, five occur in this region and three are entirely confined to the D'Entrecasteaux Channel, while an additional four species are described as rare on the basis of limited sites (F. Scott, IMAS, pers. comm.). Ninepin Point, Arch Rock and Satellite Island are particularly important for endemic species, while Butts Reef appears to have the best representation of the unique light limited assemblage due to its greater maximum depth than other reefs and strong tannin influences (Barrett *et al.* 2001).

Several studies have been conducted to assess the effects of fish farming on macroalage, and the usefulness of macroalgal species as indicators of eutrophication (i.e. nutrient enrichment). Surveys of intertidal species around Port Esperance/Dover and the lower Huon Estuary detected no clear trends in algal abundance with distance from salmon farms (Crawford *et al.* 2006). However abundance measures of sea lettuce *Ulva* spp. and neptunes necklace *Hormosira banksii* in the mid intertidal zone in spring and autumn were presented as simple ecological indicators for the effects of increased nutrients (Crawford *et al.* 2006). These two dominant taxa show different responses to nutrients, with *Ulva* spp. reaching high densities in nutrient enriched areas but *H. banksii* being more typical of unpolluted waterways. A study of subtidal algae in the D'Entrecasteaux Channel suggested that fish farm sites were associated with increased cover of opportunistic algae within 100-400 m of the farms, particularly filamentous species in sheltered regions and other opportunistic green algae at moderately exposed sites (Oh 2009). The study concluded that macroalgae are useful indicators of fish farming impacts on reef environments.

Within Australia, forests of the giant kelp *M. pyrifera* are found only in Tasmania, with smaller populations occurring on the south-east mainland Australian coast. The giant kelp has been described as a 'keystone species', providing habitat for a diverse ecological community reliant upon it for shelter, food and breeding habitat (Edyvane 2003). Widespread declines in this species have led to the recent listing of 'Giant Kelp Marine Forests of South-east Australia' as a nationally threatened community in the category of 'Endangered' (SEWPaC 2012). While potential causes of declines are numerous, several factors include warmer water temperatures associated with greater southerly penetration of the East Australian Current, sea urchin infestations, sedimentation, and the introduction of the Japanese seaweed *U. pinnatifida* (Edyvane 2003). Conversely, the giant kelp appears to respond favourably to increased nutrient supply, and flourishes at some sites adjacent to sewage outfalls and other nutrient sources. Distributional data collected up to 1999 for the D'Entrecasteaux Channel and Huon Estuary suggested, unlike in many regions of south-east Tasmania, a considerable increase in kelp area and the number of beds (Edyvane 2003). These increases were particularly evident around the Huon River, and were attributed to potential anthropogenic nutrient inputs.

A list of persistent giant kelp populations off the south and east coast of Tasmania, considered to be of particularly high conservation value, did not include any sites in the study area (Edyvane 2003). The coastline to the south, between Southport and Recherche Bay, was identified as containing a number of persistent beds, and more recent data also indicate extensive cover in this region. Overall though, data analysed for 1946-2007 in adjacent areas of Tasmania suggest major declines in kelp beds, with a 98% reduction estimated for Bruny Island region as a whole (Johnson *et al.* 2011). In the absence of recent mapping data for the study area, it is difficult to determine the current extent of kelp beds. However, declines have generally been less pronounced in this region than more northern parts of Tasmania, consistent with relatively cooler and more nutrient rich water influencing the southern coasts (Johnson *et al.* 2011).

Note that some algal communities are also associated specifically with seagrass beds, and are described in the section below.

Seagrasses

Seagrass beds are important contributors to coastal productivity and nurseries for marine species, while also serving important ecosystem services such as stabilising sediments and maintaining water quality (Jordan *et al.* 2002). Research suggests that their role as nursery habitat in Tasmania is of primary significance for small resident fishes rather than economically important scalefish species (Jordan *et al.* 1998). However, seagrass beds do provide breeding habitat for other fisheries species in Tasmania, such as the southern calamari (or 'squid') *Sepioteuthis australis* which is known to breed in the D'Entrecasteaux Channel (Pecl *et al.* 2011a). Seagrass beds occur within the study area as mapped in Section 5.1, and are dominated by the Tasmanian eelgrass *Heterozostera tasmanica*, with smaller areas of the southern paddlegrass *Halophila australis*, and also the eelgrass *Zostera capricorni* (formerly named *Z. muelleri*) in intertidal habitats. The seagrass beds are confined to shallow depths, typically less than 10 m, and relatively sheltered sandy or silty substrates (Jordan *et al.* 2002, Mount and Otera 2011).

Most investigations of seagrass beds in the study area have been in North West Bay, including seasonal assessments of cover, biomass, and blade length, and temporal assessments of seagrass extent. Depth and turbidity were shown to be the major factors controlling seagrass distribution in the bay, with a distinct decrease in the maximum depth of seagrass beds with increasing turbidity (Jordan *et al.* 2002). Seagrass beds are also important areas for algal growth that adds to their overall productivity. Surveys of algae, occurring as either epiphytic (i.e. growing on the seagrass plants) or unattached forms, recorded 42 species within the seagrass beds of North West Bay. At most sites the overall abundance was dominated by filamentous species, primarily *Polysiphonia* spp. and *Enteromorpha* spp. There was a clear relationship between algal abundance and seagrass biomass, reflecting the greater surface area for epiphytic algae to attach and potential for unattached algae to accumulate in dense seagrass beds (Jordan *et al.* 2002).

An assessment of long-term change in seagrass distribution in North West Bay was conducted on the basis of aerial photographs compiled between 1948 and 2010 (Mount and Otera 2011). The rapid assessment techniques engaged were only applied to shallow seagrass beds within the bay, since deeper beds are generally not visible in standard aerial photography. Large 'mega-quadrats' were set up at each of five sites selected for this study, including: Dru Point Delta, Barretta Bank, Graham Street Beach, Snug Beach, and Clarkes Beach. Seagrass beds included *H. tasmanica* subtidally and *Z. capricorni* in the intertidal zone, with irregular and frequent changes noted in seagrass extent over time. While periodic gains and losses have occurred, the total extent of seagrass over the past 60 years has been in decline, with a particularly large change evident in many beds in the mid-1980s. Since 2008, the seagrass beds appear to be in a growth phase and the seagrass is recolonising areas it has previously occupied, although cover is still lower than in the 1970's and early 1980's (Mount and Otera 2011). The most recent aerial photographs, captured in 2010, recorded the highest density of seagrass on Barretta Bank (Figure 33). The study concluded that the seagrass species in the bay are capable of actively and repeatedly colonising and recolonising the sea floor.

Key factors leading to potential loss of beds include nutrient inputs, which may lead to excessive epiphytical algal growth that smothers and shades the seagrass, and elevated turbidity which reduces light available and hence depth of distribution. Potential sources of these impacts include urban and industrial discharges and catchment usage, while direct damage has also occurred in some areas through swing-mooring chains, propellers, retrieval of anchors and indirectly through shading from jetty and pontoon construction (Jordan *et al.* 2002).

Figure 33 Seagrass beds with the Barretta Bank 'mega-quadrat' (yellow polygon) in North West Bay during 2010, including relatively stable beds (green polygons) and beds that have fluctuated through time (orange polygons) (Source: Mount and Otera 2011).

6.2.4 Microalgae

Microalgae are microscopic algae that provide the basis of biological production in aquatic ecosystems and grow in response to both the sun's energy and a complex interaction of physical and chemical parameters (Butler *et al.* 2000). They provide a direct food supply for shellfish and other filter-feeding animals, while they are also consumed by zooplankton (Section 6.1.6), which in turn are important for the productivity of fish, seabird and marine mammal populations. Microalgae living in the water column are referred to as phytoplankton while benthic forms are generally termed the microphytobenthos. Within the D'Entrecasteaux Channel and lower Huon Estuary, the phytoplankton have been the subject of detailed studies, while there have also been several investigations of the microphytobenthos. Some microalgae produce toxins which contaminate marine species and have important implications for environmental quality, human health and marine farming industries. Detailed information about harmful microalgae is provided with relation to water quality sampling in Section 11.2.4, and seafood safety in Section 14.3.1. The current section is aimed only at providing a general description of microalgal communities.

The composition of the phytoplankton defines the character of estuarine and coastal dynamics, with the presence and diversity of major classes such as diatoms (Bacillariophyceae), dinoflagellates (Dinophyceae) and other flagellates reflecting a complex interplay of environmental conditions. Phytoplankton composition can change rapidly depending on single or multiple factors such as temperature and salinity, degree of water stratification, types and concentrations of nutrients, and grazing pressure of zooplankton or benthic filter-feeders.

Investigations performed primarily during 2002-2005 indicated strong spatial and temporal patterns in the distribution and abundance of phytoplankton within the D'Entrecasteaux Channel and Huon Estuary. On seasonal time scales, mixed blooms of dinoflagellates and diatoms occurred in spring and blooms of predominantly dinoflagellates occurred in autumn. Comparisons with earlier data for the Huon Estuary suggested that over a longer time period (~1996−2005), there had been a significant increase in numbers of dinoflagellates, diatoms and small flagellates. Diatoms, especially *Skeletonema* spp. and *Pseudonitzschia* spp., tended to dominate in the northern parts of D'Entrecasteaux Channel, while dinoflagellates such as *Ceratium* spp. and *Gymnodinium catenatum* were more abundant towards the upper end of the Huon Estuary. These spatial differences may be related to the increased stratification and circulation of the Huon Estuary, conditions which favour dinoflagellates over diatoms (Volkman *et al.* 2009). For more detailed information on phytoplankton biomass and composition in the study area, refer to Section 11.2.4.

A study of the microphytobenthos in south-east Tasmania, including the D'Entrecasteaux Channel, Derwent Estuary and Pitt Water, found that it was comprised almost entirely (95%) of diatoms. A total of 111 diatom species from 46 genera was recorded across all of the survey sites, with the seven numerically dominant diatom species from each site constituting between 51 and 91% of the diatom community. Within the D'Entrecasteaux Channel, patterns of species dominance were assessed in three spatial zones that had been distinguished on the basis of sediment particle size, nutrient concentrations and salinity. The diatom *Navicula monoculata* var. *omissa* was a dominant component of the community in all zones, while a total of nine additional species representing *Nitzschia*, *Fragilaria*, *Ehrenbergia* and several additional genera were also important within at least one of the zones. Field investigations suggested that community composition was most strongly influenced by nutrient conditions, and hence the study concluded that benthic diatoms are a useful indicator of nutrient enrichment (Lane 2005). An additional study of mudflats in the Huon Estuary found that the microphytobenthos were important in nutrient cycling processes (Cook *et al.* 2009).

7 INTRODUCED SPECIES

7.1 Coastal weeds

The foreshores of the D'Entrecasteaux Channel and lower Huon Estuary support a wide variety of invasive weeds that threaten the survival of native plants and animals, and have negative effects on social, economic and conservation values. Weeds found around the foreshore include Weeds of National Significance (WoNS), 'declared' weed species listed under the *Tasmanian Weed Management Act 1999*, and additional environmental weeds. Environmental weeds include species which invade bushland and threaten native plants by out-competing them, and can in turn cause declines in local biodiversity (DPIPWE 2012c).

Foreshore vegetation mapping of southern Tasmania identified the dominant weed species within 1.0 ha cells located between the high water mark and 100 m inland (DTAE 2007). Within the study area, this mapping identified 31 species of weeds, with weeds present in 28.8 km^2 of the total 49.6 km^2 area surveyed (Table 15). Some of the more common weeds found include: blackberry, radiata pine, montpellier broom, Spanish heath, gorse, boneseed, briar rose and marram grass (DTAE 2007). Of the dominant species identified, 10 were declared weeds, with 6 of these also listed as WoNS. Additional council and DPIPWE Natural Values Atlas (NVA) data to 1 km from the high water mark indicate the presence of a further 17 declared weed species, including two additional WoNS (Huon Valley and Kingborough councils, unpub. data; DPIPWE 2012a). Records of weeds are relatively disparate between the council and state government databases, highlighting the need for integration and regular updating of records.

In total, 27 declared weed species have therefore been recorded along the coast of the D'Entrecasteaux Channel and lower Huon Estuary. The legal status of declared weeds requires landowners and managers to eradicate or control them, depending on the zoning for each particular weed under the Act. Eight of the declared weeds are also WoNS, as listed in the Australian Weed Strategy: boneseed, English broom, montpellier broom, blackberry, crack willow, gorse, bridal creeper and African boxthorn. There are 20 original and 12 additional recently declared WoNS (including weed species and suites of species) in Australia, and these are considered to be the country's worst invasive plants. Each of the original WoNS has a national strategy with actions to improve their management (Australian Weeds Committee 2012).

A number of regional weed-specific plans and strategies have been produced to assist with weed management in the region, as summarised in Table 16. The Southern Tasmanian Weed Strategy 2005-2010 (Schrammeyer 2005) provides a framework to identify and consolidate weed management issues in the NRM South region including the D'Entrecasteaux Channel and Huon Valley, and sets strategic actions and outcomes. Additional strategies for the Channel, Bruny Island and Huon Valley have included the following objectives: identifying and mapping priority weed species; establishing factors contributing to the introduction and spread of weeds and developing preventative measures; improving the level of training and community awareness for weed identification and management techniques; coordinating on-ground actions and regular monitoring; and developing strategies for addressing priority weed management issues in an integrated manner. Coastcare and other community groups have been involved in weed management works along the foreshore to remove weeds and perform ongoing maintenance for more effective control.

Table 15 Dominant foreshore weeds (Data source: DTAE 2007).

Scientific Name	Common Name	Declared or Environmental Weed	Area of coast (km^2)
Ammophila arenaria	marram grass	Environmental weed	1.09
Buddleja davidii	buddleja	Environmental weed	0.01
Chamaecytisus palmensis	tree lucerne	Environmental weed	0.39
Chrysanthemoides monilifera subsp. *monilifera*	boneseed	Declared weed*	1.3
Coprosma repens	mirror bush	Environmental weed	0.11
Cortaderia selloana	pampas grass	Declared weed	0.03
Cotoneaster sp.	cotoneaster	Environmental weed	0.63
Crataegus monogyna	hawthorn	Environmental weed	0.4
Crocosmia xcrocosmiiflora	montbretia	Environmental weed	0.37
Cytisus scoparius	English broom	Declared weed*	0.45
Erica baccans	erica	Environmental weed	0.01
Erica lusitanica	Spanish heath	Declared weed	1.86
Euryops abrotanifolius	euryops	Environmental weed	0.06
Foeniculum vulgare	fennel	Declared weed	0.03
Genista monspessulana	montpellier broom	Declared weed*	3.94
Hedera helix	ivy	Environmental weed	0.11
Ilex aquifolium	holly	Environmental weed	0.01
Lupinus arboreus	tree lupin	Environmental weed	0.1
Paraserianthes lophantha	Cape Leeuwin wattle	Environmental weed	0.07
Passiflora sp.	passion fruit	Environmental weed	0.01
Pinus radiata	radiata pine	Environmental weed	6.52
Pittosporum undulatum	sweet pittosporum	Environmental weed	0.22
Psoralea pinnata	blue butterfly bush	Environmental weed	0.22
Rosa rubiginosa	briar rose	Environmental weed	1.25
Rubus fruticosus aggregate	blackberry	Declared weed*	6.58
Salix species (excluding *S. babylonica*, *S.* x *calodendron* and *S.* x *reichardtii*)	willow	Declared weed*	0.57
Senecio jacobaea	ragwort	Declared weed	0.05
Typha latifolia	cumbungi	Environmental weed	0.1
Ulex europaeus	gorse	Declared weed*	1.61
Vinca major	periwinkle	Environmental weed	0.21
Watsonia meriana	watsonia	Environmental weed	0.4
not specified		Environmental weed	0.11
TOTAL			**28.80**

* = Weed of National Significance

Table 16 Weed management strategies.

Strategy/Plan	Reference	Focus Species
South NRM	Schrammeyer (2005)	30 priority weeds
Channel (excluding Bruny Is.)	Schrammeyer (2008)	42 priority weeds
Bruny Island	Chamberlain (2007)	22 priority weeds and 23 other important weeds
Bruny Roadsides	Chamberlain and Strain (2009)	26 priority weeds
Huon Valley	Strain (2007)	25 priority weeds

7.2 *Introduced marine species*

Introduced marine and intertidal species are a form of ecological pollution that can be extremely difficult – often impossible – to eradicate, and can result in severe consequences for the marine environment, aquaculture, commercial and recreational fishing, and public health (Whitehead *et al.* 2010). Potential adverse impacts of introduced species include habitat alteration, changes in trophic dynamics and community composition, fishery declines, fouling of marine structures and loss of aesthetic and amenity values (Aquenal 2002).

Vectors for introduction of these species are diverse, but include ballast water from ships, hull boring and fouling, inadvertent introduction via aquaculture stocks and equipment, and natural dispersal from adjacent infection sites. Ports frequently act as primary sites for introductions of marine species, particularly if they are located in estuarine environments. This high susceptibility to invasion can be attributed to unstable and disturbed habitats, high levels of food resources and potentially high levels of immigrants through shipping activities (Edgar *et al.* 1999). While there are currently no major shipping activities in the study area, several domestic and international shipping services previously exported products from ports in the Huon Estuary (see Section 3.4). For example, vessels formerly used for the transport of pulp from Port Huon carried ballast water from other Australian or overseas ports, although a condition of entry was that ballast water be discharged and replaced outside the Tasmanian coastal water zone (APM 1990). Of greater significance in terms of marine introductions is the close proximity of the study area to the Port of Hobart, an area with a high sustained level of shipping activity and large number of introduced marine species (Whitehead *et al.* 2010). Dispersal of larvae and spores via water currents, and attachment of juveniles and adults to vessels and equipment used locally, provide potential mechanisms for transfer from the Port of Hobart to the D'Entrecasteaux Channel and Huon Estuary.

There are currently 49 known introduced and cryptogenic (= potentially introduced) species in the study area (Table 17). This includes six 'target' introduced pest species, as categorised by the Australian Marine Pest Monitoring Manual (DAFF 2010), and a further 43 identified species. Note that another target pest, the European fan worm *Sabella spallanzanii*, was recorded on a moored vessel in Kettering in 2008. Follow up surveys around this area did not detect the species and no sightings have been reported since 2009, suggesting that it may not have established in the Channel (Hamilton 2011).

Table 17 Introduced and cryptogenic marine species (Source: Jordan *et al.* 2002, Aquenal 2003, Hamilton 2011).

TARGET SPECIES	
Scientific Name	***Common Name***
*Asterias amurensis**	Northern Pacific seastar
Codium fragile tomentosoides	dead man's fingers - green seaweed
*Crassostrea gigas**	feral Pacific oyster
*Gymnodium catenatum**	toxic dinoflagellate
*Undaria pinnatifida**	Japanese seaweed
*Varicorbula gibba**	European clam
OTHER INTRODUCED AND CRYPTOGENIC SPECIES	
Fish	**Seastars**
Salmo salar (escapee Atlantic Salmon)*	*Patiriella regularis**
Forsterygion varium	**Polychaete worms**
Molluscs	*Euchone limnicola*
Chiton glaucus	**Crustaceans**
*Maoricolpus roseus**	*Cancer novaezealandiae**
Raeta pulchella	*Carprella acanthogaster*
Theora lubrica	*Chelura terebrans*
*Venerupis largillierti**	*Elminius modestus*
Bryozoans	*Halicarcinus innominatus*
Bugula flabellata	*Petrolisthes elongatus*
Bugula neretina	**Algae**
Cryptosula pallasiana	*Callithamnion byssoides*
Tricellaria inopinata	*Cladophora lehmanniana*
Watersipora subtorquata	*Cladophora sericea*
Cnidarians	*Colaconema caespitosum*
Bougainvillia muscus	*Cutleria multifida*
Clytia hemispherica	*Ectocarpus siliculosus*
Clytia paulensis	*Enteromorpha compressa*
Halecium delicatulum	*Enteromorpha intestinalis*
Obelia dichotoma	*Grateloupia turuturu*
Ascidians	*Hincksia sandriana*
Ascidiella aspersa	*Polysiphonia brodiei*
Botrylloides leachii	*Polysiphonia subtilissima*
Botryllus schlosseri	*Pterosiphonia pennata*
Ciona intestinalis	*Ulva lactuca*

* = also recorded in 1999

Within the study area, impacts of introduced species have been best documented for the toxic dinoglagellate (microalga) *Gymnodinium catenatum* and the New Zealand screwshell *Maoricolpus roseus*. Blooms of *G. catenatum* have at times caused unacceptably high levels of toxins in commercial oysters and mussels, resulting in the periodic closure of shellfish farms in the region. Impacts from this species first occurred in the 1980s and are still continuing to the current day, with problematic blooms recorded in 2012 (see Section 14.6). A recent study recorded the screwshell *M. roseus* at densities of up to 2000 per m^2 in the D'Entrecasteaux Channel. Field experiments demonstrated that this species may drastically modify the structural complexity and biological attributes of benthic habitats and impact on the abundance and condition of commercial scallop species (Reid 2010).

Studies of the northern Pacific seastar *Asterias amurensis* have been conducted in the adjacent Derwent Estuary, and suggest large impacts on bivalve populations, overall composition of soft sediment communities, and also potentially on the Endangered spotted handfish (references in Whitehead *et al.* 2010). A survey of the Huon Estuary in 2004 noted that *A. amurensis* was relatively common but more localised than in the Derwent Estuary (Macleod and Helidoniotis 2005). Monitoring of this species was also performed in the adjacent D'Entrecasteaux Channel in conjunction with scallop surveys during 2006-2008 and suggested an expanding range and increased density over time. Based on sites surveyed, the main infestation detected was around Satellite Island and Alonnah (Figure 34), an area experiencing a sevenfold increase in seastar density between 2006 and 2008. The impact of the northern Pacific seastar is a concern in regards to the future health of the D'Entrecasteaux ecosystem as well as the sustainability of scallop beds (Tracey and Lyle 2008).

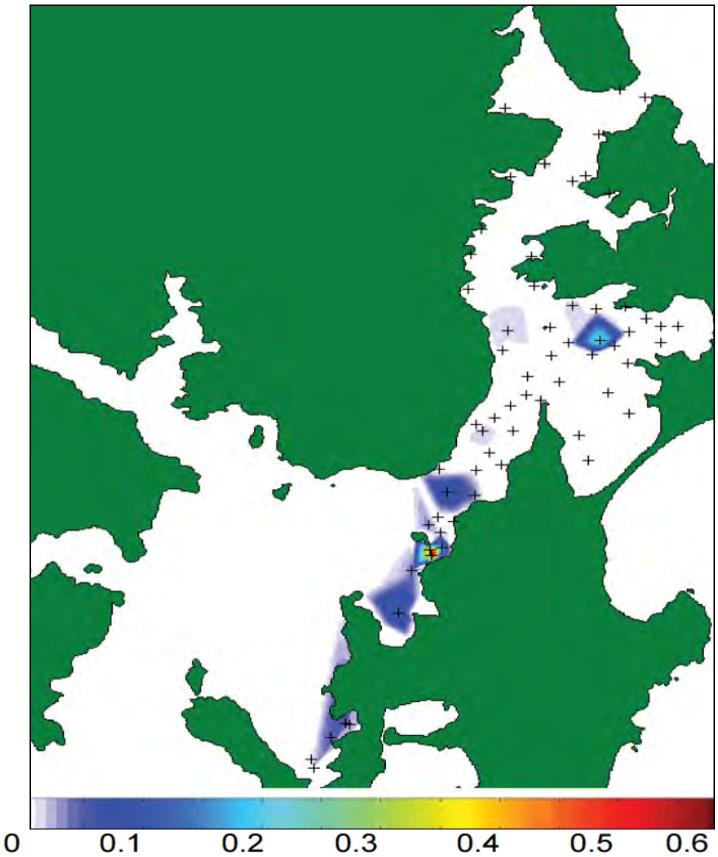


Figure 34 Density per m^2 of the introduced northern Pacific seastar based on 62 sample sites (crosses) (Source: Tracey and Lyle 2008).

The 1999 State of the D'Entrecasteaux Channel report identified just ten introduced marine species (Phillips 1999), although no targeted surveys had been conducted at that time. The large increase since then may be more a reflection of recent targeted surveying at the Kettering and Dover ports (Aquenal 2003), rather than a large number of post-1999 introductions. However, there is evidence that introduced marine species are increasing in numbers. Benthic monitoring during 1998-2003 at Tasmanian marine farm sites, a large portion of which occur in the study area, found that the proportional abundance of introduced species to the total benthic community increased by 2-3% per annum (Edgar *et al.* 2009). The most common and widespread introduced species include the bivalves *Theora lubrica* and *Corbula gibba*, and *M. roseus*. In addition, the adjacent Derwent Estuary is known to harbour at least 70 introduced and cryptogenic species (Aquenal 2002), and hence the likelihood of additional introduced species being identified, and the risk of further introductions occurring, is high. This emphasises the need to maintain a high level of hygiene for vessels and other equipment moving between the Derwent and Channel/Huon waterways. At national and state levels, there are various legislative controls and initiatives aimed at reducing the risks of marine species introductions and spread, focussing most recently on biofouling management requirements (DAFF 2011).

8 CLIMATE CHANGE

8.1 Regional climate change projections

Future climate change will impact upon the natural environment, infrastructure and heritage values of the D'Entrecasteaux Channel and lower Huon Estuary. In general, Tasmania is unique in lying at the border of regions showing contrasting drying and wetting trends predicted by global climate models. These factors make climate change projections for Tasmania difficult on the basis of broadscale models alone, and hence higher resolution modelling has been performed to generate more accurate fine-scale predictions for Tasmania and its subregions (Corney *et al.* 2010).

The most recent modelling has been performed as part of the Climate Futures for Tasmania project undertaken by the Hobart-based Antarctic Climate Ecosystem Co-operative Research Centre (ACE CRC). This project produced climate simulations to 2100 based on the downscaling of an ensemble of global climate models and application of high and low emissions scenarios (Grose *et al.* 2010). Some of the key findings include:

- Tasmanian air temperature is projected to rise by about 2.9°C under high greenhouse gas emissions or by 1.6°C under low emissions. Temperature change under the two emissions scenarios is similar until they separate in the mid-21st century and the rate of temperature rise under the higher emissions scenario increases at a faster rate. The projected temperature changes for both emissions scenarios are less than the Australian and the global average changes for the same period due to the moderating influences in Tasmania of the Southern Ocean.
- There is no significant change to projected total annual rainfall over Tasmania under either emissions scenario. However, there are significant predicted changes in the spatial pattern of rainfall, with an emerging pattern of increased annual rainfall and surface runoff in coastal regions such as the D'Entrecasteaux Channel and lower Huon Estuary.
- An increase in sea surface temperature off the Tasmanian east coast of up to 3.5°C is predicted by 2100. This enhanced warming is caused by a southward extension of the East Australian Current over the 21st century, with its influence extending to the D'Entrecasteaux Channel and lower Huon Estuary. The sea surface temperature rise, in conjunction with other processes, will be associated with an increase in rainfall on the east coast, particularly during summer and autumn.

8.2 Projected climate change impacts on the waterway

A wide range of climate change impacts have been predicted for the D'Entrecasteaux Channel and lower Huon Estuary waterways as a result of modified air and water temperatures, river flows, rainfall, wind and storm events. Potential impacts investigated relate primarily to sea level rise and coastal recession, as well as changes to water temperatures and chemical properties that influence the composition of marine and estuarine biological communities. To increase the resilience of the region's natural environment to climate change, there is a need to reduce anthropogenic causes of environmental stress and increase knowledge and understanding of the risks and available management options (Whitehead *et al.* 2010).

8.2.1 Sea level rise and coastal vulnerability

Shoreline erosion and flooding due to sea level rise are primary concerns with regard to climate change impacts on the coastal environment. The *Third Assessment Report* of the United Nations Intergovernmental Panel on Climate Change (IPCC) released in 2001 estimated a global sea-level rise of 9-88 cm from 1990 to 2100. This figure was updated to 18-59 cm between 1990 and 2095 in their *Fourth Assessment Report* released in 2007, although the report indicated that an additional 10-20 cm should be added to the upper ranges of these projections to account for melting land ice. The IPCC is currently progressing a *Fifth Assessment Report* which will provide further updated information about predicted sea level rises and other consequences of climate change.

Several studies in Tasmania have been performed to investigate the potential effects of the sea level rises predicted by the IPCC, and the areas most vulnerable to impacts. Sharples (2006) mapped vulnerability of the Tasmanian coastline to storm surge flooding and erosion as a result of sea level rise by overlaying coastal height and geomorphological data. Certain basic geomorphic (landform) characteristics predispose some shores to being more susceptible than others to physical changes associated with sea-level rise. In the D'Entrecasteaux Channel and lower Huon Estuary, areas of high vulnerability were noted particularly at the southern end of Bruny Island Neck and the entrances of the North West Bay and Esperance Rivers, while smaller areas of high risk were also identified at the mouth of Snug River, islands of the northern Channel, Missionary Bay, Great Bay, Port Cygnet, Hospital Bay at Port Huon, and several other localities. The types of impacts that may be experienced in high vulnerability areas include: flooding, erosion and landward recession, increased dune mobility, increased slumping, accelerated rock fall and cliff-collapse, rising coastal groundwater tables and increased penetration of salt water wedges into coastal ground waters (Sharples 2006). A subsequent mapping study investigated additional geomorphological parameters in the study area (see Section 2.3), including dune mobility, and hence will also assist managers in identifying coastal geomorphic hazards in relation to climate change (DTAE 2007).

The Climate Change and Coastal Risk Management Project of DPIPWE has developed information on extreme probabilities for current and future sea-levels, and conducted a desktop audit of vulnerable assets and values around the Tasmanian coast. The frequency and severity of storm surge events relative to current sea level and coastal infrastructure locations is predicted to increase within the region as a result of rising sea levels. Data produced for Hobart, which are also considered applicable to the D'Entrecasteaux Channel and lower Huon Estuary, indicated that for the year 2000 there was a 70% chance of a height 1.49 m above current Australian Height Datum (AHD) being exceeded as a 1 in 100 years event. By the year 2040, the same level of chance of exceedance rises to 1.59 m above AHD, and by the end of the century, to 1.92 m above AHD (DPIW 2008d). Assets at risk of storm surge flooding within the Kingborough and Huon Valley municipalities include conservation reserves, heritage sites, sailing clubs, camping grounds, care services, community halls, roads and several other types of public facility (DPIW 2008e).

While flooding and erosional coastal hazards have been identified at several locations in the Kingborough region, the Kingborough Council recently commissioned a more comprehensive assessment of coastal hazards across the entire municipality. The study provides a 'detailed first pass' assessment using a combination of existing data, strategically-targeted field work and 'bathtub' modelling of worst case erosion and inundation scenarios to 2100 (Sharples and Donaldson 2012). The aim is to identify all shore types potentially susceptible to erosion and recession due to sea level rise, and highlight areas where assets may be at stake. The coast was divided into compartments based on dominant landform types, with 22 compartments identified in the D'Entrecasteaux Channel. Hazard issues for each compartment have been identified, together with an interpretation of known coastal processes. While this project has not yet been completed, some preliminary results are indicated in Figure 35, highlighting coastal hazard 'hotspots' within the D'Entrecasteaux Channel and broader Kingborough municipality.

While the above studies have focussed on future projections of sea level rise and associated impacts, there is current evidence of erosion and other physical changes to the coast. For example, some roads and beaches in the study area have been observed to be inundated and eroded at times of low pressure, on-shore winds and extreme high tides. Natural changes can occur over relatively short periods, and may be independent of longer term increases in sea level or human disturbance. While this makes it difficult to separate short term changes from the longer term impacts of climate change, the major conclusion is that development should be minimised on soft shores that are susceptible to erosion and recession (DTAE 2007).

Figure 35 Coastal hazard 'hotspots' (Source: Sharples and Donaldson 2012).

8.2.2 Habitats, biological communities and fisheries species

Changes in temperature, environmental flows, ocean pH, sea level, and wind regimes are all contributing to modifications in productivity, distribution and timing of life cycle events in marine and estuarine species, affecting ecosystem processes and altering food webs (Pecl *et al.* 2011b). In addition to ocean warming, climate change is leading to alterations of ocean currents and also ocean chemistry associated with increased carbon dioxide uptake. This is turn is expected to affect marine biodiversity and resources, which may have substantial implications for communities and industries that depend upon marine and estuarine environments. A number of changes in biological communities have already taken place, and are reflected in the D'Entrecasteaux Channel and lower Huon Estuary, while risk assessment studies have examined potential impacts on fisheries species found in the region.

Biological communities and habitats

The vulnerability of the D'Entrecasteaux Channel and lower Huon Estuary to climate induced changes in marine and estuarine communities relates largely to the increasing southerly penetration of the East Australian Current (EAC), which has strengthened by 20% in the last 50 years (Hill *et al.* 2008). The resulting ocean warming, as measured off Tasmania's east coast, is occurring at three times the average rate recorded globally (CSIRO 2007). This has resulted in range extensions of species previously not recorded as far south as the D'Entrecasteaux Channel and lower Huon Estuary, or even Tasmania in some cases. Examples are the long-spined sea urchin *Centrostephanus rodgersii* and the microalga *Noctiluca scintillans*. The urchin C. *rodgersii* has been recorded in the study area, although is currently not impacting on the region to the extent observed further north in Tasmania (see Section 6.1.5). The microalga *N. scintillans* now appears to be a permanent member of the phytoplankton community in the D'Entrecasteaux Channel and lower Huon Estuary, and during bloom events has the potential to harm fish and other species through depletion of oxygen (see Section 11.2.4). Many other changes in the structure of nearshore marine communities in Tasmania have been linked to southerly extensions of the EAC, and cascading effects of ecological change in the food webs of benthic (rocky reef) and pelagic systems have been hypothesised (Johnson *et al.* 2011).

Given that a large contributor to Tasmania's high biodiversity is the assemblage of cold-water dependent species that are absent or limited elsewhere in Australia (see review in Parsons 2011), ocean warming is expected to lead to reduced species richness. For example, anticipated temperature increases are likely to be outside the tolerances of the Endangered spotted handfish (*Brachionichthys hirsutus*) found in the northern D'Entrecasteaux Channel (DPIPWE 2010b). Cold-water adapted algae could also be impacted, leading to a reduction in marine productivity. Declines in Tasmanian giant kelp beds have been attributed partly to warmer ocean temperatures (Edyvane 2003), and while the D'Entrecasteaux Channel and lower Huon Estuary have not recorded declines to the same extent as recorded further north (see Section 6.2.3), effects may increase in the future. Given that the giant kelp provides habitat for a wide range of fish and invertebrate species, future declines are likely to have significant flow on effects for entire biological communities.

Additional impacts on coastal habitats relate to sea level rise, particularly as the region under the influence of the EAC is predicted to experience greater increases in sea levels than other parts of Australia (Hobday and Lough 2011). Coastal habitats such as saltmarshes will be particularly vulnerable to the effects of climate change, as demonstrated by a recent mapping study which predicted 'future saltmarsh footprints' based on expected rates of landward retreat. The study identified a number of existing uses and activities within the study area which may impede the retreat of saltmarshes under the influence of climate change (see Section 5.2). Widening and deepening of estuaries and greater upstream penetration of tides will also modify habitats and associated communities. The loss of sandy beaches or dunes where they are bounded by environments not conducive to inland retreat has significant consequences for nesting shorebirds of the region (DPIPWE 2010b). Work has been initiated to assess bird habitats most at risk, with the focus to date on the Bruny Island coast (E. Woehler, Birdlife Tasmania, pers. comm.).

Fisheries species

A risk assessment of climate change impacts on aquaculture and wild fisheries species was performed for south-east Australia (Pecl *et al.* 2011b) and included species that are important recreationally and commercially in the D'Entrecasteaux Channel and lower Huon Estuary. Of the wild species, the southern rock lobster *Jasus edwardsii* and blacklip abalone *Haliotis rubra* were rated as being amongst the highest risk species due to the limited dispersal capacities of adults, relatively low physiological tolerances, and strong association of life stages (e.g. spawning and settlement) with environmental cues. These species are also impacted by other outcomes of ocean warming, such as range shifts in grazing species (e.g. C. *rodgersii*, above) and a decline in macroalgae. The commercial scallop *Pecten fumatus* was also identified as being at high risk due to temperature-induced changes in reproduction and growth and the effects of increased acidity on shell development, although the impacts of ocean acidification are poorly understood. Should seagrass beds be impacted by climate change, there are also implications for the southern calamari *Sepiotheuthis australis*, a species which breeds on this habitat in the D'Entrecasteaux Channel. The study noted that there have been declines in many wild species in recent years and that other stressors, such as overfishing, recruitment failure and degradation of seagrass beds, may reduce the capacity of species to cope with the effects of climate change.

In the case of aquaculture species, the above risk assessment study suggested that Pacific oysters (*Crassostrea gigas*) and blue mussels (*Mytilus galloprovincialis planulatus*) are at highest risk from climate change due to potential impacts on larval development, adult growth and susceptibility to disease. For Atlantic salmon (*Salmo salar*), moderately high sensitivity was predicted primarily related to the growout stage, with increases in disease and the lack of future suitable farm locations being key concerns. Currently, high summer temperatures in Tasmania can affect productivity and health of salmon, and cause an increase in disease outbreaks (Pecl *et al.* 2011b). A separate study of potential climate change impacts on this species suggested that while increased water temperatures are expected to effect salmonid growth and nutrition, these impacts could potentially be offset by selective breeding focussing on higher tolerance of elevated temperatures. Other options, such as relocating growout facilities to areas with significantly cooler temperatures offshore, do not appear feasible on the basis of cost, technology, operational logistics and likely storm damage (Battaglene *et al.* 2008).

9 ANTHROPOGENIC INPUTS

This section discusses, and where possible quantifies, human or 'anthropogenic' sources of pollutants and other compounds to the D'Entrecasteaux Channel and lower Huon Estuary. These are described here as 'inputs', as opposed to collectively being described as 'pollutants', because some compounds of anthropogenic origin may also occur naturally in the waterways. For example, nutrients occur naturally via ocean current contributions; however, additional anthropogenic inputs may result in modification of natural ecosystem dynamics.

Anthropogenic inputs enter the D'Entrecasteaux Channel and lower Huon Estuary from a variety of point and diffuse sources. Point sources are those which emit wastes from a discernible and confined source location, while diffuse sources contribute to inputs via land runoff, rainfall, atmospheric deposition, drainage and seepage, and cannot be traced to a precise source. Point sources in the region include nine sewage or wastewater treatment plants (WWTPs), three fish processing plants, and 20 operational finfish farming leases. Examples of diffuse sources include stormwater drains, septic and other urban runoff, tips and contaminated sites, quarries, catchment inputs carried by rivers and creeks (e.g. forestry and agricultural runoff), and wastes associated with marinas and other boating activities. Contaminants emitted from these various sources include nutrients, organic matter, pathogens, silt and a range of toxicants such as heavy metals and pesticides.

This section of the report presents available information on point source inputs to the waterways, and also documents areas and activities that may contribute to diffuse runoff. Note that certain activities are classified as 'Level 2' in accordance with the *Environmental Management and Pollution Control Act 1994* and are regulated by the Tasmanian Environment Protection Authority (EPA). Other smaller-scale activities are classified as 'Level 1' and are usually regulated by councils or regional authorities.

9.1 Wastewater treatment plant discharges

Sewage discharges are a source of nutrients, pathogens and toxicants such as metals, and have the potential to impact on ecosystem and human health. Toxicants in sewage are typically related to trade wastes and household chemical wastes. In Tasmania, WWTPs exceeding 100 kL/day design capacity are classified as Level 2 activities and hence regulated by the EPA. Requirements for environmental management are more stringent for these WWTPs than for the smaller Level 1 plants. The *State Policy on Water Quality Management 1997* also includes a number of relevant provisions, including: avoidance of discharges and prioritisation of effluent reuse wherever feasible; setting of discharge limits in line with published Emission Limit Guidelines or site-specific considerations; and the setting of mixing zones where required (Whitehead *et al.* 2010).

Prior to July 2009, the provision of water and sewerage services in Tasmania was mainly the responsibility of individual local councils. Following the establishment of three regional water corporations under the *Water and Sewerage Corporation Act 2008* by the state government, Southern Water became the water and wastewater service provider for southern Tasmania. As a result there have been changes to the management and record keeping systems for WWTPs, and limited pre-2009 data are readily available for some WWTP attributes (e.g. effluent flows) in the study area.

There are currently nine WWTPs adjacent to the D'Entrecasteaux Channel and Huon Estuary (Figure 36); noting that WWTPs at Ranelagh and Geeveston are outside the precise study area of the project but have been included due to their point-source nature and potential downstream influences. All WWTPs have secondary treatment of waste, while six currently discharge directly to waterways (Table 18). An additional WWTP at Woodbridge has very low flows and effluent is discharged to a series of evaporation/transpiration beds and then to a dam, with no set discharge point to the marine environment. However, there is the potential for wastewater to reach the Channel via smaller drains (K. McLeod, Southern Water, pers. comm.) and hence it is also categorised here as a direct input.

Figure 36 WWTP locations (Source: Southern Water, DIER).

Table 18 WWTP descriptions (Source: Southern Water, DIER).

WWTP	Activity Level	Reuse	Discharge to waterway	Industrial Trade Wastes	
				Category 3	Category 2*
Howden	1	100%	No	No	No
Margate	2	No	Yes	Yes - Fruit beverages	Yes (5)
Electrona	2	No	Yes	Yes - Fish processing	No
Kettering	1	No	Not at this stage	No	Yes (2)
Woodbridge	1	No	Yes, but not via a dedicated outfall	No	No
Cygnet	2	No	Yes	No	No
Ranelagh	2	No	Yes	Yes - Fish processing	Yes (17)
Geeveston	2	No	Yes	No	Yes (1)
Dover	2	No	Yes	No	No

* = numbers in brackets represent number of premises.

Two WWTPs currently do not discharge directly to the waterways, and hence are not expected to have any direct influence on environmental quality of aquatic environments. Effluent from the Howden WWTP is pumped to a dam and is 100% re-used by the adjacent golf club. An additional small WWTP at Kettering processes wastes from several commercial enterprises in the area and is currently managed by the Department of Infrastructure, Energy and Resources (DIER), rather than Southern Water. Whilst it is intended that treated effluent from this WWTP will be discharged to the waterway, wastewater volumes have been insufficient for plant requirements and hence effluent has been of insufficient quality for discharge. The wastewater is currently being transferred to WWTPs outside the study area (Blackmans Bay, Selfs Point and Macquarie Point), and work is underway on modifications to the plant so that it can operate independently (G. Ginneliya, DIER, pers. comm.).

Five of the WWTPs receive industrial trade wastes, with three receiving category 3 waste, and four receiving category 2 waste (Table 18). Category 3 waste includes premises such as processing plants, while category 2 waste includes premises such as service stations, supermarkets, and restaurants. Accidental spillage of raw sewage from WWTPs, pump stations and other infrastructure malfunctions occurs from time to time and is usually related to sewerage surcharge during wet weather or blockages during dry weather. Localised impacts from these sources can be significant; for more information on documented spills, see Section 9.6. Septic systems are also a key issue, as described in Section 9.1.4.

9.1.1 WWTP effluent quantity and quality

Effluent is monitored at all WWTPs on a monthly basis for flow volume, total suspended solids (TSS), biochemical oxygen demand (BOD), faecal bacteria (measured as thermotolerant coliforms), ammonia, total nitrogen (TN) and total phosphorus (TP). Nitrate-nitrite (NO_x) is also measured at Level 2 WWTPs, although some recent data are unavailable for Margate. Monitoring data give an indication of typical effluent quality and are reported to the EPA as a regulatory requirement for Level 2 outfalls. Data for 2011 are presented in Table 19, while total flows and inputs are also indicated for 2009-2012 on the basis of available data. Flow data were available from July 2009, except at Howden and Woodbridge where flow data were not available until July 2010 and November 2010, respectively. No flow data are available for years preceding 2009, and hence no estimates can be made of total inputs to the D'Entrecasteaux Channel and Huon Estuary prior to this.

Several factors should be noted with regard to effluent data presented here:

- The small WWTP at Kettering is excluded entirely from this report section because it was only commissioned in 2011, and aspects of its operation are still being resolved as described above; there have been no discharges to waterways to date.
- Data are provided for 2011 for the Howden WWTP in Table 19 to demonstrate the quantity and quality of effluent produced, but because 100% of this effluent is allocated to re-use, it is not included in analyses of total inputs.
- Data are available at most WWTPs for July 2009 to June 2012, and hence have been presented in Table 19 for half calendar years as well as years to maximise possible temporal comparisons using the available data.
- Data were not available for Woodbridge for some periods (as indicated in Table 19); however, the contribution of this WWTP to total inputs was very small (<1%) (Figure 37) and hence has little effect on temporal trends.

The combined total average daily flow from all WWTPs discharging to the D'Entrecasteaux Channel and Huon Estuary in 2011, after reuse, was approximately 3,279 kL/day (Table 19). This is very low in comparison to the adjacent Derwent Estuary for example, where combined WWTP flows of 43,500 kL/day were reported for 2008 (Whitehead *et al.* 2010). Relative contributions from each WWTP are shown in Figure 37. In terms of flow volume, Ranelagh was by far the biggest contributor and accounted for 43% of treated effluent to the waterways, while this WWTP also accounted for nearly 50% of TP inputs. However, Ranelagh, Margate and Electrona contributed relatively equal loads of TSS and together accounted for 83% of inputs. These three WWTPs were also the largest contributors of sewage-derived BOD, ammonia and TN, while Geeveston, Cygnet and Dover delivered smaller inputs and Woodbridge accounted for <1% of contaminants. In contrast, Cygnet and Geeveston were the largest contributors of NO_x, although data were unavailable for this parameter for Margate. Due to difficulties in calculating mass emissions of thermotolerant coliforms, relative loads could not be determined. Instead, the geomean values for each plant are provided, including comparisons with data from other years (Figure 38) (refer to Section 9.1.2 below).

Table 19 WWTP average daily flows, mean contaminant concentrations and annual inputs (Data source: Southern Water).

WWTP	Discharge	TSS		BOD		Ammonia		NO_x #		Total Nitrogen		Total Phosphorus		Thermotolerant Coliforms
	kL/day	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	(cfu/100mL)
Howden	56	33.1	0.7	18.8	0.4	25.0	0.5	-	-	31.7	0.6	1.2	0.0	843.6
Woodbridge	12	35.4	0.2	22.8	0.1	1.2	0.0	-	-	9.3	0.0	5.7	0.0	643.8
Margate	562	51.1	10.5	45.2	9.1	27.5	5.5	-	-	33.6	6.7	6.7	1.3	3305.9
Electrona	366	71.8	9.3	99.5	13.2	21.3	2.6	0.2	0.0	31.5	4.0	5.0	0.6	110.9
Cygnet	413	14.1	2.3	8.5	1.3	2.1	0.3	4.9	0.7	8.8	1.3	3.8	0.5	23.1
Geeveston	304	10.3	1.3	6.1	0.6	4.7	0.5	5.1	0.5	10.5	1.0	2.0	0.2	15.9
Ranelagh	1392	17.3	9.2	15.9	8.2	10.7	4.4	0.6	0.4	16.4	7.5	5.7	2.9	94.7
Dover	230	27.2	2.2	25.3	1.9	17.4	1.3	1.2	0.1	22.7	1.7	5.1	0.4	29.1
Total daily flows and inputs in tonnes per year (excluding Howden WWTP- due to 100% reuse)														
January-June														
2010*	2094	18.2		18.1		10.1		0.3		13.1		2.7		
2011	3295	14.8		15.1		7.0		0.8		11.3		3.1		
2012	2929	14.4		15.4		9.3		1.4		12.3		3.4		
July-December														
2009*	3805	22.6		16.6		8.4		0.6		11.7		2.1		
2010*	2852	70.0		14.3		9.0		0.5		13.6		3.1		
2011	3254	20.0		19.2		7.6		1.0		11.0		2.8		
Full Year														
2010*	2474	88.2		32.4		19.1		1.0		26.7		5.8		
2011	3279	34.8		34.4		14.6		1.7		22.3		5.9		

* = Also excludes the Woodbridge WWTP - data not available. # = NO_x data not available for available for Howden, Woodbridge or Margate.
Thermotolerant coliform concentrations for each WWTP are presented as a geometric mean of the 12 monthly samples.
Loads in t/yr have been calculated using average monthly values for both the input parameter and flow, as opposed to extrapolating on the basis of the average daily flow rate for the year.
Data presented for most WWTPs were derived from one effluent sample per month; annual loadings should, therefore, be viewed as 'best estimate only'.

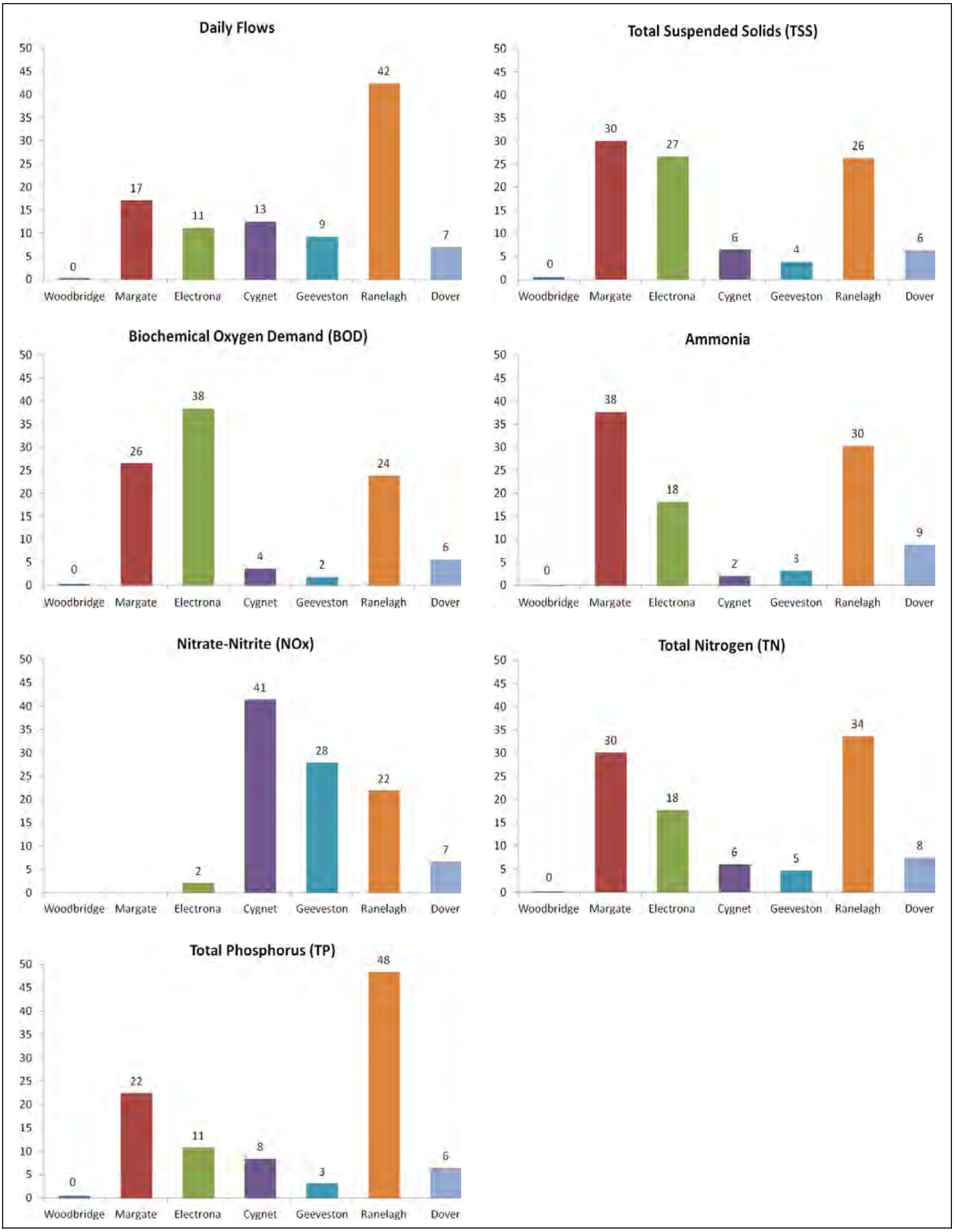


Figure 37 Relative contributions (%) of WWTPs to contaminant inputs in 2011, noting that NO_x data were unavailable for Woodbridge and Margate (Data source: Southern Water).

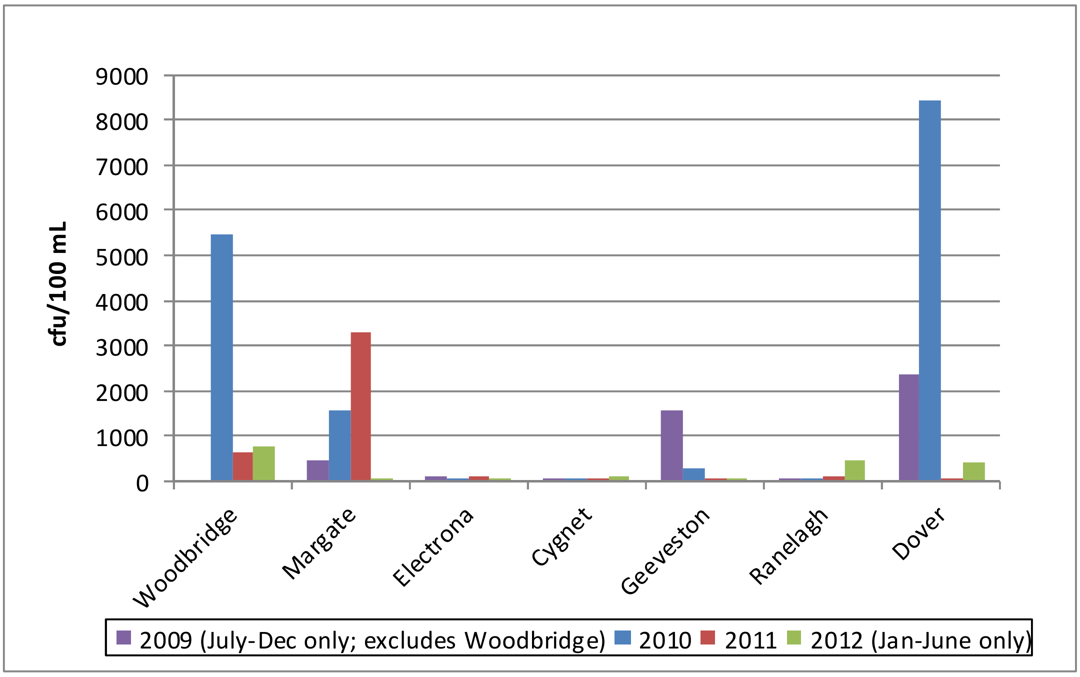


Figure 38 Thermotolerant coliforms in WWTP effluent (Data source: Southern Water).

9.1.2 Temporal trends in WWTP effluent quality and inputs

Due to the absence of effluent flow volume data prior to July 2009, longer term trends in sewage-derived inputs cannot be assessed. Comparisons over 2010-2011 suggest declines in emissions of ammonia, TN and TSS, and slight increases in BOD, NO_x and TP (Table 19), although little can be deduced about temporal changes over this small time scale. It is hoped that data presented will provide a suitable baseline for future comparisons.

Estimated thermotolerant coliform loads have varied considerably between WWTPs and over time (Figure 38), and it is difficult to identify trends between plants or temporally. While the Margate WWTP recorded by far the highest geomean concentration in 2011, this was not the case in 2010 when much higher values were recorded at both Dover and Woodbridge. Contrasting flow volumes between WWTPs prevent direct comparisons of inputs on the basis of these data. Inter-annual variability is likely to be due to factors such as plant capacity and performance, rainfall conditions and infrastructure-related issues (Whitehead *et al.* 2010).

Some earlier estimates of sewage inputs to the Huon Estuary and the combined D'Entrecasteaux Channel/Huon Estuary were made by the Huon Estuary Study (HES) and the Whole of Ecosystem Assessment for Salmon Farming (WoEASF), respectively (see Section 13.1). These studies estimated inputs on the basis of population statistics and predicted inputs/household, and did not incorporate analyses of effluent outfall data. The HES estimated in 1997 that total inputs to the Huon Estuary at that time were 28 tonnes of dissolved nitrogen and 9 tonnes of dissolved phosphorus, with these values including estimated inputs from reticulated sewerage and septic systems (Butler *et al.* 2000). The WoEASF subsequently estimated a TN sewage-derived input of 120 tonnes in 2005, although this figure included the Taroona and Blackmans Bay WWTPs in the lower Derwent Estuary as well as WWTPs in the Huon and Channel (Volkman *et al.* 2009). The total average daily flow of all WWTPs was estimated to be 5.3 ML per day in 2005, and projected to increase to 6.6 ML per day by 2010 and 10.3 ML per day by 2030. The inputs estimated here, including 22.3 to 26.7 tonnes TN per year and flows of 2.5-3.3 ML/day during 2010-2011, are very small compared to the reported and projected values of the WoEASF. Similarly, recent inputs from WWTPs discharging to the Huon Estuary are also considerably smaller than those estimated by the HES. The higher estimates of the WoEASF can be explained largely by the inclusion of several WWTPs outside the immediate Channel and Huon waterways in that study. In the case of the HES, the population-based calculation method allocated inputs from septic as well as reticulated systems, whereas the recent data presented here relate solely to point-source reticulated inputs. Differences in methodology therefore prevent direct temporal comparisons between earlier studies and recent WWTP data.

While flows and hence estimates of total inputs on the basis of effluent outfall data are not available pre-2009, earlier data are available on concentrations of some contaminants in WWTP effluent. These data are patchy, with fewer analytes monitored initially and gradually supplemented, whilst there are data gaps for some years. Keeping in mind these data limitations, Figure 39 provides average annual concentrations during 2000-2011. There appear to have been steady increases since 2001 in concentrations of BOD, ammonia and nitrogen at some WWTPs, most notably Margate and Electrona. TSS has also increased over the last 5 years at Electrona, while there is a trend for increasing ammonia, but declining TSS and thermotolerant coliform counts, at Dover. Average NO_x concentrations have demonstrated declines in recent years at most Level 2 WWTPs, with the notable exception of Geeveston. While these data are not informative about total loads discharged, they are useful in depicting general trends in effluent quality.

9.1.3 Recent management activities and new initiatives

A number of upgrades have been implemented by local councils and subsequently by Southern Water since 1999, while outstanding compliance issues have also been identified (Table 20).

In addition, a number of initiatives and upgrades are planned over the next five years, including:

- Ranelagh – an upgrade involving installation of new mechanical and electrical equipment to improve plant capacity and effluent quality, and allow for growth.
- Electrona – short-term upgrades are being considered, prior to eventual diversion to Blackmans Bay in 2014/2015.
- Margate – to be diverted to Blackmans Bay in 2014/2015.
- Geeveston – outfall to be relocated to the ocean/estuary rather than the Kermandie River.
- Dover – to be upgraded in stages.
- Cygnet – environmental studies to be conducted.
- Woodbridge – an upgrade to this system is currently being designed to allow for growth and environmental improvement.
- Howden – to be potentially diverted to Blackmans Bay in 2014/2015.

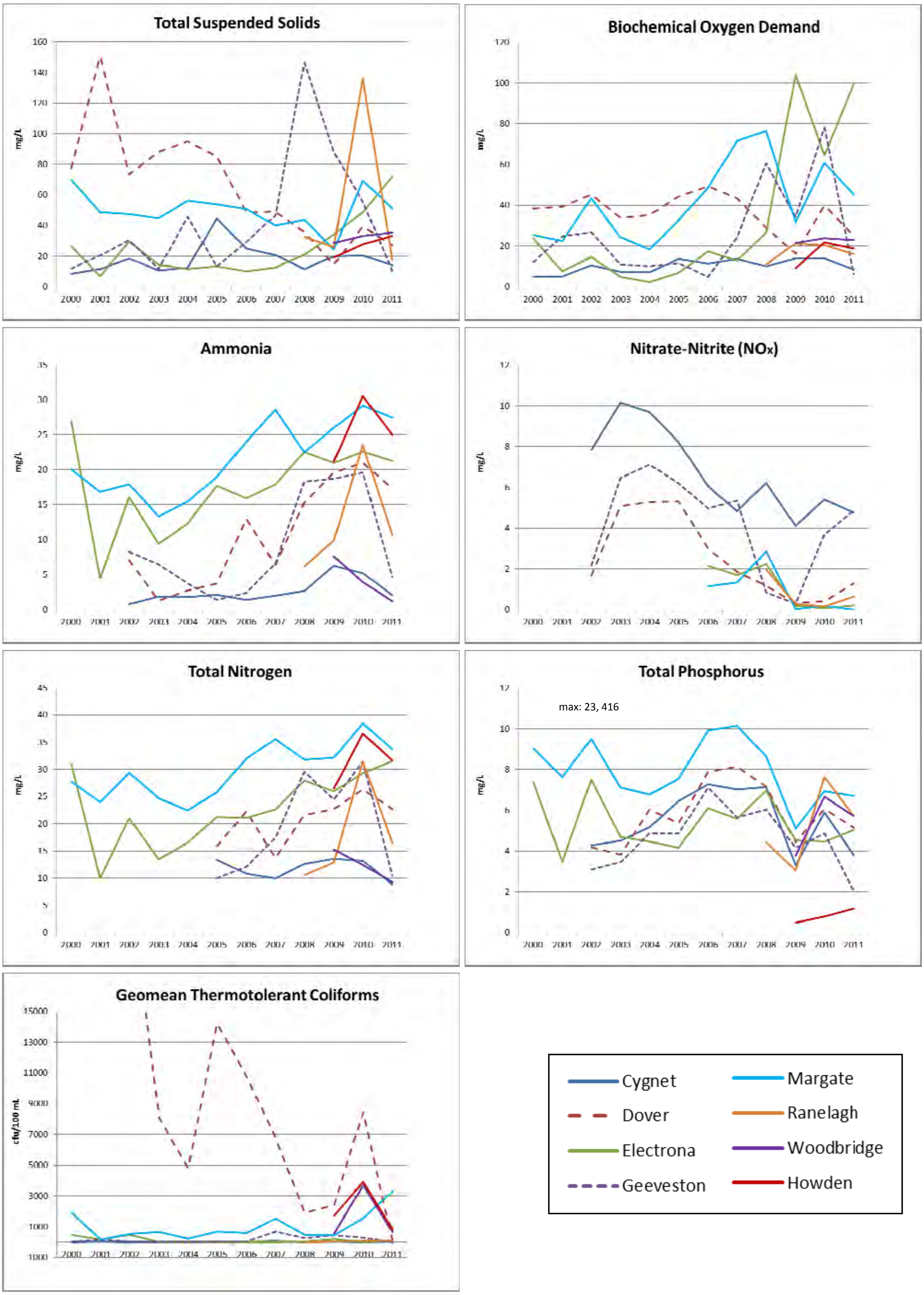


Figure 39 Average annual effluent concentrations at WWTPs (Data source: Southern Water).

Table 20 Recent upgrades to WWTPs (Source: Southern Water, DIER, GHD 2007).

WWTP	Upgrade/s performed
Ranelagh	Upgrade performed in 2004, and additional rectification work during 2012 to improve compliance with permitted discharge limits.
Electrona	Plant upgrade in 2000 to a design capacity of 270kL/d, and an additional minor upgrade in 2011.
Margate	Chlorine disinfection was installed on the lagoons in 2011/12 to address poor compliance with bacterial effluent quality.
Geeveston	Improved aeration was installed in 2010, although ongoing issues with plant bypass have been noted during wet weather events.
Dover	A new treatment system was installed in 2002/3, however further improvements are required to achieve reliable compliance.
Cygnet	New screens were installed in February 2010.
Woodbridge	A new WWTP was commissioned in 2003 with a design flow of 34.4 kL/day, which replaced the septic tank systems in Woodbridge area. The effluent disposal site includes two effluent storage tanks, four transpiration-evaporation beds, and one reuse dam. A wetland system including a trench wetland and dam was later constructed by Kingborough Council (2003-2004) to complete the effluent disposal system.
Kettering	A new WWTP including sewer rising mains and pumping stations was commissioned in 2011. As noted in Section 9.1, the system is currently operating poorly due to flows not meeting plant requirements.
Howden	A new WWTP and re-use system was commissioned in 2002 to replace septic systems of the Howden area, while Kingborough Council installed a moisture monitoring system in 2003. A minor upgrade is underway to address problems experienced during peak wet weather flows.

9.1.4 Septic systems

While some of the larger settlements of the D'Entrecasteaux Channel and lower Huon Estuary now have reticulated sewerage, a very high percentage of the region remains dependent on septic tank systems or alternative water treatment and disposal systems. Septic systems are installed on individual properties and have no connection to main sewerage pipes and WWTPs maintained by Southern Water. Within the study area, and including Geeveston on the outskirts of this area, an estimated 2,883 people are connected to reticulated sewerage (Southern Water, unpub. data). Within the same area, the total human population is estimated at approximately 14,000 (based on data provided by ABS 2012), suggesting that 80% of the population, or ~11,000 people, may be reliant on septic systems.

While design of septic systems is variable, they generally consist of a tank which retains and facilitates anaerobic digestion of solids, and a drainage field in the ground which receives and filters the liquid component. The size of the drainage field constructed is proportional to the predicted volume of wastewater and inversely proportional to how porous the soil is. Problems can occur for example where septic systems become blocked, are installed in poorly drained soils, or receive a higher volume of wastewater than they are designed to treat.

Most septics in the region are operating effectively, particularly in well drained areas where the likelihood of leaks and adjacent surface water contamination is reduced. However, contamination issues are a problem at several locations, with septic runoff occurring to roads where multiple septic system failures have occurred. Figure 40 identifies areas in the D'Entrecasteaux Channel and lower Huon Estuary that contain major concentrations of septic systems, and also highlights areas where septic system failures have been recorded.

Figure 40 Septic system hotspots (Data source: Kingborough and Huon Valley councils).

Two areas were identified as having failed septic systems within the Kingborough municipality (J. Doole, Kingborough Council, pers. comm.), while several problem areas outside, but in close proximity to, the study area were also identified in the Huon Valley municipality (Scott Edwards, Huon Valley Council, pers. comm.). System failures and leakage to roadsides have generally been associated with small lot sizes and poor soil drainage. At Kettering and in the Huon region, problems are associated with older septic systems and high loads due to permanent habitation. At Alonnah, systems are newer and associated with part-time shack habitation; however, systems are still failing due to high density dwellings and poor soils. In the latter case, it is difficult to identify suitable management options for addressing leakages (J. Doole, Kingborough Council, pers. comm.).

Upgrades have been performed to systems within some areas of the Huon Valley municipality over the past six years in conjunction with the Crown Land Shacks Project (S. Edwards, Huon Valley Council, pers. comm.). These upgrades have occurred in Eggs and Bacon Bay, Surveyors Bay and Little Roaring Beach, all near the entrance of the Huon Estuary.

9.2 *Industrial discharges and inputs*

9.2.1 Land-based sources

There are several land-based activities that involve direct discharge of waste water from industrial plants to the D'Entrecasteaux Channel and lower Huon Estuary via marine outfalls. These point sources of input discharge via dedicated outfalls, whilst diffuse land-based sources are addressed in Section 9.3.

Relevant point source activities are all based around seafood processing, including finfish and abalone, with two processing plants based in the vicinity of Margate and one at Dover all categorised as Level 2 activities. Outfall effluent quality is monitored on a monthly basis at all three sites, with the most recent data available summarised in Table 21. Analytes monitored include BOD, TSS, TP, thermotolerant coliforms, various chemical forms of nutrients, including total Kjeldahl nitrogen [TKN = the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4)], ammonia, and nitrate+nitrite (NO_x), and additional parameters such as pH and oil and grease.

Table 21 Inputs from fish processing plants (Data source: DPIPWE).

Plant	Year	Discharge	BOD	TSS	TKN	TP	NO_x	NH_3	TC*
		(kL/day)	tonnes/year						cfu/100 ml
Margate Tassal	2011	120.0	0.3	0.3	0.3	0.2	-	0.3	2.1
Dover Tassal	2011	252.0	9.3	28.1	7.0	0.6	-	5.7	38.0
Margate Tas. Seafoods	2009	0.01	0.02	0.01	0.03	0.01	0.07	-	<1
TOTALS		**381**	**9.7**	**28.6**	**7.4**	**0.9**	**-**	**-**	

* Thermotolerant coliforms (TC) presented as an annual geomean concentration.

Total discharge was estimated at 381 kL/day, with the Dover outfall contributing an estimated 66% of this. The Dover outfall also contributed 95-98% of BOD, TSS, TKN and NH_3, and 69% of TP. The Margate Tasmanian Seafoods (Tas. Seafoods) outfall contributed <5% of inputs, except in the case of TP where it contributed 14%. Note that concentrations of copper and zinc are also monitored at the Dover outfall, due to potential inputs associated with wastewater sourced from a net washing facility, although annual inputs appear to be small (estimated at 1.6 and 2.4 kg during 2011).

Current permit conditions indicate maximum annual production limits of 500 tonnes for Margate Tasmanian Seafoods, 30,000 tonnes for Margate Tassal and 25,000 tonnes for Dover Tassal. However, the Margate Tassal figure reflects an assessment process for a potential relocation of the Dover plant to Margate which was not pursued, and production at Margate is in fact closer to 4,000 tonnes. Production at Dover is also currently lower than the allowable limit (~20,000 tonnes in 2011) as the limit has recently been increased in conjunction with expanded activities (S. Richards, DPIPWE, pers. comm.). The allowable limit was increased from 8,000 to 25,000 tonnes per year in 2010. The expansion underway at Dover includes an upgrade of the wastewater treatment plant, which has not yet been completed but is scheduled for 2012-2013 subject to necessary approvals (Tassal 2012a).

Each plant monitors the above effluent quality in accordance with maximum allowable concentrations prescribed by the EPA. During 2011, effluent quality at the Margate Tassal plant was reduced compared with 2008 and 2009, despite significant improvements to operations in 2010. In light of this, a commitment was made to reviewing site wastewater generation and management and WWTP performance with a view to finding areas for performance improvement, including more efficient solids removal (Tassal 2012b). Effluent quality monitoring at the Dover Tassal plant has recorded elevated levels of BOD, TSS, ammonia and TKN, with additional analytes also elevated during some months. This reflects the inability of the current WWTP to cope with wastes, and the installation of the proposed new WWTP is expected to remedy this situation (Tassal 2012a).

A number of additional Level 2 industrial sites are located within the D'Entrecasteaux Channel and lower Huon Estuary study area, and are included in conjunction with the above fish processing premises in Table 22. Rather than discharging effluent into the waterways via dedicated outfalls, these sites direct their processing wastes to sewer (or to the above fish processing plants, e.g. fish cage net maintenance facility), as indicated in Section 9.1, or may emit contaminants via stormwater runoff or spills. In most cases, stormwater outputs are not monitored and cannot be readily quantified. A number of quarries operate in the region, with suspended solids the main water quality issue of concern. Primary collection is via sediment traps, with the finest particulates then captured in settling ponds prior to runoff being released to the environment (John Langenberg, EPA, pers. comm.). Additional recent (now closed) Level 2 industrial sites located in the study area included additional fish and fish waste processing sites, a fish composting site, and a sawmill (EPA, unpub. data).

Table 22 Level 2 industrial premises (Data source: EPA).

Activity type*	No.	Location
Fish processing	3	Margate (2), Dover
Fish cage net maintenance facility	2	Port Huon, Strathblane
Fruit processing plant	1	Cygnet
Quarry	3	Lunawanna, Alonnah, South Bruny Island

* Activities exclude Level 2 sewage WWTPs and tips/waste management sites; information on these is provided in Sections 9.1 and 9.7 respectively.

A wide range of other small-scale Level 1 industries and sites currently operate within the study area, including: marinas, slipways, boat yards and repair facilities; golf courses; saw mills and joinery works; orchards and vineyards; poultry farms; extractive industries and quarries; concrete batching plants; and service stations. Local councils are responsible for regulating most of these premises, primarily via trade waste agreements; however, no full regional inventory is available. Note that additional Level 1 activities, including fish hatcheries at Ranelagh and on the Russell River, discharge wastes to more upstream parts of the Huon River system and hence contribute to overall inputs.

9.2.2 Marine farming

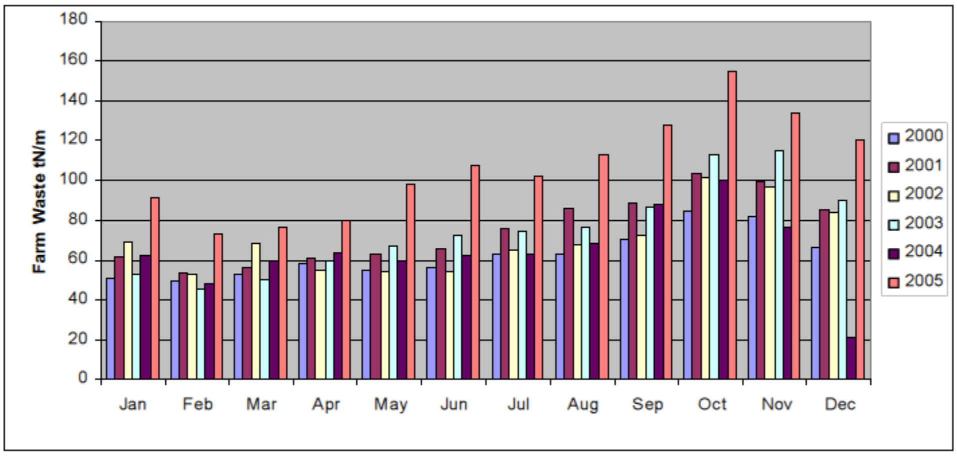
The Huon Estuary and D'Entrecasteaux Channel are important areas for the state's marine farming industry, with a significant portion of Tasmania's shellfish and finfish farms located in the region. For example, two thirds of the state's marine fish farms by area occur within these waterways, and south-east Tasmania, including this region and the Tasman Peninsula, accounts for 50% of salmonid production (F. Bourne, DPIPWE, pers. comm.). Both farmed shellfish and fish convert total nitrogen to ammonia as a result of body processes, and hence contribute to concentrations of biologically available nutrients. However, there are no external inputs of nutrients at shellfish farms, while finfish farm inputs result from the addition of food pellets, both uneaten and processed as fish faeces, and are hence the focus of this section of the report. Additional inputs at fish farms may include copper and zinc via use of metal-based antifoulants on nets, and antibiotics administered when required to mitigate disease.

The evaluation and assessment of the Broadscale Environmental Monitoring Program (BEMP) described in Section 10.4 will undertake a detailed temporal analysis of organic inputs to the waterways associated with finfish farming within the context of broader system inputs and dynamics, and hence analysis of those inputs is not repeated here. Findings of the BEMP evaluation and assessment should, therefore, be considered in conjunction with the current report. Previous estimates of inputs from fish farms developed through system-wide studies are summarised below and are also described in the context of nutrient modelling studies in Section 13.1.

Organic inputs to the water column associated with fish farms are high in nitrogen and, in basic terms, can be described as nitrogen in fish feed input minus nitrogen in harvested salmon. A simple way to characterise this is via a feed conversion ratio (FCR) which reflects the weight of feed required to produce one kg of fish product. A conservative FCR for the Tasmanian industry is 1.4, although some farms are consistently achieving a ratio lower than this (DPIPWE 2011e). Based on feed data provided by industry, the Huon Estuary Study (HES) estimated the total annual nitrogen input at finfish farms in the Huon Estuary in 1997 to be 191 tonnes, with 123 tonnes or 64% input into the estuary, and 36% removed as harvested fish. Of the load to the estuary, 13% was estimated to be particulate and 87% dissolved (Butler *et al.* 2000), while the total contribution represented approximately 20% of the internal sink of nutrients in the estuary.

The Whole of Ecosystem Assessment for Salmon Farming (WoEASF) subsequently estimated farm waste on the basis of feed input data for all finfish farming areas of both the Huon Estuary and the D'Entrecasteaux Channel. Calculations of input estimates were founded on several assumptions; firstly, that all pellets were consumed by the fish, and secondly, that 5% and 0.8% of the total feed was discharged as waste nitrogen and phosphorus, respectively, in dissolved and particulate forms (Volkman *et al.* 2009). The assessment found that seasonal waste input was lowest in February and highest in October, while the annual load dropped slightly in 2004, but increased significantly in 2005 (Figure 41). Across the entire region, it was estimated that the amount of nitrogen added to the marine environment as farm waste in 2002 was 843 tonnes, with 14% of this particulate and 86% dissolved (Volkman *et al.* 2009). It is not feasible to make temporal comparisons with the HES estimate, because the latter was limited to the Huon Estuary. For modelling purposes, projected estimates of fish farm outputs by 2009 were subsequently calculated on the basis of maximum anticipated growth in the fish farming industry. Projected data suggested that the amount of finfish waste nitrogen being added to the ecosystem could have been expected to rise by up to 310% to 2,590 tonnes by 2009 (DPIW, referenced in Volkman *et al.* 2009). During the same period, the annual output of phosphorus from fish farms was anticipated to increase from 146 to a maximum of 455 tonnes (Table 23). It should be noted that these projected data may be quite different from actual feed data and should not be interpreted as definitive inputs. The evaluation and assessment of the BEMP, referred to above, will incorporate an assessment of updated feed input data.

Based on the WoEASF findings, and most notably the modelled effects of the above maximum projected 2009 fish farm inputs (see Section 13.3), caps on total permissible dissolved nitrogen output (TPDNO) were introduced for the region in 2008. Separate caps were developed for the two relevant plan areas based on total food input (as a proxy for total nitrogen), with a cap of 1,140.76 tonnes introduced for the D'Entrecasteaux Channel Marine Farming Development Plan (MFDP) Area and and a cap of 1,084.63 tonnes for Huon River and Port Esperance MFDP Area (DPIPWE 2011e; G. Woods, DPIPWE, pers. comm.). Monitoring of dissolved nitrogen output is performed using the methodology developed as part of the WoEASF (Wild-Allen *et al.* 2005). The TPDNOs effectively restrict production of salmonids within the two plan areas. It has been reported that the industry has not yet reached the TPDNO limits within the D'Entrecasteaux Channel MFDP Area (DPIPWE 2011e).



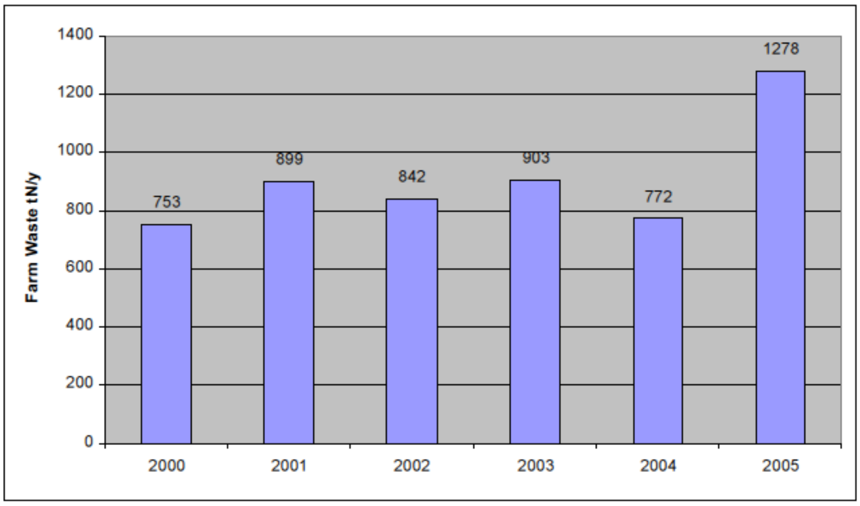


Figure 41 Estimated annual farm waste nitrogen by season (top) and year (bottom) (Source: Volkman *et al.* 2009).

Table 23 Total nitrogen and phosphorus inputs from fish farms in 2002 and maximum projected inputs by 2009 (Source: Wild-Allen 2008).

Year/Farm locations	Total Nitrogen (tonnes per year)	Total Phosphorus (tonnes per year)
2002		
Total Huon	313	54
Total Channel	530	92
Total Farms	843	146
Projected, 2009		
Total Huon	542	95
Total Channel	2048	360
Total Farms	2590	455

Data on usage of metal-based antifoulant paint have not been separately derived for the D'Entrecasteaux Channel and lower Huon Estuary, however the total annual usage by major fish farm companies of the region equalled ~240,000 L during 2006-2007 and was projected to decrease to 100,000 L by 2012-2013 (D. O'Brien, Huon Aquaculture, Management & Development, pers. comm.). Copper is the main ingredient in the majority of antifouling products, present in the form of copper oxide (Cu_2O), with a much smaller usage of a zinc based product. Estimates of total Tasmanian use of copper ranged from a peak of 74,400 kg in 2005 down to 19,300 kg in 2011 (D. O'Brien, Huon Aquaculture, Management & Development, pers. comm.). Over this period, the amount of copper per kg of paint has also declined. The salmonid farming industry is aiming to replace the use of copper-based antifoulants with in-situ cleaning technology at all depositional sites by 2015 (DPIPWE 2011e).

Antibiotics are necessary to treat bacterial disease occurring in farmed Atlantic salmon, and are generally administered in feed. Oxytetracycline (OTC) is the most common antibiotic used, accounting for more than 70% of total antibiotic use during 2006-2008. Annual use in the combined Channel and lower Huon Estuary farming areas ranged from ~3.5 to 6.5 tonnes between 2006 and 2008, representing 70-94% of total use by the Tasmanian salmonid farming industry (Macleod and Eriksen 2009). A strong seasonal component to the use of antibiotics was noted, with the greatest requirement in the summer months when water temperatures are elevated and pathogens tend to be most virulent. More recent data indicate a considerable decline in the use of antibiotics, with levels of OTC use for the region declining progressively from 3 tonnes to 158 kg between 2009 and 2011 (DPIPWE, unpub. data). Water sampling has returned results below the detection limit of the analyses, and hence the likelihood of effects in the water column is negligible and testing has ceased; however, monitoring has continued for antibiotic residues and persistence in the sediments (see Section 12.2.7). The salmonid farming industry is working with the Australian Pesticides and Veterinary Medicines Authority to assess risks in relation to use of antibiotics (DPIPWE 2011e), however declining levels of use are also helping to resolve this issue.

9.3 Riverine inputs

In addition to point sources of anthropogenic inputs to the D'Entrecasteaux Channel and lower Huon Estuary, various catchment activities may contribute pollutants and other compounds, which enter surface water on land and eventually creeks, rivulets and rivers. These diffuse sources of anthropogenic inputs generally undergo considerable dilution in waterways. Water quality monitoring at key riverine locations can provide some information about nutrient loads entering the D'Entrecasteaux Channel and lower Huon Estuary via diffuse catchment sources.

The state government has gauged stream flows and performed monthly water quality monitoring at a network of river sites around Tasmania, with data made available via the Water Information System of Tasmania (WIST) database (DPIPWE 2012b). These data have provided the primary means of calculating nutrient inputs from catchment/riverine sources, although the water quality monitoring program was discontinued at a statewide level in 2011. In recognition of their importance for interpreting results of the BEMP (see Section 10.4) in the D'Entrecasteaux Channel and lower Huon Estuary, monitoring has been maintained and is ongoing at three river sites adjacent to the study area. These sites include the Huon River downstream of the Judbury River Bridge, Esperance River at the Dover water supply intake, and the Snug River at the Snug Tiers Road Bridge (M. Jack, DPIPWE, pers. comm.).

Bobbi (1998) estimated TN and TP inputs from the Huon and Kermandie rivers during 1996-1997. For the Huon, estimates were based on data from an upstream monitoring station above Frying Pan Creek, and subsequent application of a scaling factor (based on catchment area) to adjust for flows anticipated further downstream. Nutrient loads were estimated by determining the relationship of TP and TN to turbidity, the latter being monitored continuously. The nutrient load of the Kermandie River was estimated using relationships between nutrient concentrations and rising and falling flows of the river. The HES further analysed data incorporating the results of Bobbi (1998), while the WoEASF also estimated nutrient inputs from riverine sources (see Section 13.1) using a similar approach of scaling up data from upstream sites (Butler *et al.* 2000, Volkman *et al.* 2006).

As part of the BEMP evaluation and assessment currently underway (Section 10.4), initial estimates of annual TN and TP inputs during 2000-2012 have been calculated using WIST nutrient monitoring and river flow data, and have been provided for inclusion here (J. Ross, IMAS, pers. comm.). An available flow versus nutrient relationship was applied to data for the Huon River at Judbury, while inputs from other river systems were calculated by applying median nutrient concentrations to recorded flows. In the absence of a routine water quality monitoring site on the North West Bay River, inputs via this system were estimated using nutrient concentrations recorded in the adjacent Snug River. The combined average annual inputs from all river systems for which data were available during 2000-2012 was 885 tonnes TN and 22 tonnes TP (Table 24). The Huon River contributed 90% of TN and 81% of TP, whilst the next largest contribution was from the Esperance River (5.4% TN, 8.6% TP).

Table 24 Average annual riverine nutrient inputs derived from water quality and flow data (Source: J. Ross, IMAS pers. comm., except where an alternative source is indicated).

River System	Time period	TN (Tonnes)	TP (Tonnes)
Huon	1996-1997 (Bobbi 1998)	1016	29
	1996-1998 (HES; Butler *et al.* 2000)	910	25
	2002-2003 (WoEASF, Wild-Allen *et al.* 2005)	1155	173
	2000-2012 (Huon at Judbury)	Range: 640 -987 Average: 782	Range: 14 -20 Average: 17
	2009-2011 (Mountain River at Ranelagh)	Range: 8 -20 Average: 16	Range: 0.5 -1.1 Average: 0.9
Kermandie	1996-1997 (Bobbi 1998)	77	7
	2002-2003 (WoEASF, Wild-Allen *et al.* 2005)	32	4
	2009-2012	Range: 19 – 27 Average: 24	Range: 1.5 – 2.0 Average: 1.8
Esperance	2004-2011	Range: 31 -76 Average: 48	Range: 1.2 -3.1 Average: 1.9
Snug	2000-2012	Range: 0.3 -4.1 Average: 1.5	Range: 0.01 -0.1 Average: 0.04
North West Bay	2009-2012	Range: 6 -17 Average: 13	Range: 0.2 -0.5 Average: 0.4
Total (Average)	**2000-2012**	**885**	**22**

The initial 2000-2012 estimates presented here for the Huon are lower than those of earlier studies (Table 24). However, as a result of differences in methodology and data available for estimating loads, it is not possible to make direct comparisons between data sets currently available or interpret temporal trends. A more detailed assessment of current nutrient inputs will be conducted as part of the BEMP evaluation and assessment as it progresses.

9.4 Stormwater

Stormwater runoff is the water from rain that flows across the land, carrying with it litter, vegetative debris, loose soil and a range of pollutants that have been deposited on the land surface, including pathogens, nutrients, heavy metals, pesticides and hydrocarbons (Whitehead *et al.* 2010). This water eventually enters the waterways untreated, and can cause significant local degradation of water quality and aquatic habitats. Locations of stormwater infrastructure adjacent to the D'Entrecasteaux Channel and lower Huon Estuary have been mapped to some extent by councils, however no inventory of stormwater outfalls has been compiled at this stage. Some mapping data are available for North West Bay, which suggest that 16 stormwater outfalls discharge directly to the bay (Kingborough Council, unpub. data). The waterways receive stormwater by way of rivulets, creeks and stormwater outlet pipes, including discharges from four major rivers and more than 36 smaller rivers, creeks and streams (Wild-Allen *et al*. 2005). The quality of stormwater discharged is strongly linked to catchment land uses and the condition of rivulet banks and riparian strips. Construction sites, roads, industrial sites, commercial areas and eroding stream banks are major contributors to stormwater pollution (Whitehead *et al.* 2010).

Tasmania's *State Policy on Water Quality Management 1997* has identified that stormwater is a significant management issue, and a State Stormwater Strategy has recently been developed (DPIPWE 2010c). Since 1999, a number of stormwater management projects have been undertaken in the study area, including installation of stormwater litter traps or gross pollutant traps at Margate, Electrona and Snug, and application of Water Sensitive Urban Design (WSUD) techniques in a subdivision at Snug. WSUD is the design of stormwater infrastructure that aims to minimise impacts of urbanisation on waterways and estuaries. This is achieved by source control strategies that treat, store, and infiltrate stormwater runoff onsite before it can affect receiving waters (Whitehead *et al.* 2010). The Snug Tiers Road Subdivision, located adjacent to the Snug River, adopted WSUD principles by using landscaped swales, biofilter soaker beds, and permeable pavements (J. Doole, Kingborough Council, pers. comm.).

No targeted monitoring program for stormwater quality has been performed in the study area. However, Kingborough Council monitored nutrients in small rivulets and creeks during 1991-2001, including at least six sites adjacent to the D'Entrecasteaux Channel. Analysis of these data may, therefore, assist in identifying areas vulnerable to elevated inputs, although a detailed assessment of stormwater outlets and potential contaminants discharged to them would be beneficial. For example, stormwater from the Huntingfield industrial zone and associated subdivisions drains into Coffee Creek and eventually to North West Bay. On the basis of size and range of commercial premises, this area is considered a high priority in terms of stormwater assessment and management (J. Doole, Kingborough Council, pers. comm.).

9.5 Litter and marine debris

Litter is visually and aesthetically unpleasant and may constitute a hazard both to human health (e.g. broken glass, used syringes) as well as to aquatic life (e.g. plastics). The term 'marine debris' is used to describe the various types of litter that find their way into the marine environment. Sources of marine debris in the D'Entrecasteaux Channel and lower Huon Estuary include marine farms, commercial and recreational vessels and land based sources such as stormwater (see Section 9.4 above). There are a number of marine debris 'hotspots' in the region, where the build-up of marine debris on shorelines has caused concern for local residents. Typical debris includes sections of rope, bait box straps, buoys, aluminium cans, poly pipe and plastic packaging. On some shorelines, legacy issues are being uncovered by erosion caused by rough weather conditions (F. Ewing, Tassal, pers. comm.).

In 2009, the Tasmanian Seafood Industry Council (TSIC) instigated a commonwealth government funded seafood industry marine debris survey and cleanup program in the D'Entrecasteaux Channel and Lower Huon Estuary. This project found that aspect, type of shore (rocky or sandy), and relief (gentle or sloping) are important factors in the concentration of debris. For example, sections of the Bruny Island coastline facing west, north-west and north tend to be hotspots for debris accumulation (Ogier 2009). To address this problem, an 'Adopt a Shoreline' initiative has been developed, with local salmon and shellfish farmers nominating shorelines for which they will have the primary responsibility for monitoring and removing marine debris (see Figure 42). Both community and industry based shoreline cleanups are continuing in the region, with the involvement of school groups also playing an important education role.

Figure 42 Shorelines included in the marine debris 'Adopt a Shoreline' TSIC cleanup program (Data source: Ogier 2009).

9.6 Reported spills and incidents

Pollution spills and other incidents are required to be reported to the EPA, and are recorded and categorised in a spills database. The majority of reported spills and incidents are associated with sewage and oil spills.

Sewage spills often occur at times of heavy rain when sewerage infrastructure becomes stressed with influx of stormwater or due to power failures. In many cases the volume of the spill is unknown or can only be roughly estimated, and hence it is not possible to quantify the volume of sewage and associated pollutants spilled to the waterways each year (Whitehead *et al.* 2010). The number of reported sewage spill incidents which may have affected the waterways of the D'Entrecasteaux Channel and lower Huon Estuary during 2007-August 2012 are listed in Table 25. Note that the number of spills in a given year may be related to level of reporting or meteorological conditions (i.e. heavy rain), and is not necessarily a reflection of temporal variation in effectiveness of management practices. The largest percentage of sewage spills and incidents were reported for Dover and Geeveston. The majority of spills were relatively minor or of unknown volume, with the exception of some larger spills (>1 ML) associated with heavy rainfall/stormwater influx (e.g. July 2011) (C. Coughanowr, DPIPWE, pers. comm.).

Information is also available for oil spills during 2007-2011 (Table 25), with most reported oil and fuel spills being small land-based spills that flow to stormwater drains or are spills of diesel related to shipping and boating operations. 'Other' incidents have only been reported since 2011 and include events such as discoloured water and fish kills (C. Coughanowr, DPIPWE, pers. comm.).

Table 25 Reported spills and incidents (Source: EPA, Southern Water).

Year	Oil	Sewage (treatment plants)	Sewage (pump stations)	Sewage (other; e.g. blockages)	Other
2007	1	1	1		
2008				1	
2009	1	1	5	2	
2010	2	3	2		
2011	1	4	5	2	2
2012 (to Aug.)*		2	5	7	
Total	**5**	**11**	**18**	**12**	**2**

* Additional data for 2012 were only available for sewage spills.

9.7 Landfills, tips and contaminated sites

9.7.1 Landfills and tips

Landfills may contribute pollutants to water bodies in the form of leachate, surface runoff, sediment and wind-blown rubbish. Refuse disposal sites are Level 2 activities regulated by the EPA and must meet specified permit conditions, which typically include leachate and surface water management, and monitoring of leachate, groundwater and nearby waterways. Parameters commonly monitored include nitrate, ammonia, phosphate, pH, BOD, chemical oxygen demand, faecal indicator bacteria, metals and organic contaminants (Whitehead *et al.* 2010). Leachate quality varies from site to site depending on the site design, refuse composition, water content, stage of decomposition, temperature, and oxygen availability. Some contaminants which may be present in leachate are hazardous even in very low concentrations, such as hydrocarbons, pesticides, herbicides and metals. Since these compounds may be relatively persistent, leachate monitoring is generally conducted for many years following closure of a tip site.

Information on current and historic landfills and tips has been sourced from the Tasmanian Risk Assessment Methodology for Historical Landfills database of the EPA and from councils. Figure 43 shows the locations of all documented former tips and current waste transfer stations adjacent to the D'Entrecasteaux Channel and lower Huon Estuary. There are no active landfills in the study area for municipal wastes, with former tips at Baretta (Electrona), Cygnet, Geeveston, Dover and northern Bruny Island all replaced with waste transfer stations since 1999 or, in the case of Dover, prior to 1999. Further information on these sites is included in Table 26, including details on environmental monitoring. The most recent results from monitoring surveys were not available at the time of compiling this report, but no concerns were identified with leachate contaminating adjacent environments and waterways. All waste from Bruny Island is transferred to the station at Baretta, with all waste from this station then transported to the Copping landfill, east of Sorell. In the case of the Cygnet, Geeveston and Dover waste transfer stations, recyclables are transferred to the Materials Recovery Facility in Derwent Park for processing, while general waste is transferred to the Southbridge Waste Transfer Station at Huonville for compaction before being transferred to the Copping landfill.

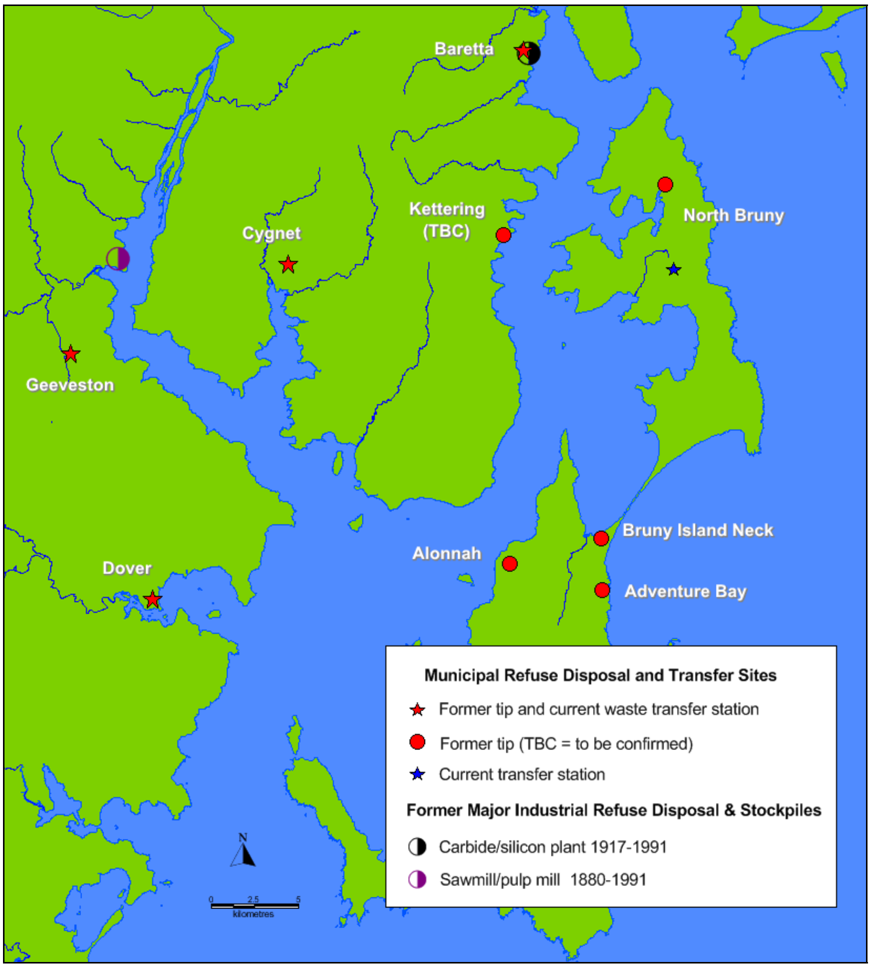


Figure 43 Landfill, waste transfer and former heavy industrial sites (Data source: Kingborough and Huon Valley councils, EPA).

Former tips have been recorded at several additional sites at the southern end of Bruny Island, and a potential former tip site (yet to be confirmed) was also recorded at Kettering (Figure 43). Little additional information is available for these sites, although the tips at Bruny Island Neck and Alonnah are known to have closed during the 1990s (Kingborough Council, unpub. data). Note that other types of waste facilities are also regulated by the EPA in the study area, including an inert waste landfill at Leslie Vale, a solid waste (shells) disposal site at Oyster Cove, a fruit (apple) waste depot at Lymington, and several waste transport operations. In terms of industrial stockpiles, the primary site of relevance is a former carbide works at Electrona which is described below in Section 9.7.2.

Table 26 Former rubbish tips (Source: Kingborough Council, Huon Valley Council).

Former tip site	Area (ha)	Years of Operation	Rehabilitation measures	Monitoring
Baretta	16	1955–2008	Full site rehabilitation (with likely completion by 2015) involving: capping entire landfill with an impervious layer; top dressing and vegetating; weed management; upgrading of site surface water management system	Quarterly groundwater monitoring 2006-ongoing; surface runoff monitoring – event based
North Bruny Island	3	?-1995	Site rehabilitated and revegetated	None
Cygnet	3.1	?-2005	Perimeter fences constructed; waste covered with 300mm clean fill; perimeter cut-off drains constructed to vegetated sites; leachate and recirculation systems maintained; revegetation with local pasture grasses	Quarterly surface water and leachate monitoring 2002-ongoing
Geeveston	3.9	?-2005	Perimeter fences constructed; waste covered with 300mm clean fill; perimeter cut-off drains constructed to vegetated sites; leachate and recirculation systems maintained; revegetation with local pasture grasses	Quarterly surface water and leachate monitoring 2002-ongoing
Dover	1.5	?-1993	?	None

9.7.2 Other contaminated sites

Land and groundwater contamination associated with contaminated sites may negatively impact on water quality within D'Entrecasteaux Channel and lower Huon Estuary. Contaminated sites and potentially contaminating activities for this region can be identified from databases maintained by the EPA and also the Kingborough Council. Registered contaminated sites are listed on the EPA Contaminated Sites database, while some 'potentially contaminating activities' can be identified through the New Environmental Licensing and Monitoring System and the Environmentally Relevant Land Use Register, the latter containing historical information on specific land uses or potentially contaminating activities. Kingborough Council has also developed a database of potentially contaminating activities (as defined in Schedule 11 of the Kingborough Planning Scheme 2000), although it should be noted that both the EPA and council databases are likely to contain only a subset of contaminated and potentially contaminated sites and activities within the region. Due to the absence of mapping data for some of the EPA records, it has not been possible to cross-match the EPA and Kingborough Council listed sites and hence these two sources are reported separately below.

Queries of the above EPA databases identified 2 records of registered contaminated sites, and 63 records of potentially contaminating activities. Note that some overlap was detected in entries within separate EPA databases and information on numbers of sites presented here should be considered as a general guide only. As illustrated in Figure 44, the potentially contaminating activities consisted of a relatively even number of petroleum storage facilities and other current Level 2 activities, and a higher number of historic activities. It was noted that many of the EPA database records have not been verified and hence should be interpreted with caution (B. Terry, EPA, pers. comm.). A project is currently being performed to map and verify sites recorded in the databases.

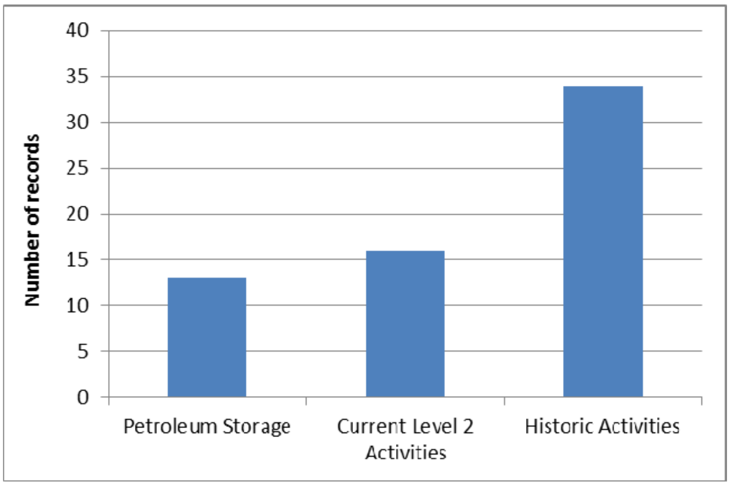


Figure 44 Contaminating activities categorised by activity type (Data source: EPA).

The Kingborough Council database of potentially contaminating activities has been developed to inform assessments of proposals which involve: development of land for sensitive uses, public open spaces or recreational activities; soil removal and disposal; and generation of dust and stormwater runoff. Where any of these are proposed, current and historic potentially contaminating activities need to be identified as part of the assessment. It should be noted that the database is still under development (A. McGuire, Kingborough Council, pers. comm.); however, a summary of relevant activities identified to date within the study area is provided in Table 27. Activities specifically addressed in earlier report sections, including sewage WWTPs and tips, have been omitted from the table. Note that an individual site may record multiple potentially contaminating activities, for example if it uses chemical sprays and also generates wastewater.

Table 27 Potentially contaminating activities on the coast of the Kingborough municipality (Data source: Kingborough Council).

Activity Type	Current	Historic
Agriculture and food production (abattoir, fertiliser manufacture, animal husbandry)	2	5
Aquaculture (land-based processing and other infrastructure)	12	5
Recreational and public facilities (camp grounds, golf courses, public toilets)	5	-
Cemetery	9	5
Electrical transformers	1	1
Explosives	1	3
Fuel storage (fuel depots, service stations)	4	15
Industrial (manufacturing, processing, machinery storage)	7	5
Marine (marinas, boat building, boat repairs and maintenance)	6	1
Orchard/Nursery	11	6
Quarry	1	2
Vineyard	7	2
Wastewater (non-municipal)/wastewater irrigation	3	-

Major historic industries

There are two industrial sites worthy of further mention due to the large scale and intensiveness of former operations, extended periods of use, and the potential for residual contamination. These are a former pulp mill at Port Huon on the shores of Hospital Bay, and a carbide factory/silicon plant at Electrona, with locations of both sites illustrated in Figure 43.

The 130 ha pulp mill site at Port Huon operated from 1962 to 1991, with a period of in-operation during 1982-1986, at a location with a long history of industrial use. From 1880-1926, it was the site of a major sawmill and associated wharf facilities, reputed at the time to be the largest mill in the Southern Hemisphere (APM 1990). The site served as a pilot mill during 1927-1932, and also provided cool stores and wharf facilities for apple exports. Considerable quantities of sawdust were discharged into Hospital Bay during early milling operations, with the effect of modifying mudflat areas at the mouth of the Kermandie River and distributing floating sawdust over adjacent regions of the Huon River. This material was still evident in sediment cores collected ~80 years later (Chesterman 1995).

The subsequent pulp mill was established to make unbleached Neutral Sulfite Semi-chemical pelleted pulp from locally grown eucalypt for bulk shipment to board mills in mainland Australia. Pulp mill wastewater was discharged into Hospital Bay via a series of drop pipes along the length of the wharf aimed at providing better dispersion (APM 1990). This water contained a variety of compounds extracted from the wood, including lignosulfonates, tannins, wood sugars and ellagic acid, and also inorganic sodium salts, silica, sulphur, and small quantities of caustic soda and anthraquinone. Due to the presence of lignin and tannins, the wastewater was highly coloured. The mill discharged very high loads of non-filterable residue (NFR) and BOD (e.g. 8,805 mg/L BOD on average; Wotherspoon *et al.* 1994) which exceeded environmental regulations but were permissible by way of a ministerial exemption (APM 1990). When mixed with seawater, the organic NFR material flocculated and settled on the bed of Hospital Bay, resulting in an anaerobic ‘blanket’ of hydrogen sulphide-rich mud. At their maximum extent during 1982, these anaerobic muds extended over an area of 72 ha (Butler *et al.* 2000). Impacts on biota appeared to be associated with the reduced (i.e. oxygen deficient) conditions rather than the presence of toxic compounds (APM 1990).

A decommissioning plan was prepared for the mill in 1995, and was supplemented by a further survey report for Hospital Bay in 1996. Surveys during 1993-1996 reported a gradual decline in the extent of the anaerobic muds following closure of the mill, with the affected area reported to be 1 ha by 1996 (Hyde 1996). Sediment surveys during 1994 also analysed metals and recorded elevated levels (e.g. zinc up to 1,000 mg/kg) that were attributed to possible inputs via sewage discharges from Geeveston, natural weathering, and lead arsenic and zinc based sprays used in apple orchards in the past, given that the mill did not use metal-based sprays or additives (Chesterman 1995). More recent studies have recorded elevated metals and pesticides and depressed oxygen levels in Hospital Bay (see Sections 11.4 and 12.3), and it has been suggested that fine residual organic matter from pulp discharges may be acting as a ‘sponge’ for contaminants. It was recommended that further sampling be conducted, particularly prior to any activities that may disturb the sediments and hence potentially mobilise contaminants (Butler *et al.* 2000).

Another site with a long history of industrial activity is located at Electrona, bounded by North West Bay on its eastern side, the Snug River in the south and Peggys Beach to the north. Information presented below is based on correspondence obtained by Kingborough Council in 2002 under the Freedom of Information legislation, and additional feedback provided by the EPA. The ~32 ha site operated as a carbide plant from 1917–early 1980s, and then as a silicone plant during 1987–1991, and includes a dis-used industrial waste disposal area located immediately west of the smelter site. The carbide plant shipped limestone from Ida Bay, reduced it to lime by burning in a kiln, then roasted with coke in an electric furnace to produce high-grade carbide, calcium carbide, some ferro-alloys, acetylene and carbon black products. The plant had an exemption for emissions of hydrated lime slurry to North West Bay (maximum of 3 tonnes per day as calcium hydroxide) and adjacent land. The site was later converted to a silicon smelter with a theoretical capacity of 10,000 tonnes/year of metallurgical grade silicon, although the operation was short-lived and closed after just three years of operation.

In the late 1990s, there was evidence of a contaminant leaching from a dump of spent carbide on the Electrona site, triggering contaminant investigations. A site assessment indicated that leachate was flowing into a small water course that ultimately discharged to the Snug River. Initial sampling of leachate and waste residue identified that it potentially posed a risk to human health and the environment due to elevated calcium concentrations and high pH values (up to 12.3). This triggered more detailed investigations, with a report prepared in 2000 identifying a number of potential issues of environmental concern. These issues primarily related to waste carbide dumps on the 'oval' and a site adjacent to North West Bay, and contamination from a sulphur stockpile. These issues were due to the long-term operations of the carbide plant.

A groundwater monitoring program was subsequently conducted during 2000-2002, with four rounds of sampling indicating pollutant levels within acceptable levels for the current use of the site. Remedial and management works included removal of the sulphur waste stockpile, and the placement of fencing and warning signs around the drainage gully impacted by the alkaline material to deny public access and hence reduce health risks. The potential environmental nuisance of discolouration to the Snug River caused by leachate run-off after heavy rains has been mitigated by planting natural vegetation in the drainage gully, while tree trunks have been used to stabilise the sediment and minimise its transport towards the river. The state government Environment Division indicated in a letter to the (then) owner in 2002 that additional measures would be investigated if there was evidence of the above remedial techniques being inadequate.

9.8 Summary of inputs

As concluded by earlier system-wide studies (Butler *et al.* 2000, Volkman *et al.* 2009), catchment inputs via river waters and marine fish farms remain the largest sources of nutrient inputs to the D'Entrecasteaux Channel and lower Huon Estuary region. Smaller inputs occur via sewage and industrial WWTPs, while septic systems, sewage and oil spills, and stormwater outlets are additional sources that cannot currently be quantified.

Riverine and fish farm sources of nutrients were previously reported to be approximately equivalent in size, although maximum projected fish farm inputs to 2009 suggested that this source may have expanded to become the dominant anthropogenic source for the region. A lack of WWTP flow data prior to 2009 prevents a long-term temporal assessment of inputs, although effluent quality data reflect steady increases since 2001 in concentrations of BOD, ammonia and nitrogen at some WWTPs, most notably Margate and Electrona. Concentrations of nutrients and other analytes are elevated in some industrial effluent discharges; however, total inputs are significantly smaller than for sewage WWTPs. There is evidence of residual environmental issues at two former heavy industrial sites at Port Huon and Electrona, although pollutants in Port Huon sediments may be contributed by a number of sources, and measures have been implemented at Electrona to mitigate impacts on the waterways.

While there are numerous gaps in data available for anthropogenic inputs, the following general conclusions can be made: marine farming activities and associated nutrient inputs have increased significantly since 1999; population growth in the region (see Section 3.1) is indicative of increased inputs of domestic waste, although introduction of reticulated sewage and 100% re-use at Howden may have reduced sewage emissions to North West Bay; and increased production at fish processing plants suggests likely increases in industrial discharges. Hence, subject to improvements in waste treatment and management, and proposed future diversions of effluent from some WWTPs, there is an overall trend for increasing discharges of various types of anthropogenic waste to the waterways. At the same time there have been declines in some inputs, for example in the use of antibiotics by the salmonid farming industry. The BEMP evaluation and assessment, described in Section 10.4, will provide a more detailed assessment of current sources of nutrients, and address some of the gaps in the current report such as recent feed input data for fish farms.

10 INTEGRATED STUDIES

10.1 Huon Estuary Study: Environmental Research for Integrated Catchment Management and Aquaculture

The Huon Estuary Study (HES) was a three-year research program (from 1996, published 2000) aimed at improving knowledge and providing a scientific framework for management of the Huon Estuary. The inadequacy of knowledge of the physics, chemistry and biology of the Huon Estuary system – an area supporting a burgeoning fish farming industry – was the impetus for the project (Butler *et al.* 2000). A general lack of detailed scientific baseline environmental data on the marine environment had led to concerns relating to: (i) potential adverse effects of local environmental degradation from waste on fish farms, leading to increased disease and poor growth, and (ii) perceived and real risks of the broader environmental effects of fish farming on the regional coastal environment, and the ramifications of other human activities on environmental quality and fish farming. The HES was founded on the need to evaluate the environmental quality and understand the working of the estuary as a system. Although fish farming was a key reason for the research, the HES sought to look at this industry in the context of the entire estuary and also the catchment where appropriate.

The HES conducted a major field sampling program during 1996-1998, involving more than 60 sites surveyed for a range of biological, chemical and physical parameters (Figure 45). Key aspects included nutrient and phytoplankton dynamics, optical absorption properties, organic content of sediments, contaminants, fish farm fallowing, and hydrodynamic and biogeochemical modelling. Key findings from the HES are summarised in other sections of the current report, including water quality (Section 11), sediment quality (Section 12) and nutrient cycling (Section 13) results.

10.2 North West Bay: Assessment and Monitoring of Nutrients and Habitats

This integrated study of North West Bay arose primarily out of recommendations identified in the D'Entrecasteaux Channel and North West Bay Strategic Management Plan and Strategic Action Plan (Phillips 2000). It was identified that the viability of the large range of uses and values in North West Bay, including salmonid farming and other industries, recreational activities and tourism, were dependent on its continued ecological health and productivity. Key objectives of this study included mapping seagrass, macroalgae and unvegetated habitats, assessing nutrient conditions, establishing representative long-term monitoring sites and protocols, and presenting findings within the context of strategic management (Jordan *et al.* 2002).

Extensive field surveys of water column nutrients, sediments and benthic habitats were performed during 2001-2002 and provided input for a hydrodynamic model simulating flushing and other key physical processes. Information on uses, significant ecological features (Figure 46), heritage values and human health were also compiled, and recommendations provided on monitoring and management. Key findings from water and sediment surveys are included in Sections 11 and 12, respectively of the current report, while habitat mapping studies contributed to the findings presented in Section 5.1.

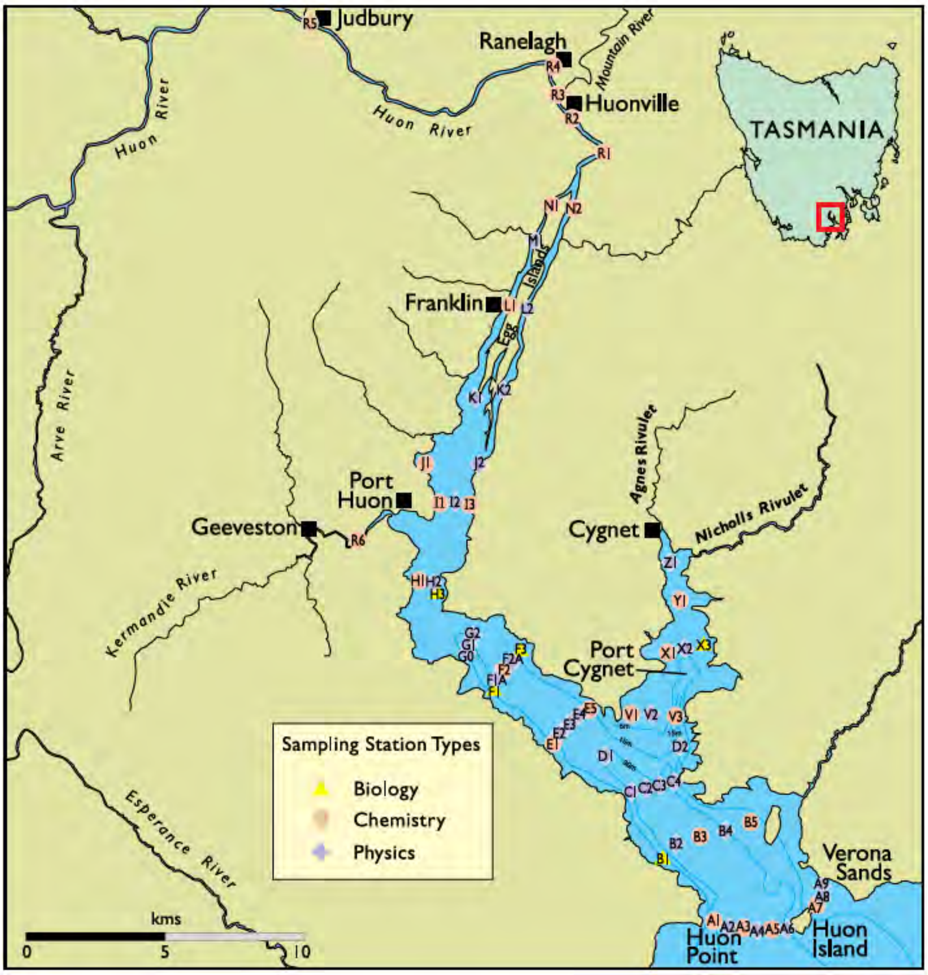


Figure 45 Huon Estuary Study sampling sites (Source: Butler *et al.* 2000).

10.3 A Whole-of-Ecosystem Assessment of Environmental Issues for Salmonid Aquaculture

This system-wide investigation of the Huon Estuary and D'Entrecasteaux Channel was part of the Environment Research Program of the CRC for Sustainable Aquaculture of Finfish ('Aquafin CRC') and was conducted in two phases. The initial research component was conducted as part of the project 'System-wide issues for sustainable salmonid aquaculture' (Volkman *et al.* 2006), and was subsequently continued and advanced through the project 'A whole of ecosystem assessment of environmental issues for salmonid aquaculture' (Volkman *et al.* 2009). The broader objectives and findings of the two projects are collectively summarised here as the Whole of Ecosystem Assessment for Salmon Farming (WoEASF).

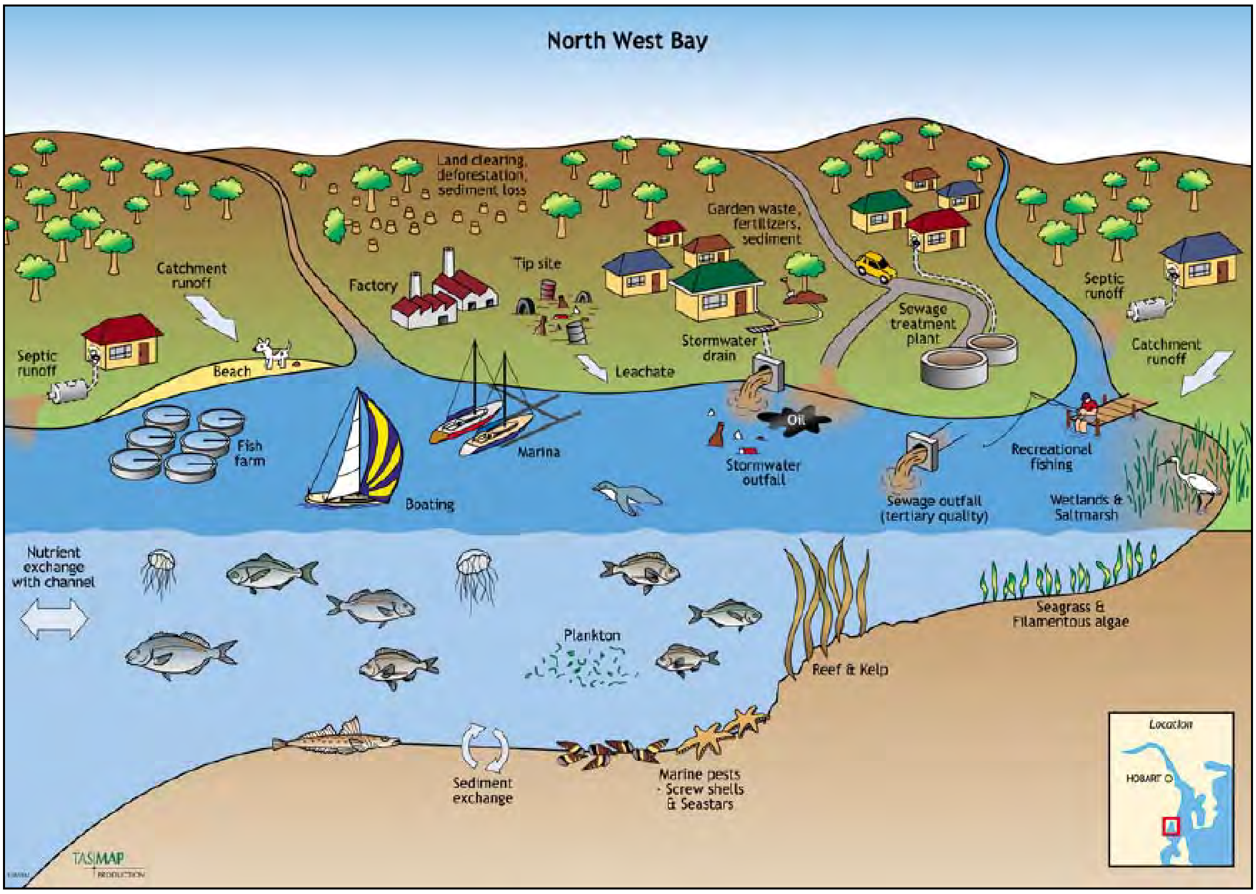


Figure 46 Conceptual diagram of North West Bay (Source: Jordan *et al.* 2002).

The WoEASF was aimed at characterising and modelling key oceanographic attributes, ecological features, and nutrient sources and cycling in the Huon Estuary and D'Entrecasteaux Channel, and determining how these may affect or limit fish farming. The project arose from the recommendations of two former studies: a former Aquafin CRC project investigating the effects of fish farm stocking and fallowing on sediment health (Macleod *et al.* 2004), which led to an agreement amongst industry and regulatory bodies to place more emphasis on environmental issues at the system-wide scale; and the HES (Butler *et al.* 2000; See Section 10.1), which identified that eutrophication (i.e. nutrient enrichment) was the major environmental risk for the region. Hence the focus of the WoEASF was on determining the overall assimilative capacity of the region in response to release of nutrients, organic matter and associated changes in ecosystem function (Volkman *et al.* 2009).

The majority of the field data were collected for this study during 2002-2005 and were used to calibrate and validate a sophisticated three-dimensional coupled hydrodynamic, sediment and biogeochemical model that captured major physical and biological processes. The hydrodynamic modelling approach used a series of nested models, including high resolution, intermediate scale and larger regional models (Figure 47). The biogeochemical component of the model simulated the cycling of carbon, nitrogen and phosphorus through dissolved and particulate organic and inorganic forms in the water column and surface sediments. The coupled model was used to investigate potential implications of fish farm expansions, as described in Section 13.3, with model findings contributing to the establishment of the farm input limits described in Section 9.2.2. Key findings from water and sediment quality studies are also included in Sections 11 and 12 of the report. The summary reports for the project (Volkman *et al.* 2006, 2009) were supported by numerous additional technical reports, and hence a wide range of authors are cited in relation to this study.

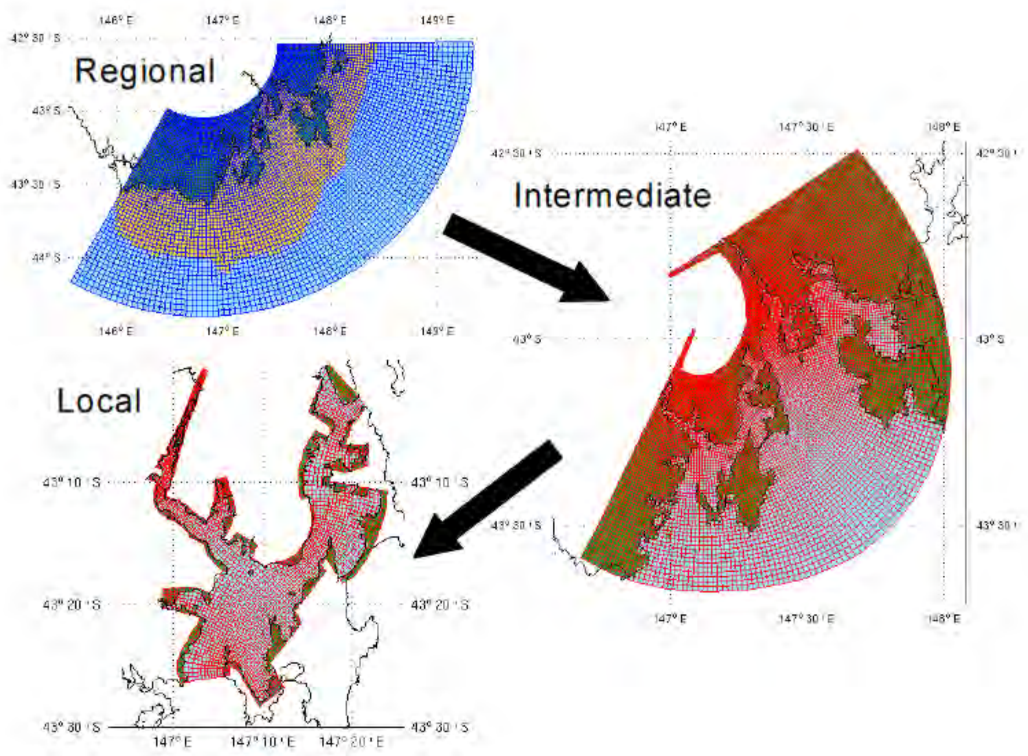


Figure 47 Nesting procedure for hydrodynamic modelling (Source: Herzfeld 2008).

10.4 Broadscale Environmental Monitoring Program

As part of the above WoEASF, a monitoring program was devised for the Huon Estuary and D'Entrecasteaux Channel with the aim of identifying temporal changes and thereby facilitating appropriate management action (Volkman *et al.* 2009). The program was designed to detect the effects of processes judged to be most threatening to the region, and were guided by the results of the WoEASF field measurements and modelling studies. Water and sediment quality parameters nominated for monitoring were selected on the basis of a risk assessment considering both the likelihood and consequence of a change in ecosystem functioning, with the potential for harm used to estimate risk (Thompson *et al.* 2008). The selection of sampling sites was guided by the results of the WoEASF coupled hydrodynamic, sediment and biogeochemical model, which identified some areas to be particularly susceptible to the impacts of increased nutrient inputs (i.e. eutrophication).

As noted in Section 11, some of the water quality trigger values developed at a national scale are not appropriate to the Huon Estuary and D'Entrecasteaux Channel, while in general ANZECC (2000) recommends that region-specific trigger values are developed on the basis of local data. The monitoring design developed by Thompson *et al.* (2008), therefore, also included recommended quantitative performance measures that could be used in a regulatory manner to adaptively manage the ecosystem. These proposed measures were developed on the basis of indicators of ecological condition, and incorporated a thorough review of existing data and high resolution biogeochemical modelling in order to estimate baselines and trigger values.

The monitoring design was refined through consultation with government and industry and provided guidance for the development of the Broadscale Environmental Monitoring Program (BEMP). This on-going program was instigated in March 2009, and is conducted as a condition to finfish farming licences in the

D'Entrecasteaux Channel and Huon River/Port Esperance Marine Farming Development Plan (MFDP) areas, in accordance with Licence Schedule 3BEMP (DPIPWE 2010d).

Fifteen sites are monitored, one each at the northern and southern entrances to the D'Entrecasteaux Channel ('boundary' sites), seven within the D'Entrecasteaux Channel, five in the Huon Estuary and one control site in Recherche Bay (Figure 48). In some cases sediment and water quality samples are collected at the same sampling station, while in other areas the precise sampling locations differ for water and sediment analytes.

Figure 48 BEMP sampling stations (Data source: DPIPWE 2010d).

The monitoring program has a water matrix and a sediment matrix, each containing a range of analytes within the components biota, chemistry (sediment), nutrients, dissolved oxygen and phytoplankton (water). The full suite of analytes, as well as survey frequency for each, is indicated in Table 28. Note that two analytes measured annually, benthic infauna and stable isotopes, were to be analysed in March 2009 and every four years thereafter. Samples in intervening years are collected during March and retained in storage, with analysis undertaken only if certain environmental trigger values are exceeded.

This monitoring program has now been underway for more than 3 years and is currently being reviewed by government with the assistance of the Institute for Marine and Antarctic Studies (IMAS) in the interpretation of data. The BEMP evaluation and assessment will examine the sampling station specific and regional data against the proposed trigger values and in relation to predictions of earlier WoEASF modelling. The assessment will take into account inter-annual variability and nutrient loading effects associated with fish farming, natural marine sources, the catchment and other anthropogenic inputs. It should be noted that the BEMP evaluation and assessment is focussed primarily on assessing changes associated with salmonid farming and hence may not provide a surrogate for a 'whole-of-system' assessment. This being said, the sampling station locations appear conducive to providing a broader assessment of system-wide environmental status. The above evaluation and assessment may therefore provide some updated information on water quality conditions in the D'Entrecasteaux Channel and Huon Estuary, and hence its results should be considered in conjunction with the current report.

Table 28 BEMP analytes and survey frequency (Source: DPIPWE 2010d).

Matrix	Component	Analyte/Parameter	Survey Frequency
Sediment	Biota	Infauna	Annually (March)
	Chemistry	Redox, Stable Isotopes, Particle size, Sulphide	Annually (March)
Water	Nutrients	Ammonia (total ammoniacal nitrogen), Nitrate, Phosphate, Silica, Total Nitrogen, Total Phosphorus	Monthly May-January and fortnightly February-April
	Dissolved Oxygen	Dissolved oxygen, Temperature, Salinity, Saturation	Monthly May-January and fortnightly February-April
	Phytoplankton	Pigments by way of HPLC, cell counts, chlorophyll-*a*, abundance	Monthly May-January and fortnightly February-April

10.5 Comparative studies of the Huon and Derwent Estuaries

A number of studies have conducted comparisons of the environmental conditions of the Huon and Derwent estuaries on the basis that they are geographically proximate drowned river valleys that share many similarities but have been exposed to contrasting levels of anthropogenic influence. The Huon Estuary is described as lightly urbanised and industrialised compared with the more extensively developed Derwent Estuary. The Huon is, therefore, considered to be a useful environmental reference point for the Derwent, and more indicative of 'baseline' (un-impacted) conditions for the region, particularly with relation to anthropogenic inputs of metals. A summary of comparative studies of the two estuaries is included below.

Geochemical comparisons between estuaries with non-industrialised and industrialised catchments: the Huon and Derwent River estuaries

The purpose of this study was to compare sedimentary metal loadings between the two estuaries. The Huon Estuary, with its minor urban development and lack of metal refining or manufacturing industries, provides a good area in which to assess the background trace metal signatures from the surrounding geological source terrain (Jones *et al.* 2003). While possible pollution effects were detected at a few isolated locations (see Section 12.2.4), the estuary was demonstrated to contain low concentrations of potentially toxic trace elements. It was, therefore, considered a suitable reference for assessing the degree of trace metal enrichment in the adjacent industrialised Derwent Estuary.

Ecological Status of the Huon Estuary: Comparative Study of the Derwent and Huon Estuaries

This study included detailed surveys of benthic infauna communities and sediment conditions and quality in the Huon Estuary to be compared with similar data collected in the Derwent Estuary (Macleod and Heliodoniotis 2005). The Huon was considered an important reference point for the Derwent, as it has similar biogeochemical, physical and climatic characteristics, but is much less developed with respect to urban and industrial activities. The benthic data were collected to develop baseline information and functionally relevant indicators and targets for sedimentary environments, and to quantify the distribution and spread of key introduced marine pest species.

The survey of the Huon Estuary was conducted in October 2004 and included analysis of benthic infauna, particle size distribution, redox potential, sulphides, organic carbon content and heavy metals at 25 sites distributed from the upper estuary through to estuary mouth (see Figure 68). The results suggested similarities in community distributions between the Huon and Derwent estuaries, with faunal composition consistently related to the natural geomorphology and salinity gradient of the estuaries. Community distribution in the Huon was slightly less complex than the Derwent, due to a smaller number of anthropogenic influences. The abundance of introduced species was generally lower in the Huon than in the Derwent, although variable abundances and distributions were recorded on the basis of environmental preferences, proximity to points of introduction, and species interactions. It was concluded overall that the Huon is a relevant and valuable biological reference point for comparison with the Derwent and consequently can provide useful parameters for developing management guidelines for both estuaries (Macleod and Heliodoniotis 2005).

The Tail of Two Rivers in Tasmania: The Derwent and Huon Estuaries

This study critically examined available physico-chemical data for each estuary and its context in regard to catchment and regional environment (Butler 2005). The two estuaries were considered to be similar in many ways, and an overview of their river and estuary hydrology and estuarine chemistry was provided. However, as a consequence of contrasting levels of anthropogenic influence over the past 200 years, environmental conditions of the two estuaries were considered disparate. The Huon Estuary had been modified, but its environmental quality remained high compared to the adjacent Derwent, with almost all monitoring results below the Australian guidelines. The study concluded that the Huon Estuary, though not pristine, serves as a useful baseline against which the contamination of the Derwent Estuary can be better evaluated. It also suggested that nutrients from fish farming and the lower catchment, causing increased phytoplankton biomass and possibly depleted levels of dissolved oxygen in bottom waters, appear to be the primary existing challenges for environmental management of the Huon Estuary (Butler 2005).

11 WATER QUALITY

Maintaining water quality in estuaries and coastal waters is a key factor in protecting the health of these ecosystems. Water quality can be defined by a range of physical, chemical and biological parameters, which are used collectively to describe and assess the state or health of the waterways (Jordan *et al*. 2002). Physical parameters are used to describe attributes relating largely to circulation and penetration of river-sourced and marine waters, while the concentration and distribution of chemical parameters is determined by a combination of natural sources and anthropogenic inputs. Biological indicators tend to respond to both the physical and chemical parameters, providing an overall picture of water quality conditions for biota. Anthropogenic inputs of pollutants and other compounds may enter the waterways via a range of point and diffuse sources, as described in Section 9.

Water quality is important not only for maintaining the ambient health of waterways and the biota they support, but also for protecting the health of humans who utilise estuaries and coastal waters for various activities. This section describes the results of water quality monitoring for both general environmental health and for human health; the former on the basis of the most extensive temporal and spatial ambient water quality datasets compiled for the region, and the latter based on targeted recreational water quality monitoring programs undertaken by councils.

11.1 Water quality guidelines

The National Water Quality Management Strategy (NWQMS) aims to achieve the sustainable use of Australia's and New Zealand's water resources by protecting and enhancing their quality while maintaining economic and social development. The NWQMS has developed national water quality guidelines which identify default trigger levels for various water quality parameters, including regional trigger levels for nutrients and additional selected parameters, and nation-wide trigger levels relating to toxicants such as heavy metals and pesticides (ANZECC 2000).

The regional trigger levels that are most applicable here were developed for slightly disturbed estuarine ecosystems in south-east Australia. These may not be entirely relevant to Tasmanian ecosystems, as they did not include analysis of Tasmanian data. A precautionary approach should therefore be adopted when applying these default trigger values to the D'Entrecasteaux Channel and lower Huon Estuary. Separate trigger levels were developed for estuarine and marine ecosystems in south-east Australia, as specified in Table 29.

Table 29 Water quality guidelines for nutrients and additional analytes in south-east Australia (Source: ANZECC 2000).

Ecosystem	Chlorophyll/Nutrients (µg/L)						DO (% sat)		pH		Turbidity (NTU)
	Chl_a	TP	FRP	TN	NO_x	NH_4^+	Lower Limit	Upper Limit	Lower Limit	Upper Limit	
Estuaries	4	30	5	300	15	15	80	110	7.0	8.5	0.5-10
Marine	1	25	10	120	5	15	90	110	8.0	8.4	0.5-10

Chl_a = chlorophyll a, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NO_x = oxides of nitrogen, NH_4^+ ammonium, DO = dissolved oxygen.

In the case of toxicants, trigger levels were only developed for 'freshwater' and 'marine' ecosystems, and hence the latter are presented here (Table 30). The guidelines for toxicants specify trigger levels for the protection of aquatic ecosystems at four different protection levels: 99%, 95%, 90% and 80%, whereby the protection level signifies the percentage of species expected to be protected. The highest protection level (99%) is chosen as the default value for ecosystems with high conservation value and the 95% trigger value could apply to ecosystems classified as slightly-to-moderately disturbed (ANZECC 2000). Trigger levels for selected heavy metals and other toxicants in marine waters, focussing on those that have surveyed in the study area, are included in Table 30.

Table 30 National water quality guidelines for toxicants in marine water (Source: ANZECC 2000).

Contaminant	Level of Protection			
	99%	95%	90%	80%
Metals (µg/L)				
Cadmium	0.7	5.5	14	36
Chromium	0.14	4.4	20	85
Cobalt	0.005	1	14	150
Copper	0.3	1.3	3	8
Lead	2.2	4.4	6.6	12
Mercury	0.1	0.4	0.7	1.4
Nickel	7	70	200	560
Vanadium	50	100	160	280
Zinc	7	15	23	43
Organics (µg/L)				
Endrin	0.004	0.008	0.01	0.02
Chlorpyrifos	0.0005	0.009	0.04	0.3

Note that ANZEEC (2000) encourages the development of state- and even site-specific guidelines for analytes, recognising that background natural conditions are highly variable and should be considered when determining appropriate trigger values for 'unacceptable' impact. In Tasmania, alternative draft water quality indicators were prepared for estuaries by Murphy *et al.* (2003), based on a comprehensive survey of 22 estuaries, and have been applied in some assessments of water quality data for the D'Entrecasteaux Channel and Huon Estuary (Crawford *et al.* 2006). In addition, as part of a Whole of Ecosystem Assessment for Salmon Farming (WoEASF) in the D'Entrecasteaux Channel and Huon Estuary, Thompson *et al.* (2008) developed draft environmental trigger values considered more appropriate for this region, including a combination of relative (i.e. % change) and absolute trigger values.

The above sets of alternative trigger values are not currently being widely applied, and hence for the purpose of the current report, comparison is made only with the ANZECC (2000) guidelines. However, as knowledge of the D'Entrecasteaux Channel and Huon Estuary waterways grows, it will be useful for more region-specific guidelines to be fine-tuned and applied more widely in assessments of environmental health.

11.2 Ambient water quality monitoring

A wide range of studies and monitoring programs have investigated water quality of the D'Entrecasteaux Channel and lower Huon Estuary since 1999; however, results summarised here are based primarily on major integrated studies that have surveyed an extensive suite of sites over extended periods. Results from smaller, or more localised, studies have also been referred to for analytes that have been little studied in the region or to help fill spatial data gaps. A comprehensive list and description of water quality data sources compiled for the region since 1999 is provided by Parsons (2012). Note also that the focus here is on key physical parameters and chemical analytes used widely in environmental health monitoring, and any additional parameters that are particularly relevant to the study area.

The sites surveyed by major studies are displayed in Figure 49, although it should be noted that some analytes were only sampled from a subset of the sites illustrated. What is immediately obvious is that the major studies to date have included a limited number of sites for the main D'Entrecasteaux Channel compared with the Huon Estuary and North West Bay. It should also be noted that none of the major studies referred to in this section include ongoing monitoring of water quality in the region, with surveys conducted primarily between 1996 and 2005. Hence, the water quality conditions described may not be representative of conditions in 2012. More recent monitoring of water quality, including measurements of salinity, temperature, dissolved oxygen, nutrients, phytoplankton, chlorophyll a and HPLC pigments, is ongoing as part of the Broadscale Environmental Monitoring Program (BEMP) described in Section 10.4.

11.2.1 Salinity, temperature, dissolved oxygen and pH

Salinity, temperature, dissolved oxygen and pH influence the types and rates of biogeochemical processes and affect the distribution, diversity and abundance of marine and estuarine species (Whitehead *et al.* 2010). These parameters also provide important contextual information about estuarine circulation and assist with the interpretation of other analytes such as nutrients.

Salinity

Most plant and animal species have specific salinity tolerances, and hence variation in salinity dictates to a large degree the types of biota present. Salinity also plays an important role in sedimentation processes and the behaviour of dissolved nutrients and other compounds (Butler *et al.* 2000, Whitehead *et al.* 2010).

The Huon Estuary is characterised as a salt-wedge estuary, with saltwater penetrating as far upstream as Ranelagh under low river flow — some 40 km from the mouth of the estuary (Butler *et al.* 2000). The estuary is strongly stratified in its upper reaches, with a prominent 'halocline', or gradient between fresh and marine waters. A shallow, fresher layer flows seaward over a deeper, marine bottom layer that flows more slowly in an upstream direction. A persistent halocline is present in the upper estuary under most conditions; however, during high river flow this halocline may be displaced downstream a considerable distance.

The above combination of fresh and marine waters results in highly variable salinities, as documented during the extensive surveys of the Huon Estuary Study (HES) in 1996-1998 (Butler *et al.* 2000). Salinity data were presented in comparison to the Derwent Estuary, including assessments of both surface and bottom-water salinity (Figure 50), with upstream areas experiencing the largest differences between surface and bottom salinities due to the highly stratified nature of the estuary in this area. In contrast, salinities in the lower estuary were typically high, with little variation between surface and bottom observations. The Huon Estuary had reduced upstream penetration of saltwater compared with the Derwent due to its narrower upper reaches (Butler *et al.* 2000).

The portion of the Huon Estuary occurring within the study area of the current report, including Port Huon and more downstream sites, recorded mean surface water salinities of ~22-34 parts per thousand (ppt), with values recorded as low as 15 ppt (Figure 50). In contrast, bottom water salinities in the salt wedge were consistently ~34-35 ppt, reflecting fully marine conditions. Monitoring in the D'Entrecasteaux Estuary during 2002-2003 as part of the WoEASF reflected a dominant maritime influence, with surface waters recording only one observation below 30 practical salinity units (PSU; a measure similar to ppt) (Thompson *et al.* 2005). Mean monthly values across all sites ranged from 31.5 to 34.7 PSU, with a distinct reduction in salinity during July 2002 (Figure 51).

Figure 49 Water quality sampling sites of integrated studies.

Temperature

The HES collected temperature data from 63 sites, but these particular data were not reported and hence information for the estuary could not be compiled from this source. A subsequent survey of a reduced number of sites during 2002-2003 recorded water temperatures in the range of 12.9 to 17.8ºC (Crawford *et al.* 2006), while temperatures up to 21–22ºC have been recorded in shallow depths (Jones *et al.* 2003).

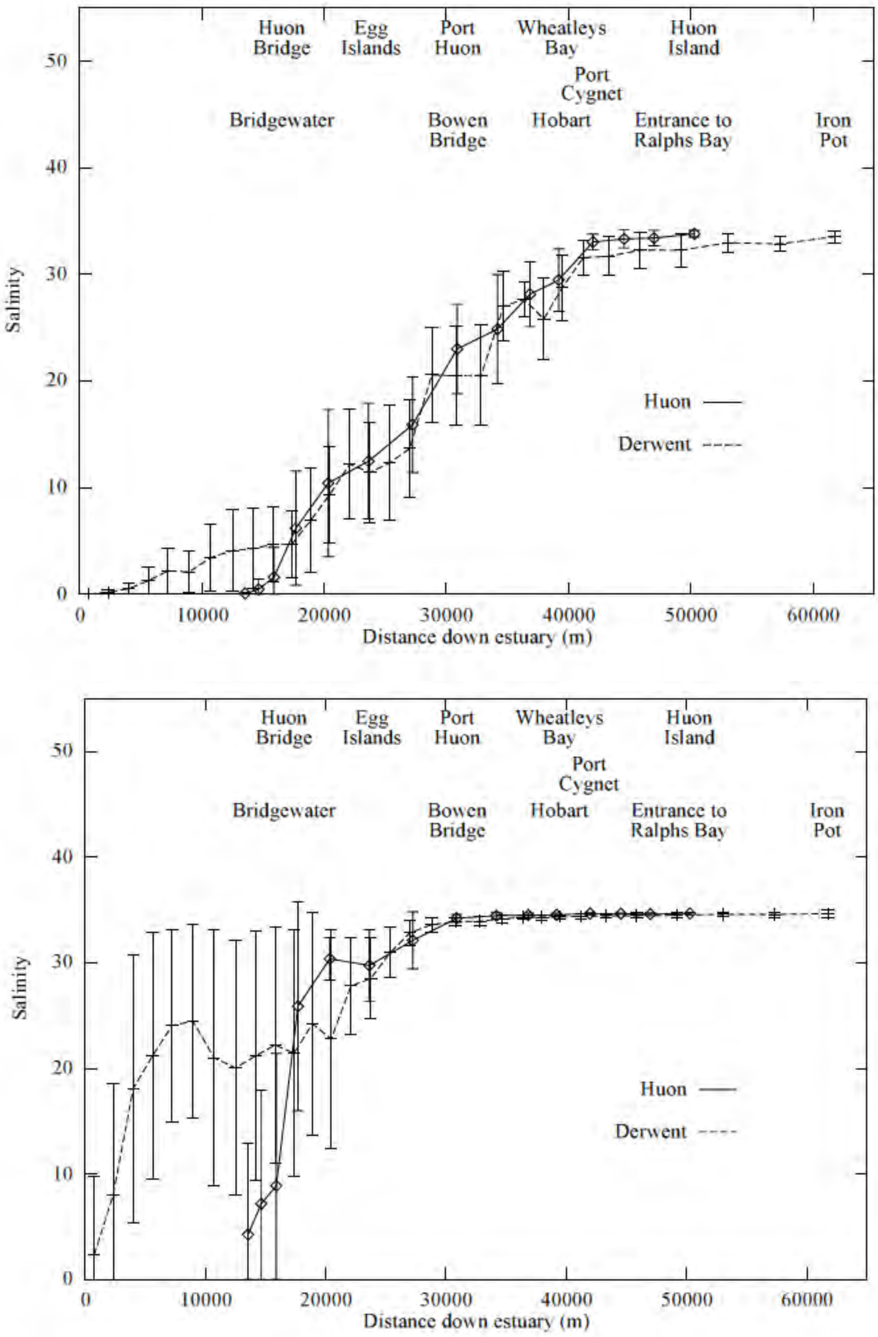


Figure 50 Mean salinity (ppt) in the Huon and Derwent estuaries: surface water (top) and bottom water (bottom) (Source: Butler *et al.* 2000).

Monitoring in the D'Entrecasteaux Channel during 2002-2003 for the WoEASF recorded mean surface temperatures in the range of ~10 to 19ºC (Figure 51), with minimum temperatures coinciding with minimum salinities and hence reflecting the influence of cooler freshwater inputs (Thompson *et al.* 2005). The southern end of D'Entrecasteaux Channel tended to be the coldest site during summer and the warmest site during winter, reflecting its strong connection to offshore waters, while North West Bay experienced the highest temperatures over an annual cycle. In general, a temperature gradient (up to 1ºC) existed along the D'Entrecasteaux Channel during summer and autumn, with the northern end associated with higher temperatures (Herzfeld *et al.* 2005).

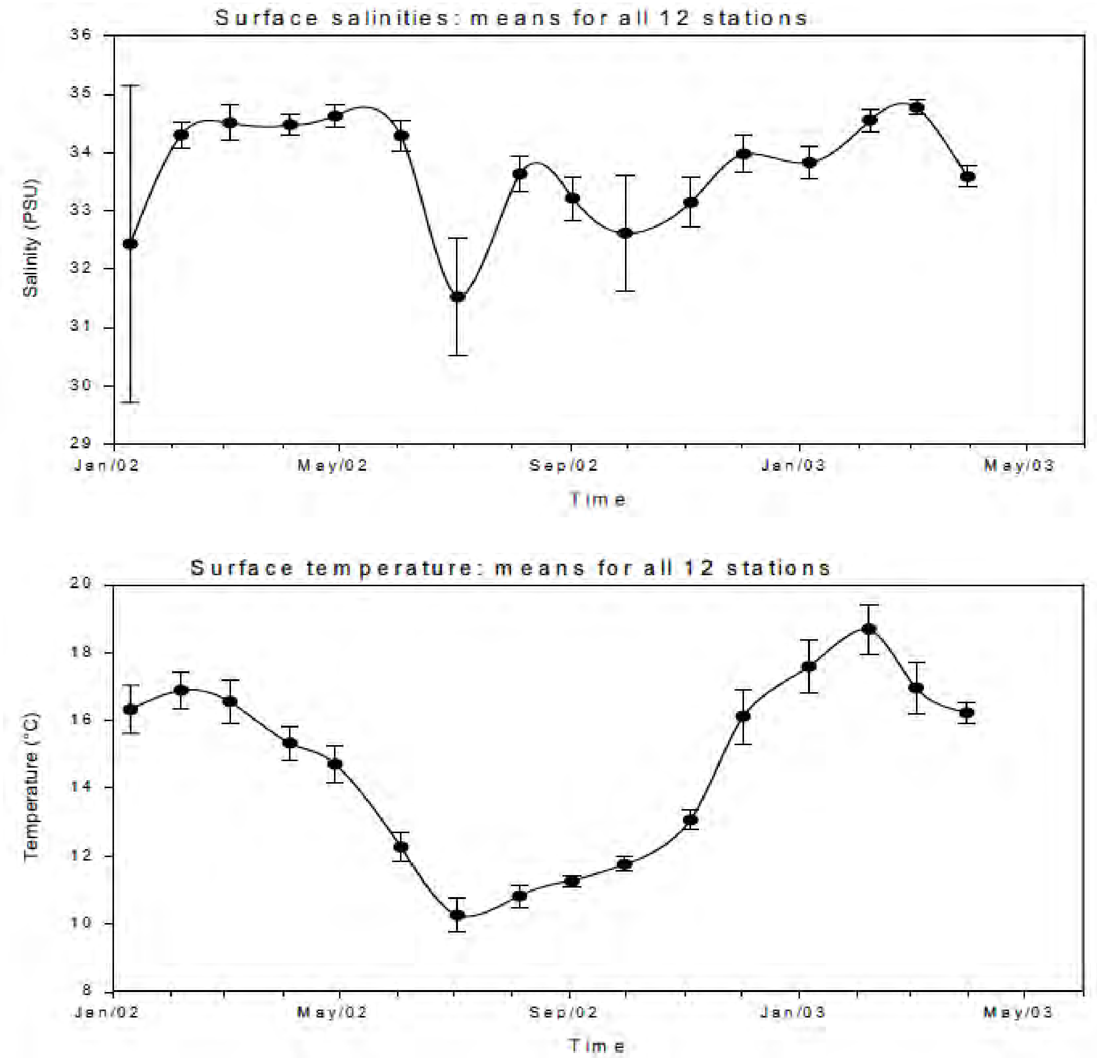


Figure 51 Mean surface salinity (top) and temperature (bottom) in the D'Entrecasteaux Channel (Source: Thompson *et al.* 2005).

Dissolved Oxygen

The dissolved oxygen (DO) concentration of the water column is sensitive to organic enrichment and eutrophication, with more serious eutrophication events resulting in hypoxia or anoxia (i.e. deficiencies in oxygen; Thompson *et al.* 2008). A reduction in DO can result in fundamental changes to nutrient cycling, leading to higher and potentially toxic concentrations of certain nutrients and sulphides in bottom waters and sediments, with significant effects on the biota. Surveys of the D'Entrecasteaux Channel and lower Huon Estuary have variously reported dissolved oxygen concentrations in units of micromoles per kilogram or litre (µM/kg or µM/L), milligrams per litre (mg/L) or as % saturation. Conversions from the former units to % saturation are based on water temperature and salinity, and where possible % saturation data are reported below to facilitate comparisons with the ANZECC (2000) guidelines.

The HES found that waters of the Huon Estuary were generally close to oxygen saturation (80–100%; i.e. ~200-250 µM/L) and therefore were consistent with acceptable guidelines for estuaries (ANZECC 2000). There were localised exceptions; for example, some parts of the upper estuary experienced oxygen levels depleted to 40% saturation. This is demonstrated for sites R1 and R2 at Ranelagh in an example (February 1997) dissolved oxygen longitudinal section of the estuary in Figure 52 (Butler *et al.* 2000). However low DO in the upper reaches is a natural characteristic of salt wedge estuaries, and is associated with sea water being isolated for extended periods from the atmosphere (L. Koehnken, Technical Advice on Water, pers. comm.). Other exceptions to saturated conditions were detected at sites in the lower-middle estuary during the HES studies, including Port Cygnet, the vicinity of Brabazon Point, and the middle of the main estuary, with some subsurface samples mildly undersaturated (60-80%). These conditions reflect oxygen concentrations below the ANZECC (2000) guidelines for estuaries. More detailed investigations revealed much greater depletions of dissolved oxygen, with occasional values as low as 3.6% saturation recorded in the lower estuary (Butler *et al.* 2000). Subsequent surveys in 2002-2003 recorded oxygen levels as low as 74% saturation at some lower estuary sites (Crawford *et al.* 2006), but no evidence of severe DO depletion comparable to that recorded during the HES was detected.

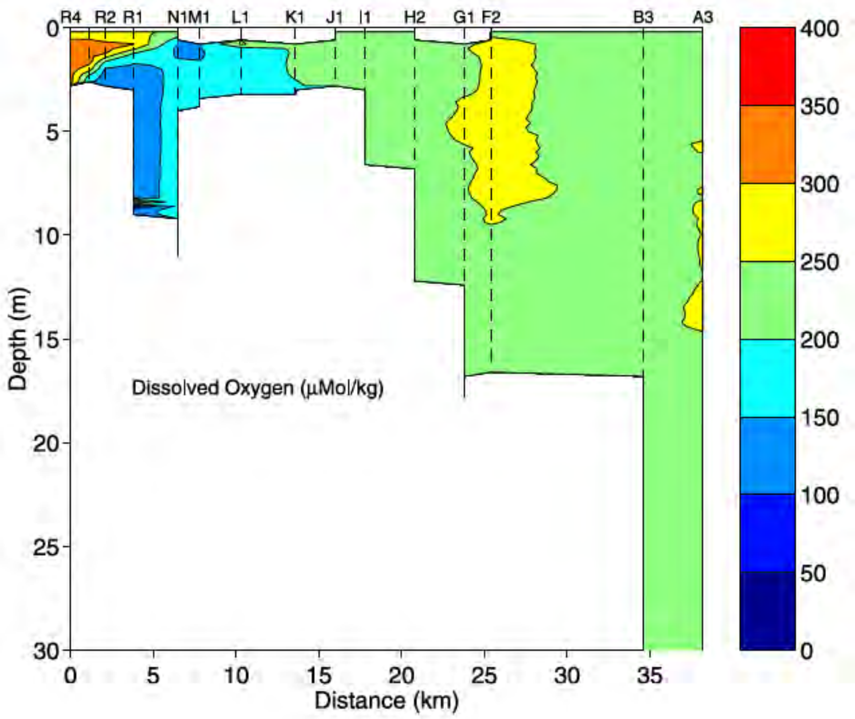


Figure 52 Dissolved oxygen (µM/kg) longitudinal section of the Huon Estuary during February 1997, extending from Ranelagh in the upper estuary (left) to Huon Island at the estuary mouth (right (Source: Butler *et al.* 2000).

At the other end of the spectrum, the upper limit default trigger value prescribed by ANZECC (2000) is occasionally exceeded during dense microalgal blooms in the Huon Estuary. An example of this occurred during May 1998 when surface and mid-depth samples throughout much of Port Cygnet were supersaturated with oxygen to a maximum level of 160% (Butler *et al.* 2000).

Dissolved oxygen was monitored in the D'Entrecasteaux Channel during 2002-2003 as part of the WoEASF, and was recorded in bottom and surface waters using a submersible sensor. Calibration titrations using bottled samples indicated that the sensor measurements underestimated DO on average by 6.6%; however, this error was considered unlikely to bias conclusions about environmental health due to the small range of concentrations encountered (Thompson *et al.* 2005). DO was slightly reduced at sites in the northern Channel, within the vicinity of North West Bay, Dennes Pt and Oyster Cove, compared with sites in the middle and lower Channel. All values recorded are indicated in Figure 53, while average concentrations across all sites ranged from 7.85 to 8.23 mg/L, reflecting saturation levels >99% and hence within acceptable ANZECC (2000) guidelines. Note however that North West Bay in the northern Channel is susceptible to periodic oxygen depletion in its upper reaches, with surveying during 2007-2008 recording values mostly above 85% saturation, but occasionally falling as low as 58.2% saturation in bottom waters during summer (Temby and Crawford 2008). This reflects periodic degraded conditions characterised by DO levels well below the ANZECC (2000) lower limit guideline.

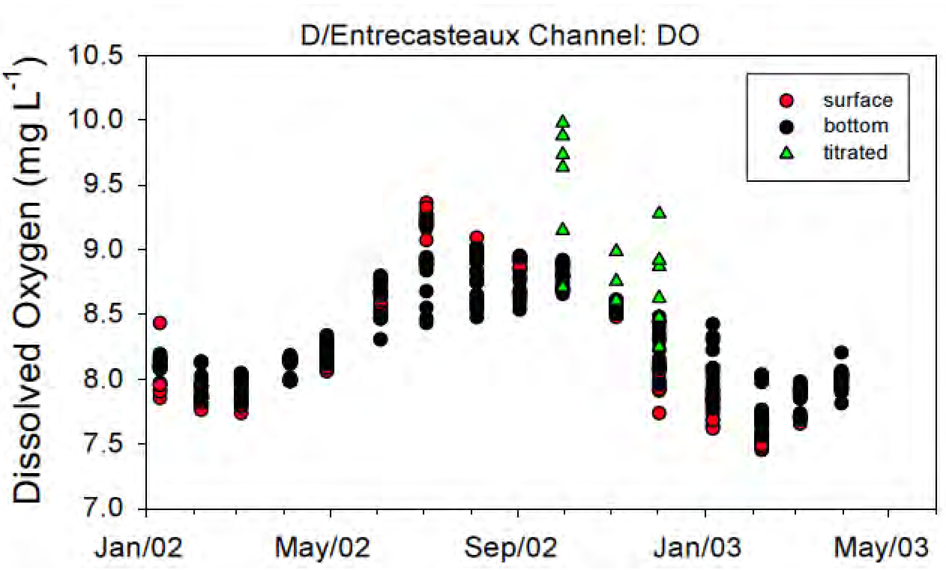


Figure 53 Dissolved oxygen concentrations in the D'Entrecasteaux Channel (Source: Thompson *et al.* 2005).

pH

Measurements of pH are collected to monitor acidity, or the hydrogen ion (H+) concentration, in water. This parameter has not been included as a standard component of system-wide monitoring programs in the D'Entrecasteaux Channel and Huon Estuary, but some limited data are available. A survey of the Huon Estuary during 1997 recorded pH values in the range of 7.3 to 7.8 at a depth of 2 m (Jones *et al.* 2003), while subsequent monitoring in Port Cygnet and North West Bay recorded pH values in the range of 7.7-8.7 (Temby and Crawford 2008). A survey of sites associated with a marine effluent discharge in Port Esperance reported pH values of 8.0-8.2 during 2010 (Tassal 2010). All of the values reported fall within the acceptable ANZECC (2000) guidelines for estuarine and marine waters, with the exception of spring or summer values recorded in association with high freshwater inputs at the headwaters of Port Cygnet and North West Bay.

11.2.2 Suspended particulate matter, turbidity and water clarity

Trends in water clarity and particulate loads (i.e. the amount of fine particles suspended in the water column) have been assessed using a range of measures in the D'Entrecasteaux Channel and lower Huon Estuary. Techniques have primarily included direct measures of suspended particulate matter (SPM), turbidity measured in Nephelometric Turbidity Units (NTU) (a measure of the scattering of light through water caused by fine particles), and Secchi disc depth (a measure of the transparency of the water). Measures of particulate matter are particularly relevant in coastal waterways that are vulnerable to high levels of catchment runoff, whereby large inputs of fine particles and associated nutrients may jeopardise the health of the waterways for aquaculture or other activities. Note however that sources of particulate matter include phytoplankton as well as dissolved substances and suspended material (Jordan *et al.* 2002).

Additional approaches have been used to assess the optical properties of the Huon Estuary and D'Entrecasteaux Channel, although these are not widely used indicators of environmental health in estuarine and coastal systems and hence have not been described here. However, one important aspect in characterising the study area environment is the influence of humic substances (i.e. coloured compounds derived from terrestrial plant remains) on the Huon Estuary. The Huon catchment includes considerable areas of waterlogged soils classified as peats, with runoff from these soils strongly coloured with dissolved humic material. This material breaks down very slowly and results in the estuary being darkly coloured and light limited, although this does not result in elevated turbidity. Diminished light penetration is most prevalent in the upper estuary, although a smaller influence of humic inputs can extend along the entire estuary, and also neighbouring parts of the southern D'Entrecasteaux Channel, during high river flows. Surveys of optical absorption properties found that throughout the entire estuary, humic material dominated over other particle types such as phytoplankton and detritus, and recorded values that are amongst the highest known for any Australian water body (Butler *et al.* 2000). The mixing of highly coloured fresh waters with clearer oceanic waters intruding into the lower to middle estuary make the Huon Estuary optically complex and also has implications for phytoplankton blooms (Section 11.2.4).

The HES recorded low SPM concentrations that were generally ≤3 mg/kg in freshwater areas and ≤2 mg/kg at marine sites. Apart from a very few instances, concentrations in the Huon Estuary were consistently less than 6 mg/kg (Butler *et al.* 2000). National guidelines have not been prescribed for SPM, although ANZECC (2000) suggested that ranges for SPM were similar to those for turbidity (i.e. maximum limit of 10), suggesting that the above values are likely to be within acceptable levels. Subsequent measurements of turbidity in the Huon Estuary during 2002-2003 recorded spatial and seasonal variation, with higher values regularly recorded at the most upstream sites and during winter (Figure 54) (Crawford *et al.* 2006). Values recorded were consistently within the acceptable guidelines of ANZECC (2000). It is notable that some tributaries discharging to the Huon Estuary carry elevated loads of particulate matter and hence may cause localised degradation of water quality. An example is the Kermandie River, which was surveyed by the HES and recorded SPM values mostly between 6 and 12 mg/kg but reaching as high as 39 mg/kg (Butler *et al.* 2000).

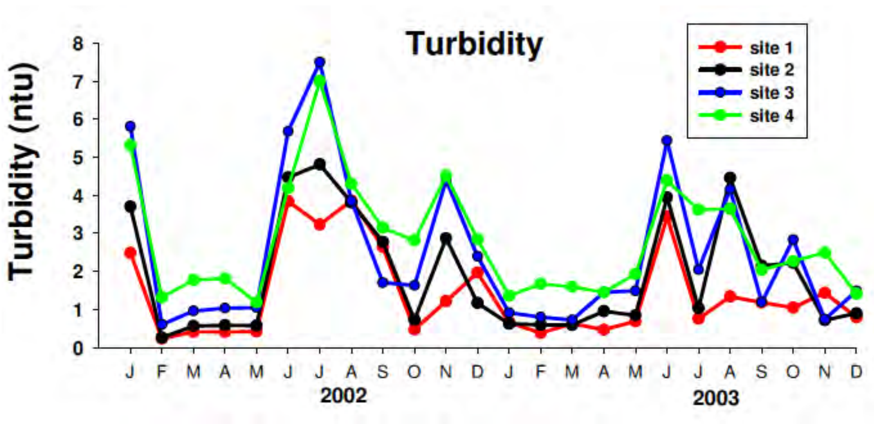


Figure 54 Turbidity levels in the Huon Estuary; estuary mouth (site 1) through to Port Huon (site 4) (Source: Crawford *et al.* 2006).

Secchi disc measurements were recorded as an indicator of water clarity in the D'Entrecasteaux Channel during surveys performed by the WoEASF in 2002-2003 (Thompson *et al.* 2005). Secchi disk depths were temporally variable, with reduced depths associated with high winter rainfall, and greatest clarity recorded during summer. Mean Secchi disk depths for individual sites were highest at the southern end of D'Entrecasteaux Channel, indicative of more transparent water than recorded at the northern end of the Channel (Figure 55) (Thompson *et al.* 2005). A separate study of North West Bay demonstrated the potential effects of high rainfall and river flow events on local water quality. Turbidity recorded typical background values of 0-1 NTU, but spiked at 38 NTU following a period of high rainfall (Figure 56) (Jordan *et al.* 2002). This demonstrates the occurrence of dramatic, although transient, episodes of elevated turbidities against the ANZECC (2000) guidelines in areas proximate to freshwater inputs.

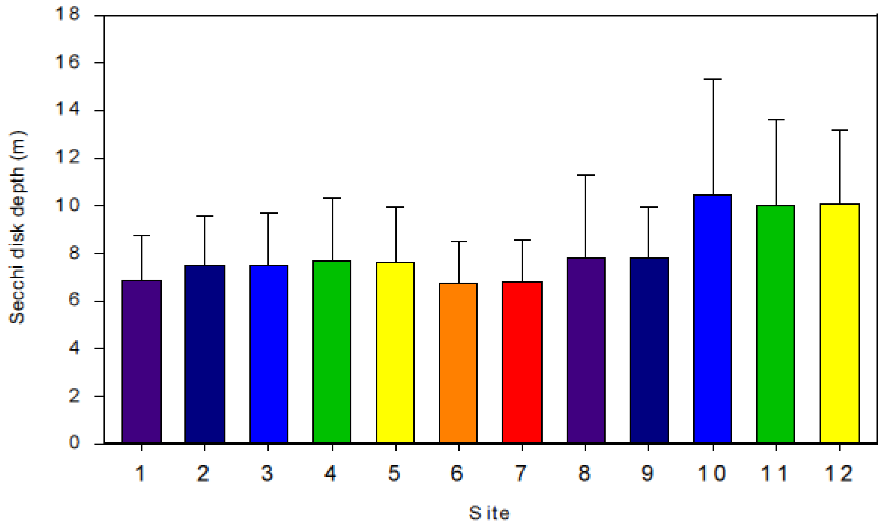


Figure 55 Mean annual Secchi disk depths in the D'Entrecasteaux Channel: north (site 1) to south (site 12) (Source: Thompson *et al.* 2005).

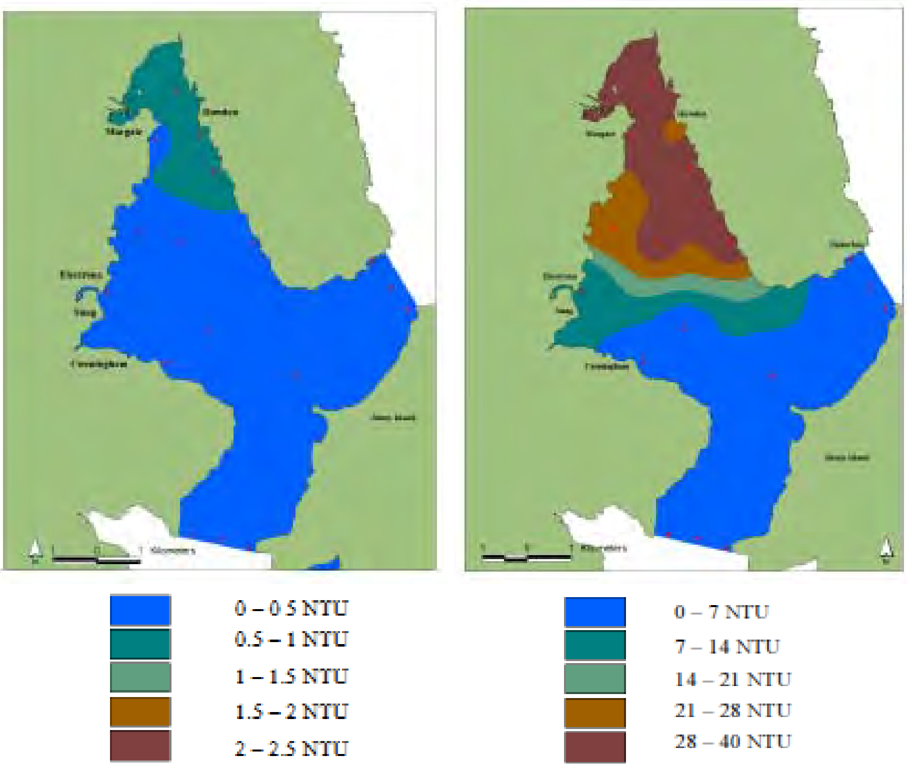


Figure 56 Turbidity in North West Bay before (left) and after (right) a high rainfall event (Source: Jordan *et al.* 2002).

11.2.3 Nutrients

Nitrogen (N) and phosphorus (P) are nutrients that comprise the essential building blocks for estuarine and marine plant and animal growth, and their various forms (i.e. dissolved organic, dissolved inorganic, and particulate form) are key components of nutrient cycles. Additional elements in the pool of available nutrients include carbon and, within marine systems, silica (Jordan *et al.* 2002). Nutrients are derived from a variety of natural and anthropogenic sources, with ocean currents delivering the majority of the dissolved inorganic nitrogen and phosphorus present in the D'Entrecasteaux Channel and lower Huon Estuary. As a result, the primary temporal patterns in surface nutrient concentrations are typical of temperate latitude cycles with greater concentrations during winter and relatively depleted concentrations during summer (Volkman *et al.* 2009). However marine-sourced nutrients may be supplemented by additional inputs from natural land-based and anthropogenic sources, such as livestock wastes, fertilisers used in agriculture and forestry, fish farms, industrial and sewage wastewater treatment plants (WWTPs), and various additional sources.

Nutrient concentrations are a direct measure of eutrophication (Thompson *et al.* 2005), a process in which excessive plant growth leads to elevated levels of organic matter within the ecosystem. Excessive growth of phytoplankton and macroalgae triggered by elevated nutrient levels can lead to a number of water quality and other problems in estuaries and coastal waters. Implications include, for example: threats to seafood safety from toxic algal blooms (see Section 14); fluctuating oxygen levels causing physiological stress to fish and other organisms; loss of seagrass; and habitat modification via excessive filamentous algal growth (Whitehead *et al.* 2010).

Since nutrients are a primary controlling factor for growth of phytoplankton, and these algae have optimal N and P requirements for growth, reductions in either one of these elements may limit growth and hence restrict phytoplankton biomass. In marine ecosystems, the optimal nitrate:phosphate (NO_3:PO_4) ratio for phytoplankton growth, known as the Redfield Ratio, is 16:1. Hence, where a ratio >16:1 is recorded, P is considered limiting, while ratios of <16:1 suggest N to be limiting. However, the 16:1 ratio was developed in open-ocean systems, and a range of human inputs and natural effects may cause departures from the classic ocean pathway for nutrient interactions between waters and phytoplankton. Nevertheless, gross changes in the ratio are considered a useful indicator for assessing factors controlling phytoplankton production in coastal waters, with nitrogen the limiting nutrient for plant growth in most marine and estuarine systems (Butler *et al.* 2000).

Nutrients are constantly cycling in the environment between the water column, biota, sediments and the atmosphere. In order to fully understand the cycling and availability of nutrients it is necessary to quantify inputs, exports and 'fluxes' (or rates of transfer) between the various environmental components. Further information on nutrient cycling in the D'Entrecasteaux Channel and Huon Estuary is provided in Section 13. The current section is focussed on reviewing major data sets for ambient nutrient levels in the region and comparing these with the National Water Quality Guidelines (ANZECC 2000), keeping in mind the limitations of these guidelines with respect to Tasmanian systems (Section 11.1, and also described further below). The most biologically available form of nitrogen is ammonium (NH_4) followed by nitrate (NO_3), while orthophosphate (PO_4) is the most bioavailable form of phosphorus. Silica has also been identified as important in marine and estuarine systems, and is a limiting nutrient for some types of phytoplankton such as diatoms (Whitehead *et al.* 2010). Data collected for these or related forms of nutrients are reviewed below, while a description of relevant chemical forms is included in Table 31. Note that chlorophyll-*a* is frequently measured in conjunction with nutrients as an indicator of phytoplankton response and eutrophication potential, but is described in Section 11.2.4.

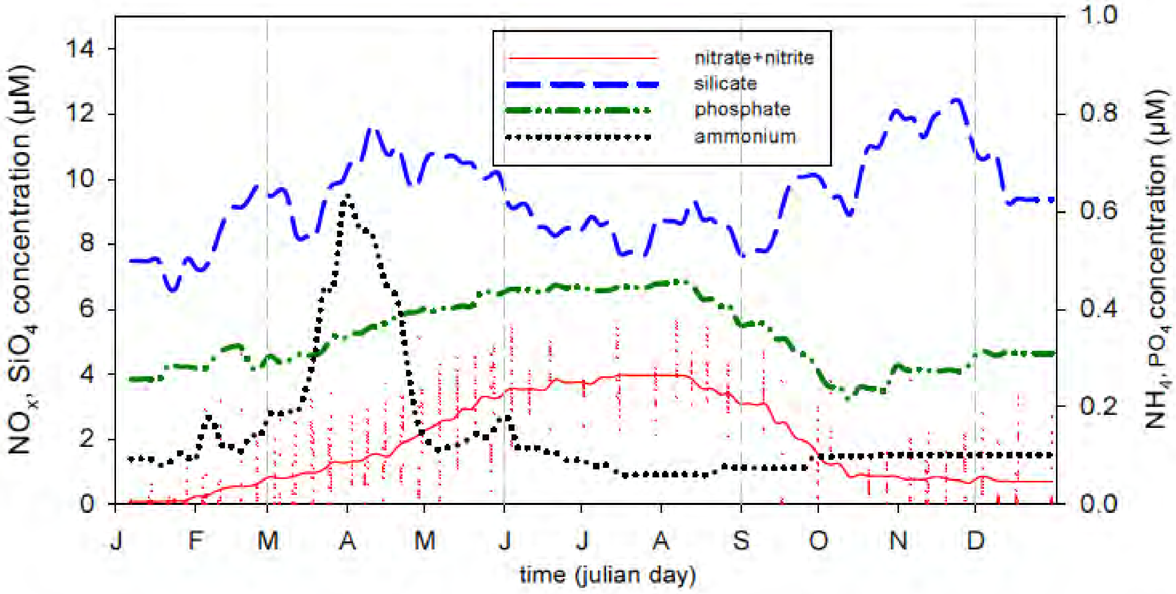
Table 31 Nutrient forms (Source: Jordan *et al.* 2002, Whitehead *et al.* 2010).

Nutrient Form/s	Description
TN	Total nitrogen (TN) a measure of all the forms of dissolved and particulate nitrogen found in water. It is the sum of dissolved inorganic nitrogen (DIN) – i.e. including nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and ammonium (NH_4^+) – as well as organic nitrogen both as dissolved organic nitrogen (DON; e.g. urea, humic compounds) and particulate organic nitrogen (PON; e.g. phytoplankton).
NH_3 & NH_4^+	Ammonia (NH_3) is a soluble gas in water, whilst ammonium (NH_4^+) occurs as dissolved inorganic ions in water. The value is frequently reported as the sum of both forms and is referred to as total ammonia or just ammonia. The majority of ammonia in seawater changes into ammonium [and hence, the ANZECC (2000) guideline for ammonium is frequently applied to values for total ammonia]; however, this is strongly regulated by pH. Ammonium is an important nutrient for aquatic algae and bacteria and elevated levels may cause algal blooms.
NO_x, NO_2, & NO_3	In marine waters, the majority of nitrate + nitrite (NO_x) is present as nitrate, since nitrite (NO_2) is rapidly converted to nitrate (NO_3) during the nitrification process (an important step in the nitrogen cycle; refer to Section 13).
TP	Total phosphorus (TP) is a measure of all the forms of dissolved and particulate phosphorus found in water. Particulate phosphorus primarily consists of plants and animals in the water column, precipitates of phosphorus, and phosphates in and adsorbed to mineral surfaces. Dissolved phosphorus consists of inorganic orthophosphates and organic compounds.
PO_4	Orthophosphate (PO_4) (frequently referred to simply as 'phosphate') comprises dissolved inorganic phosphorus and is the primary constituent of filterable reactive phosphate (FRP), known alternatively as dissolved reactive phosphorus (DRP) or soluble reactive phosphorus (SRP).
SiO_4	Silicate is the most biologically available form of silica, a nutrient with particular importance for diatoms (a common type of microalga) in marine and estuarine systems.

A review of the system-wide datasets for nutrient levels in the D'Entrecasteaux Channel and Huon Estuary was performed by Volkman *et al.* (2009) and provides the primary source of information summarised here, supplemented by data provided in Crawford *et al.* (2006). The major nutrient datasets compiled include sampling of ~20 sites in the Huon Estuary Study (HES) during 1996-1998, 4 sites in the Huon Estuary (Crawford *et al.* 2006) and 12 sites in the D'Entecasteaux Channel during 2002-2003, and 11 sites in the combined Huon Estuary and D'Entrecasteaux Channel during 2004-2005. High levels of temporal and spatial variation complicate direct comparisons between the datasets (Volkman *et al.* 2009), and hence results are summarised individually under headings below. The current report provides an overview of data collected to 2005, while a more detailed assessment of recent nutrient data will be performed by the evaluation and assessment of the BEMP described in Section 10.4.

Huon Estuary 1996-1998

The HES data were retrospectively analysed by Volkman *et al.* (2009), and reflect increased nitrate, phosphate and ammonium concentrations with depth in the Huon Estuary, but greatest silicate concentrations at the surface. Temporal trends were consistent across all depths, with nitrate and phosphate concentrations peaking in winter, ammonium concentrations peaking strongly in autumn, and silicate concentrations displaying no significant seasonal patterns (Figure 57, top). Riverine inputs were the major source of dissolved silicate to the ecosystem, as demonstrated by a strong relationship with salinity (Figure 57, bottom), while peaks in nitrate and phosphate were associated with the winter intrusion of offshore marine waters. Seasonal variation in N:P ratios suggested that levels of nitrogen limited the growth of phytoplankton during summer months (N:P ratio of <5:1) (Butler *et al.* 2000).



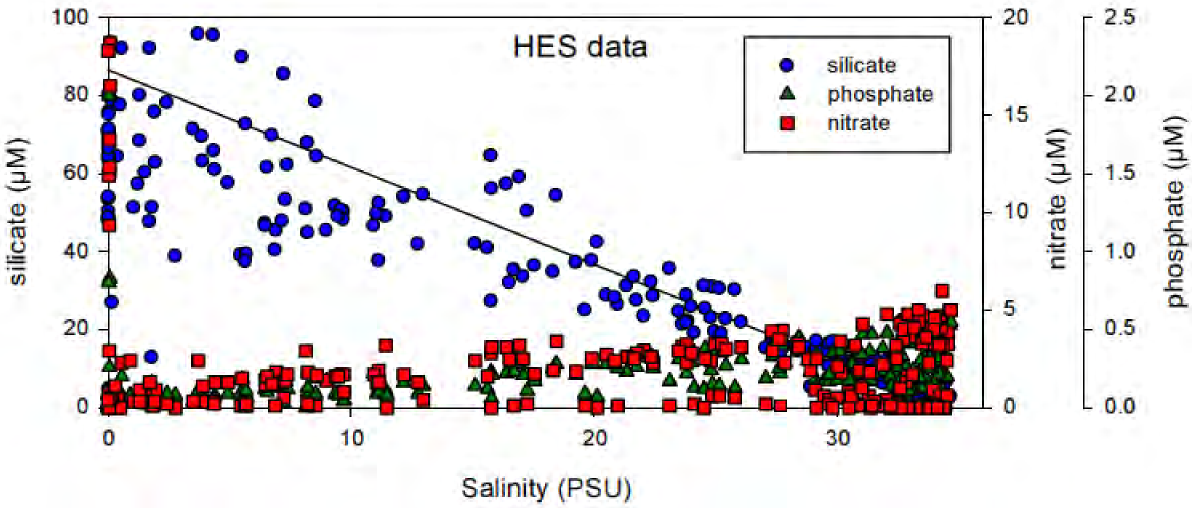


Figure 57 Huon Estuary Study nutrient data: weekly sampling (top) and quarterly sampling data related to salinity (bottom) (Source: Volkman *et al.* 2009).

Nutrient levels recorded in the Huon Estuary, as well as associated concentrations of chlorophyll-a, phytoplankton cells (Section 11.2.4) and organic carbon (Section 12.2.2), characterised the Huon Estuary as a mesotrophic system (i.e. having intermediate concentrations of nutrients and, therefore, being moderately productive). This classification is adopted in the current report, although note that the highly variable conditions in the Huon Estuary straddle the definitions of mesotrophic and oligotrophic (i.e. reduced nutrient) systems, with modelling work defining much of the estuary as oligotrophic (Section 13.3). No comment is provided in the recent literature as to whether the mesotrophic status of the estuary is natural, or can be at least partly attributed to upstream flow diversions (see Section 2.5) and catchment activities.

Ranges in values of nutrients recorded during HES are compared to the ANZECC (2000) guidelines in Table 32, with the guidelines converted to units of µM to facilitate comparisons with HES data. Several chemical forms, including nitrate+nitrite (NO_x), TN, DRP, TP and ammonia (ammonium) recorded exceedances of guidelines for estuarine waters, while marine sites included values exceeding guidelines for NO_x, TN and DRP. However, Butler *et al.* (2000) concluded that several chemical forms of nitrogen and phosphorus exceeded these trigger levels for entirely natural reasons due to incursions of nutrient-rich subantarctic waters around southern Tasmania. Concentrations of NO_x and dissolved P during late autumn, throughout winter and in early spring exceeded the guidelines by more than 50%, but the majority was sourced from the deeper ocean and cannot be controlled by regional or local reductions in anthropogenic inputs. In addition, the large natural marine sources were supplemented by high concentrations of total nitrogen (mostly dissolved organic nitrogen) derived from the naturally occurring humic substances in the Huon catchment (see Section 11.2.2). These factors makes the ANZECC (2000) trigger values for 'slightly disturbed' estuaries in south-east Australia too low for application in the region.

Table 32 Huon Estuary Study nutrient data compared to national guidelines converted to µM to facilitate comparisons (Source: Butler *et al.* 2000).

HES Results			ANZECC Guidelines (2000)
Nutrient (µM)	**Estuarine (all sites)**	**Marine**	**estuarine/ marine (µM)**
Nitrate + Nitrite	<0.05–7.2	<0.05–5.3	1.07/0.36
Nitrite	<0.03–2.25	<0.03–1.49	—
Total Ammonia	<0.02–2.60	0.06 –1.00	1.07/1.07
Total Dissolved N	<0.5–26	2.8–11.5	—
Total Nitrogen	<0.5–45	4.4–11.5	21.43/8.57
Dissolved Reactive P	<0.03–0.71	0.18–0.64	0.16/0.32
Total Dissolved P	<0.08–1.86	0.25–0.69	
Total Phosphorus	<0.08–3.16	0.31–0.76	0.97/0.81
Dissolved Reactive Si	<0.5 - 106	0.8–3.8	—

Huon Estuary 2002-2003

During 2002-2003, monitoring of four of the former HES sites extending from the estuary mouth (site 1) to the vicinity of Port Huon (site 4) typically recorded elevated NO_x values (nitrate + nitrite) in winter and early spring, and very low to negligible levels during summer months (Figure 58) (Crawford *et al.* 2006). The most upstream site near Port Huon regularly had the lowest values, while the range in values across all sites was ~0 to 5.7 µM. Ammonia concentrations ranged from 0 to 2.4 µM and averaged around 1 µM across all sites and over time, with no consistent temporal or spatial patterns evident, although higher values recorded at the most upstream site during autumn were consistent with earlier HES data. Phosphate concentrations ranged from 0 to 0.6 µM, again with no clear seasonal pattern or differences between sites, except that the Port Huon site regularly had the lowest values. Consistent with the HES, nitrogen was limiting for phytoplankton growth during summer and much of the year, with ratios of N:P only exceeding 16:1 during the winter months.

Ranges in nutrient values were similar to those recorded in the earlier HES surveys (Crawford *et al.* 2006), with ANZECC (2000) trigger values consistently exceeded for NO_x during winter and also some autumn and spring months, and also frequently exceeded for phosphate at all sites. The guidelines for ammonia (ammonium) were also exceeded, although the specific laboratory method used was subsequently found to produce values approximately double those recorded using the CSIRO methodology applied to the HES and

2002-2003 D'Entrecasteaux samples (described further below). Hence values need to be interpreted with caution, with possibly only a subset during summer and autumn months exceeding the ANZECC (2000) guidelines when adjusted for methodology. It should be noted however that the laboratory method applied to Huon Estuary sites in 2002-2003 was in accordance with Australian standards and is used widely in other estuaries around Australia and for other water quality studies in Tasmania. Hence, the issue of methodology further complicates comparisons of nutrient levels to guideline values.

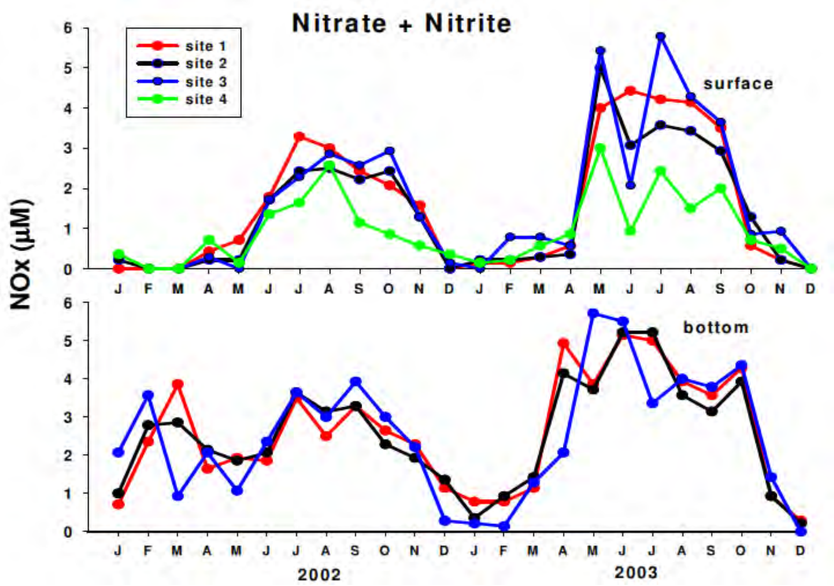


Figure 58 Nitrate + nitrite (NOx) values in the Huon Estuary during 2002-2003 (Source: Crawford *et al.* 2006).

D'Entrecasteaux Channel 2002-2003

Monitoring at 12 sites in the D'Entrecasteaux Channel during 2002-2003 recorded elevated concentrations of nitrate and nitrite during winter, but no clear seasonal trends in ammonium concentrations (Figure 59). Average phosphate concentrations were generally in the range of 0.2-0.3 µM, while surface silicate peaked in conjunction with elevated winter river flows. The nutrient concentrations observed in the D'Entrecasteaux Channel indicated similar seasonal patterns to those observed in the Huon Estuary, with peaks in nitrate and phosphate coinciding with winter intrusion of offshore marine waters (Volkman *et al.* 2009). Combined concentrations of nitrate and nitrite again indicated exceedances of the ANZECC (2000) marine guideline for NO_x. Phosphate levels also exceeded the guideline value at times, primarily in bottom waters, while ammonia concentrations were consistently below the guideline level.

The relatively low concentrations of NH_4, combined with low chlorophyll-*a* (Section 11.2.4) and relatively high concentrations of DO (Section 11.2.1) indicated that the D'Entrecasteaux Channel is fundamentally an oligotrophic (i.e. lacking in nutrients) ecosystem (Thompson *et al.* 2005). Naturally oligotrophic ecosystems are highly susceptible to ecological change induced by artificial increases in nutrient loading. Some sites are likely to naturally experience more nutrient loading than others, especially those with relatively high terrestrial inputs of nutrients or carbon such as North West Bay. Several other studies of this bay recorded elevated levels of nitrate and total nitrogen at the head of the bay, believed to be due to sewage effluent and/or river inputs (Jordan *et al.* 2002, Temby and Crawford 2008). Barnes Bay on Bruny Island was also identified as being vulnerable to additional nutrient loading due to evidence of elevated chlorophyll-*a* and NH_4 levels, and a low anticipated exchange rate (Thompson *et al.* 2005).

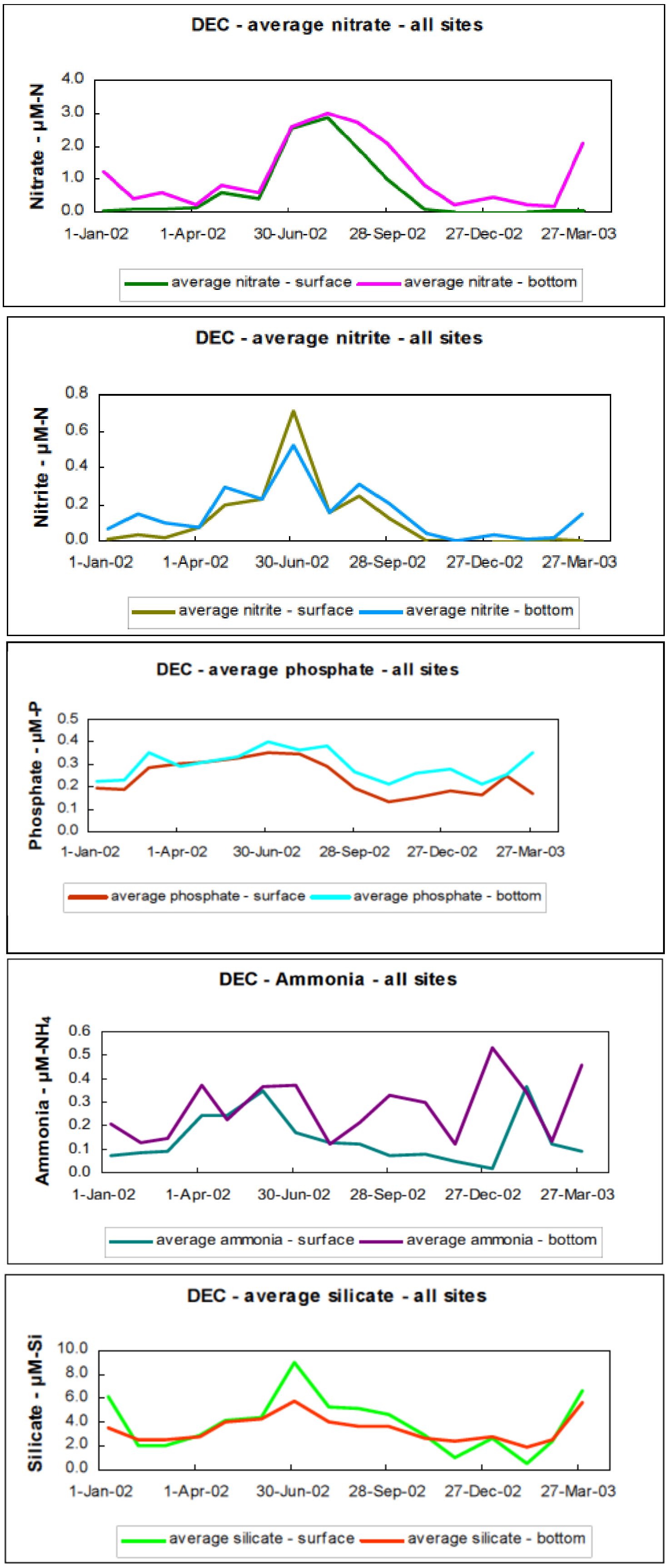


Figure 59 Mean nutrient concentrations in the D'Entrecasteaux Channel during 2002-2003 (Source: Thompson *et al.* 2005).

D'Entrecasteaux Channel and Huon Estuary 2004-2005

Additional nutrient sampling was conducted during September 2004 to June 2008 at a subset of sites surveyed during 2002-2003, including 11 sites spread across the Huon Estuary and D'Entrecasteaux Channel (Figure 49). Nitrate, phosphate and silicate concentrations were all significantly different between surface and bottom waters, with nitrate and phosphate higher in the marine bottom waters and silicate higher in the more freshwater influenced surface waters.

The median nitrate concentration reached 1.45 µM near the bottom, exceeding the ANZECC (2000) guidelines for NO_x, while phosphate levels in bottom waters also exceeded the guideline concentrations for both marine and estuarine waters. Averaged surface nutrient concentrations from all 11 sites showed strong seasonal trends (Figure 60). The most pronounced temporal pattern was a decrease in nitrate during summer of more than two orders of magnitude compared with winter. Mean surface phosphate concentrations were also significantly reduced during spring and summer, while silicate concentrations displayed a similar (although statistically non-significant) trend (Volkman *et al.* 2009). Silicate was the only nutrient to demonstrate a significant spatial pattern in surface concentrations, occurring at higher levels in the Huon Estuary than the D'Entrecasteaux Channel. Consistent with earlier studies, it was concluded that nitrate and phosphate concentrations peaked during winter due to an intrusion of nutrient-enriched offshore waters, and that nitrogen was the nutrient most likely to limit phytoplankton growth, especially during summer (Volkman *et al.* 2009).

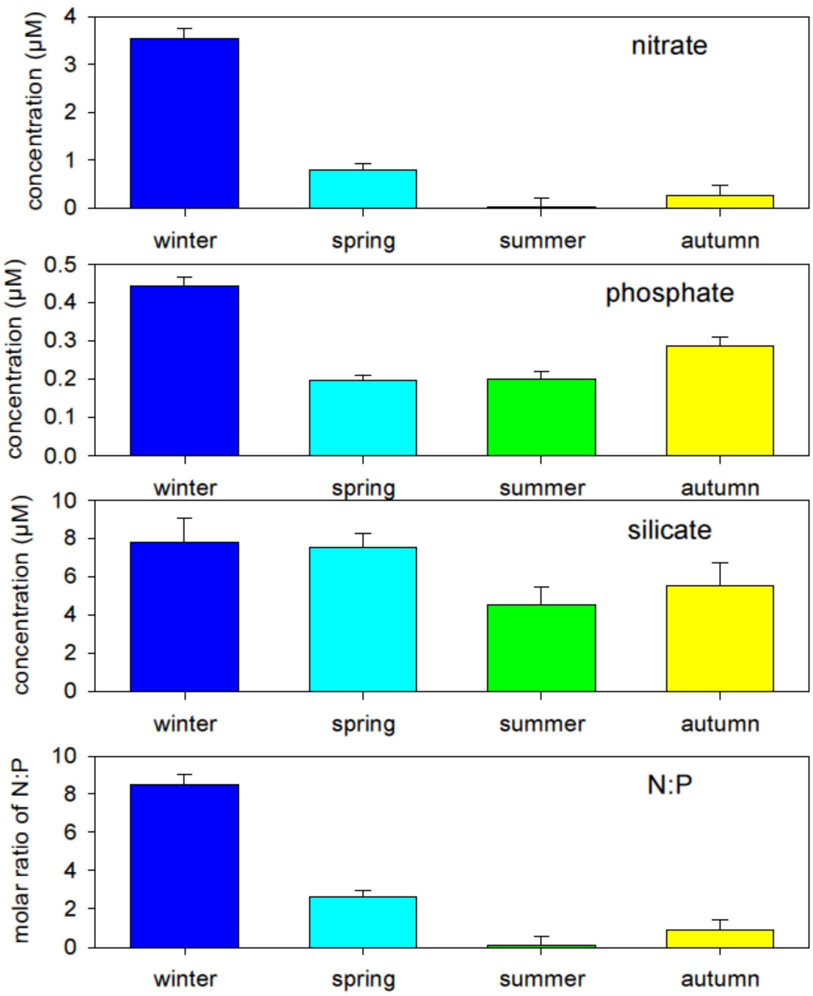


Figure 60 Seasonal mean surface nutrient concentrations in the D'Entrecasteaux Channel and Huon Estuary during 2004–2005 (Source: Volkman *et al.* 2009).

11.2.4 Phytoplankton, chlorophyll-*a* and other pigments

Phytoplankton (see Section 6.2.4) of the D'Entrecasteaux Channel and lower Huon Estuary are a key aspect of the region's environmental status, influencing both marine ecosystem health and also its value for both recreation and commercial aquaculture activities (Volkman *et al.* 2009). Phytoplankton respond to both natural and anthropogenic sources of nutrients, and may form dense blooms (i.e. a proliferation of cells in the water column) that contribute to degraded environmental conditions associated with eutrophication. The type, abundance and distribution of phytoplankton that develops in response to increased nutrient loadings are important in determining the severity of negative environmental impacts.

An important feature of the phytoplankton community in the Huon Estuary since the mid-1980s is the formation of harmful algal blooms (HABs) of the introduced toxic dinoflagellate *Gymnodinium catenatum*. Large blooms of *G. catenatum* have also been reported less frequently in the broader D'Entrecasteaux Channel, and shellfish farms in both areas have experienced forced closures due to risks of human poisonings associated with biotoxins from this species (see Section 14.3.1). An additional HAB-forming species, the non-toxic dinoflagellate *Noctiluca scintillans*, has extended its range from mainland eastern Australia waters to also become resident in Tasmania, including the D'Entrecasteaux Channel and lower Huon Estuary. While not producing a toxin, blooms of *N. scintillans* may result in oxygen depletion and elevated ammonia levels, with consequent death of fish and aquatic animals. Dense blooms have caused problems for salmon farming in south-east Tasmania (Thompson *et al.* 2008). Additional toxic and non-toxic phytoplankton species have been recorded in the region and also have the potential to cause negative impacts.

Sampling of phytoplankton is, therefore, used to monitor environmental quality in several ways. Firstly, measures of phytoplankton density or biomass are surveyed as an overall indicator of water quality and ecosystem health, with elevated counts associated with degraded, nutrient enriched conditions. Secondly, measures of phytoplankton composition are used to assess levels of HAB species that pose risks to humans and other organisms as well as general ecosystem health. Vertical migration is performed by some phytoplankton, including *G. catenatum*, and hence an understanding of temporal and spatial patterns of migration is important in the design of effective sampling programs. Phytoplankton are monitored using a range of direct and indirect measures, including cell counts and identification, and also analyses of pigments found in phytoplankton tissues. The most commonly surveyed pigment is chlorophyll-*a*, a nationally accepted indicator of phytoplankton biomass that is incorporated in the ANZECC (2000) guidelines. High Performance Liquid Chromatography (HPLC) is a technique increasingly used to separate and quantify an array of chlorophylls and other accessory 'marker pigments' called carotenoids, which act as indicators of phytoplankton plant biomass and biological markers for different types of phytoplankton.

Results of monitoring for chlorophyll-*a* and for a range of additional measures used to monitor phytoplankton biomass and community composition are presented below.

Chlorophyll-a

The HES found that mean surface and mid-depth chlorophyll-*a* concentrations were significantly reduced in the upper Huon Estuary (mean range 0.06 to 0.69 mg/m^3) compared with the middle or lower estuary (mean range 0.13 to 1.76 mg/m^3). Significant depth variation was also detected, with higher concentrations at mid-depths (mean range 0.30 to 3.91 mg/m^3) than at the surface during most surveys in the lower and middle estuary. Depth-integrated samples (i.e. collected over a broad depth range) are, therefore, considered the most appropriate sampling technique for chlorophyll-*a* in the Huon Estuary. Weekly monitoring at five sites during 1997/1998 recorded very high levels of temporal variation (Figure 61), with peaks in values associated with large dinoflagellate blooms. While mean values were consistently below the ANZECC (2000) guideline value of 4 µg/L (equivalent to mg/m^3) for estuarine waters, values during bloom events reached up to 17.23 mg/m^3 and far exceeded the guideline.

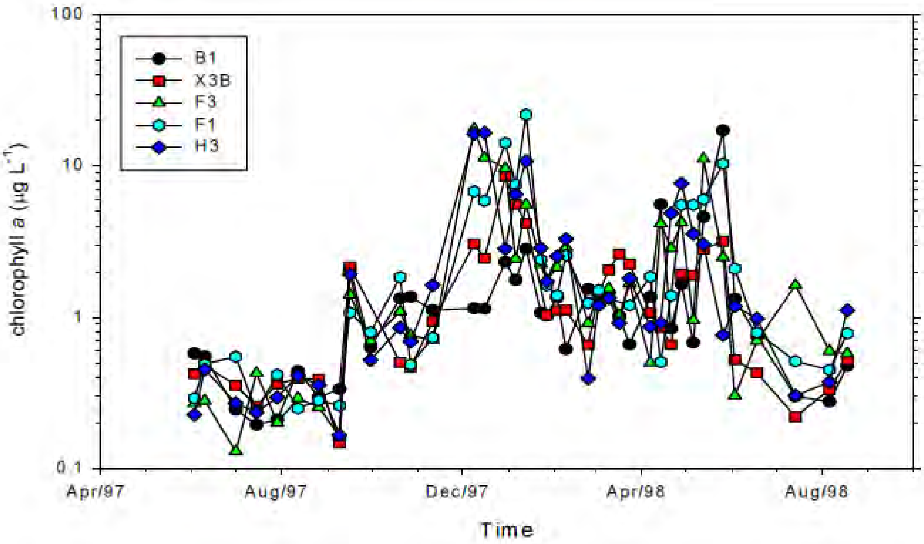


Figure 61 Chlorophyll-*a* concentrations at five Huon Estuary sites (Source: Thompson *et al.* 2008).

Subsequent analyses of chlorophyll-*a* were performed as part of the WoEASF, including monthly depth-integrated sampling of Huon Estuary and D'Entrecasteaux Channel sites during 2002-2005, supplemented by data available for North West Bay in 2001. When plotted against time, the resulting chlorophyll-*a* values reflected the seasonal occurrence of spring and autumn phytoplankton blooms (Figure 62). Analysis by site showed that D'Entrecasteaux Channel sites tended have a lower concentration of chlorophyll-*a* than sites in the Huon Estuary, while the average concentration increased sharply with distance upstream in the latter (Volkman *et al.* 2009). Compared to the ANZECC (2000) guidelines, D'Entrecasteaux Channel values were without exception below the guideline for estuarine waters, with mean site values for the open Channel also below the marine guideline value of 1 µg/L. However, mean values for North West Bay sites and highest readings at all other sites exceeded the marine guideline. The mean values for the Huon Estuary were below the guideline for estuarine water, although small numbers of values exceeded the guideline at sites immediately upstream of the estuary mouth.

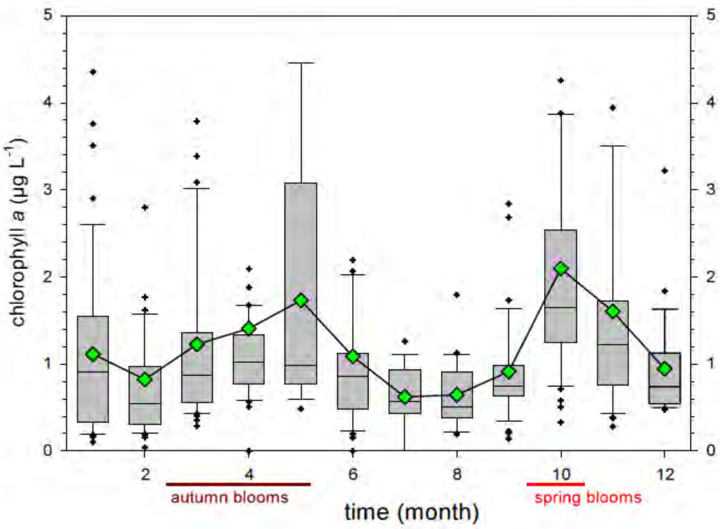


Figure 62 Average chlorophyll-*a* concentrations in the D'Entrecasteaux Channel and Huon Estuary during 2001-2005 (Source: Volkman *et al.* 2009).

Subsequent comparisons of the HES and WoEASF Huon Estuary data were conducted to assess any longer-term patterns in the Huon Estuary. The chlorophyll-*a* concentrations indicated a marked rise in phytoplankton biomass from 1996 to 2005 (Volkman *et al.* 2009), by ~ 200%, as demonstrated for 1996-2003 data in Figure 63. The mean chlorophyll-*a* value during 1996-1998 was 0.74 µg/L, 60% less than a mean value of 1.83 µg/L calculated from 2001-2004 data (Thompson *et al.* 2008).

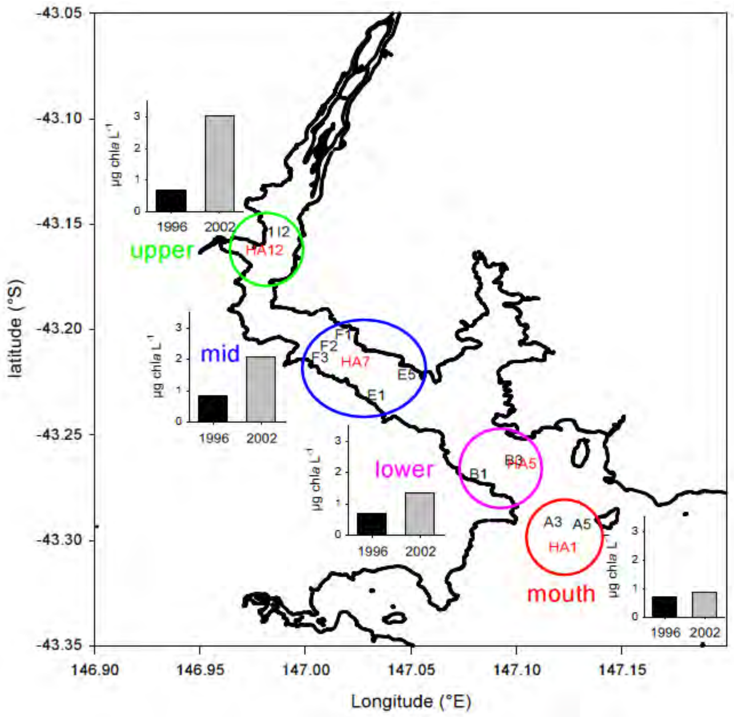


Figure 63 Temporal comparison of mean chlorophyll-*a* values (1996=1996-1998; 2002=2002-2003) for subregions of the Huon Estuary (Source: Thompson *et al.* 2008).

Phytoplankton composition and biomass

Sampling conducted by the HES revealed phytoplankton blooms dominated by diatoms and dinoflagellates in four species/groups in the Huon Estuary: the diatoms *Chaetoceros* spp. and *Pseudonitzschia* spp. and the dinoflagellates *Ceratium* spp. and *Gymnodinium catenatum*. While numbers of dinoflagellates and diatoms were comparable, phytoplankton biomass estimated using cell numbers and cell sizes was much greater during dinoflagellate blooms than during diatom blooms (Butler *et al.* 2000). Blooms of the two dominant dinoflagellate species/groups tended to alternate, with blooms of *Ceratium* spp. in spring and mid-summer, and blooms of *G. catenatum* in early summer and autumn. There was considerable variation in bloom size and frequency between years, with dinoflagellate blooms strongly related to chlorophyll-*a* levels, and diatom blooms primarily ephemeral (i.e. short-lived, transitory).

The relative contribution of seven marker pigments (carotenoids) indicated that 84% of surface samples in the upper estuary had no fucoxanthin (indicative of a lack of diatoms), compared with 2.5-19.4% in the middle and lower estuary. The strong differences in pigment composition between low salinity and marine dominated waters reflect key differences between riverine and marine communities. The HES phytoplankton data were correlated with nutrient data, suggesting a classical temperate plankton cycle: high surface nutrients in winter (when phytoplankton are light-limited), a spring and late summer diatom bloom, and mid-summer to autumn dinoflagellate blooms (Volkman *et al.* 2009).

Subsequent phytoplankton data collected during 2001-2005 in the Huon Estuary and D'Entrecasteaux Channel showed no few clear temporal trends, although most species exhibited some decline during winter. Marker pigments revealed significant seasonal variation in the abundances of diatoms and dinoflagellates, with the spring bloom including a mixture of diatoms and dinoflagellates and the autumn bloom consisting predominately of dinoflagellates. Microscopic examinations revealed differences in the dinoflagellates between these seasons, with the spring dinoflagellates being largely *Ceratium* spp., while the autumn dinoflagellates were mostly the toxic species *G. catenatum* (Volkman *et al.* 2009), as stated earlier.

Based on biomass estimates, the dinoflagellate *Ceratium* spp. was the dominant genus, as illustrated in Figure 64, followed by *Skeletonema* spp., *G. catenatum*, *Chaetoceros* spp., and *Pseudonitzschia* spp. These taxa showed contrasting distributions, with dinoflagellates much more abundant in the Huon Estuary (sites 13, 14, 15) than in the D'Entrecasteaux Channel, and diatoms more abundant at the northern end of the D'Entrecasteaux Channel (sites 1-4) than elsewhere. Note that the sites included in Figure 64 refer to those marked as 2002-2003 Channel sites and 2004-2005 Huon Estuary sites in Figure 49, with subsets of these sites also assessed during other years as indicated in that figure. The spatial differences in diatom versus dinoflagellate abundance was hypothesized to be related to the increased stratification and circulation of a salt wedge estuary (Huon Estuary), both potentially favouring dinoflagellates over diatoms (Volkman *et al.* 2009). However, the dinoflagellate *Noctiluca scintillans* was an exception, being most abundant in North West Bay (site 2; Figure 64).

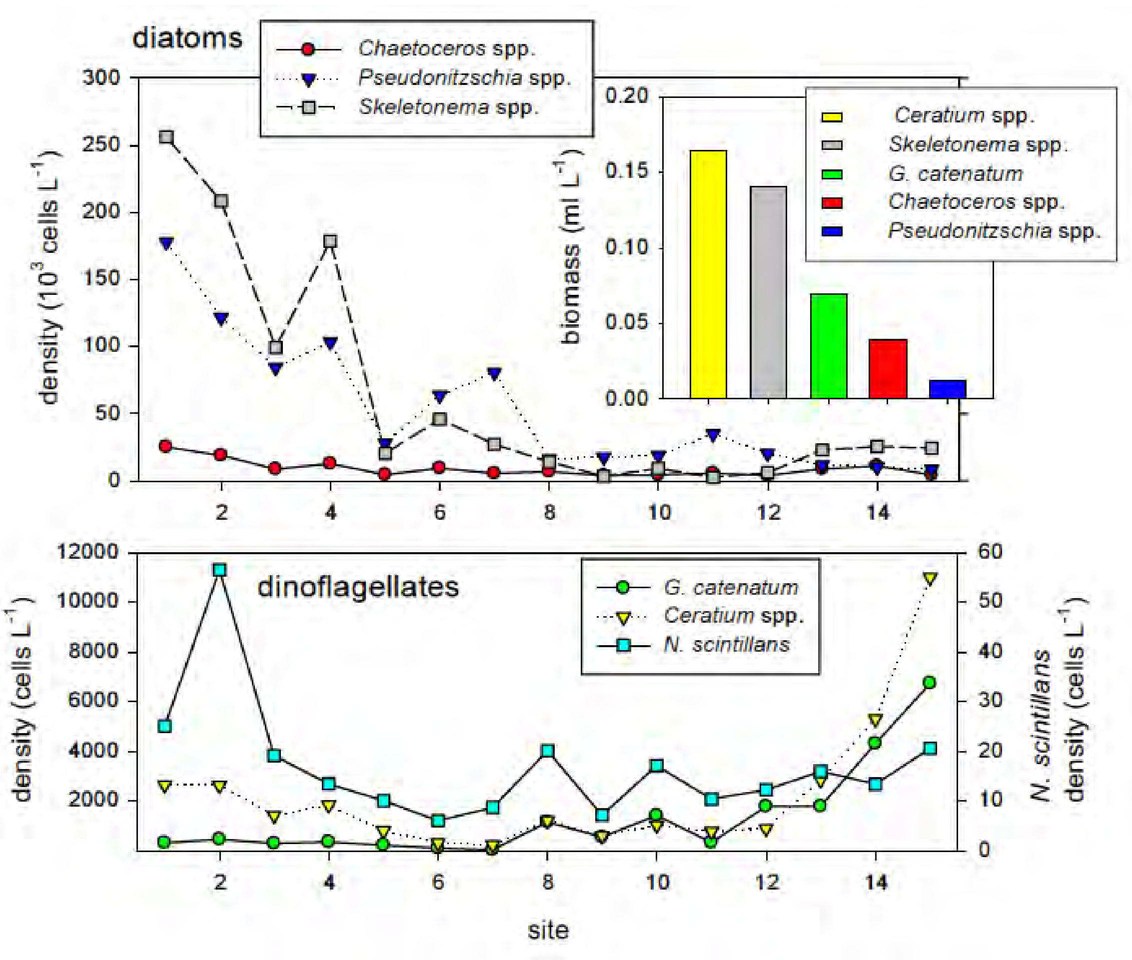


Figure 64 Average densities of phytoplankton in the D'Entrecasteaux Channel (sites 1-12; from north to south) and Huon Estuary (sites 13-15; from mouth to middle estuary) during 2001-2005 (Source: Volkman *et al.* 2009).

Comparisons of the HES results with more recent data for the Huon Estuary and D'Entrecasteaux Channel suggested that phytoplankton composition was broadly similar between the two waterways. The major difference was the presence of summer or autumn dinoflagellate blooms, including more *Ceratium* spp. but especially more *G. catenatum* in the Huon Estuary (Thompson *et al*. 2005). Pigment concentrations indicated marked changes from 1996 to 2005 in phytoplankton community composition with peridinin (dinoflagellates) and fucoxanthin (diatoms) increasing. The greatest increase occurred in dinoflagellates, a finding which may be due to changes in stratification, runoff or nutrients (Thompson *et al.* 2008). In addition, the strengthening East Australia Current is the presumed mechanism for the recent arrival of *N. scintillans* and may be bringing additional new taxa to Tasmania including *Ceratium* species from more northern waters (Volkman *et al.* 2009).

Dinoflagellates: Gymnodinium catenatum and Noctiluca scintillans

Two species of phytoplankton occurring in the D'Entrecasteaux Channel and lower Huon Estuary, the dinoflagellates *Gymnodinium catenatum* and *Noctiluca scintillans*, have serious implications for natural ecosystems and the aquaculture industry and hence have received particular attention in studies of the region. Density data for these two species are presented above, while a long-term dataset on *G. catenatum* cell density is also presented in Section 14.3.1 with relation to seafood safety. Further information is provided below to describe the status of these species and the factors believed to contribute to risks of bloom events.

The toxic dinoflagellate *G. catenatum* exhibits a high level of inter-annual variation, for example being absent one year and then forming extensive blooms during the same seasonal period of the following year (Butler *et al.* 2000). Considerable recent research has focussed on the factors that trigger bloom events in the Huon Estuary, building on earlier findings reported by Hallegraeff *et al.* (1995). The HES summarised the environmental conditions promoting blooms as: temperatures of 12°C and over; weak to strong water column stratification caused by a humic rich, low-salinity surface layer; and, in some cases, low wind stress (Butler *et al.* 2000). However, this set of conducive conditions does not fully explain some of the temporal variation observed in bloom events. Other factors considered to be critical to the success of *G. catenatum* may be linked with its capacity for strong vertical migration, which could facilitate access to both surface and deep nutrients and prevent flushing from the estuary. Dynamics of resting cysts (i.e. a dormant stage in the sediments) could also be a contributing factor, and further study was recommended on the distribution of resting cysts and seasonality of their germination.

Subsequent laboratory investigations found that *G. catenatum* grows equally well on a range of nutrient chemical forms and can use urea as its sole nitrogen source. In addition, it is capable of 'surge uptake' of nitrogen following a period of starvation. These results contrast with knowledge of many other phytoplankton species, and suggest that the physiological flexibility of *G. catenatum* may assist it to outcompete other species for available nitrogen. Other notable findings were that particular surface bacteria, *Alcanivorax* and *Marinobacter* spp., were necessary for growth and bloom development (Volkman *et al.* 2009).

An additional species in the Huon Estuary and D'Entrecasteaux Channel is *N. scintillans*, a non-toxic dinoflagellate species first recorded in New South Wales in the 1970s, and subsequently recorded as a range extension to Tasmania in 1994. Since that time, there has been an apparent increase in frequency and distribution of blooms which, whilst not toxic, have the potential to harm or kill fish and other marine life through depletion of oxygen (Volkman *et al.* 2009). The occurrence of *N. scintillans* in the Huon Estuary and D'Entrecasteaux Channel region, therefore, has potentially serious implications for the Atlantic salmon aquaculture industry as well as natural biological communities.

The ecological impact of *N. scintillans* on the Tasmanian marine ecosystem has remained poorly understood and hence studies were conducted to investigate aspects of its ecology. This species is heterotrophic (refer to Section 6.1.6), and spring bloom formations can be explained by the abundance of its phytoplankton prey at this time. Laboratory trials at temperatures as low as 7°C supported field evidence that *N. scintillans* populations can survive low Tasmanian winter temperatures (Volkman *et al.* 2009). Interestingly, culture experiments found that amongst other prey, *G. catenatum* is a suitable food source for *N. scintillans*, and hence this capacity may have positive effects by minimising toxic blooms.

The dinoflagellate *N. scintillans* now appears to be a permanent member of the phytoplankton community in south-east Tasmania, and has been recorded widely in the Huon Estuary and D'Entrecasteaux Channel (Figure 65). There is good evidence that the recently arrived *N. scintillans* now has a significant influence on the phytoplankton dynamics in the region, both as a bloom-forming species in its own right and also due to its capacity to effectively feed on *G. catenatum* (Volkman *et al.* 2009).

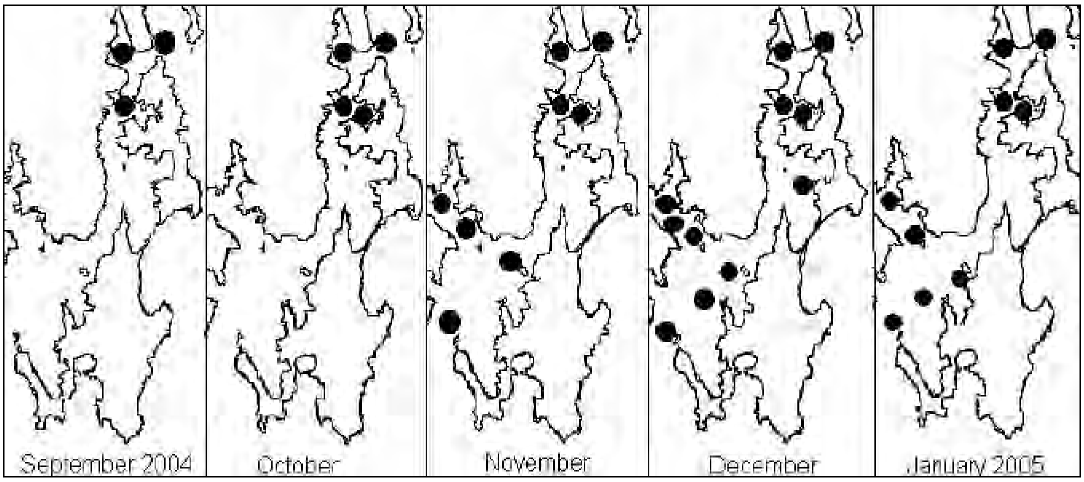


Figure 65 Distribution of *Noctiluca scintillans* (Source: Volkman *et al.* 2009).

11.2.5 Heavy metals and pesticides

There have been few system-wide investigations of heavy metals in the D'Entrecasteaux Channel and Huon Estuary given that metal contamination has been a relatively low risk in the region compared with the adjacent Derwent Estuary. One source is the use of copper-based (and, to a lesser extent, zinc-based) antifouling treatments on finfish farming nets, as described in Section 12.2.4, while sewage outfalls and chemicals used in horticulture are other examples of potential metal sources.

The HES surveyed trace metals and the metalloid arsenic at 14 sites along the gradient of the Huon Estuary during August/September 1998 and at riverine sites on the Huon River and Kermandie River (Table 33). They found that all metal concentrations within the estuary were below ANZECC (2000) guidelines, with the exception of cobalt which only exceeded the guideline for protection of 99% of aquatic biota (0.005 µg/L) and hence indicated a low risk of impacts. Concentrations of copper and cadmium were comparable to those in pristine systems such as Bathurst Harbour and Port Davey on the south-west coast; however, the Huon Estuary had a higher concentration of particulate iron, and possibly colloidal iron and manganese, with which nickel and cobalt are associated (Butler *et al.* 2000).

Values for the Huon River (freshwater) site were also low and below the ANZECC (2000) guidelines for freshwater; however, the Kermandie River site located downstream from the Geeveston WWTP recorded a higher metal load associated with a substantial load of suspended solids (Butler *et al.* 2000). When samples from the Kermandie River were filtered to remove particulate material, metal concentrations were generally much reduced but remained elevated for copper. This could have been due to naturally higher concentrations, use of copper in the horticulture industry, and/or discharges of sewage effluent (Butler *et al.* 2000). It was considered likely that the higher concentrations of trace metals associated with the Kermandie River plume decline sharply as it enters the estuary, with much of the trace metals load associated with suspended particulate matter deposited onto the sediments of Hospital Bay.

Table 33 Metal concentrations in Huon Estuary waters (Source: Butler *et al.* 2000).

Metal/Metalloid (µg/kg)	Huon Estuary (12 sites)	
	UF	F
Cadmium	0.0018–0.0057	0.0010–0.0049
Cobalt	<0.013–0.142	<0.013–0.116
Copper	0.109–0.241	0.085–0.188
Iron (µg/L)	9.0–262	0.9–196
Lead	0.019–0.082	–
Manganese (µg/L)	0.3–16.1	0.3–15.2
Mercury (µg/L)	<0.002	–
Nickel	0.22–0.33	–
Uranium	0.79–3.47	–
Vanadium	1.06–1.80	–
Zinc (µg/L)	0.30–2.20	0.21–2.13
Arsenic (µg/L)	–	0.087–1.71

UF = unfiltered; F = filtered. Units are in µg/kg except where indicated otherwise.

Most other surveys of metals in the D'Entrecasteaux Channel and Huon Estuary have been limited to one-off studies associated with proposed developments, such as marinas and fish processing plants. A survey of water quality downstream of a dredging operation at the Port Huon Marina (Aquenal 2006a) recorded heavy metal concentrations that were generally below guideline values, although the 90% and 80% guideline values for copper and 99%-90% guideline values for zinc were exceeded in some samples. However, given that this sampling was conducted during a sediment disturbance event, values cannot be considered indicative of ambient conditions. In a separate survey performed for a fish processing plant outfall in Port Esperance, metal concentrations were nearly all below detection level (Tassal 2010), although some analytical detection levels were not sufficiently sensitive to test against the 99% or 95% ANZECC (2000) guideline values.

The HES also investigated pesticides at the six of the sites surveyed for heavy metals, with a wide range of organochlorine, organophosphorus and other pesticides tested. None of the pesticides could be detected at any of the six estuarine sites, although the analytical limit of detection for organochlorine and organophosphorus pesticides was 0.1 µg/L and for the other pesticides it was 0.05 µg/L (Butler *et al.* 2000). These analytical limits lacked the sensitivity needed to detect values exceeding the ANZECC guidelines, including the 80% guideline (i.e. the lowest level of protection) in some cases.

11.3 *Recreational water quality*

11.3.1 Indicator organisms and recreational water quality guidelines

Water contaminated by sewage and animal faeces may contain pathogenic micro-organisms (bacteria, viruses, protozoa) which pose a health hazard when the water is used for recreational activities, particularly those involving total immersion. During these activities, there is a risk that water could be swallowed, inhaled or come into contact with ears, nasal passages, mucous membranes and cuts in the skin, allowing pathogens to enter the body (NZMFE 2002). The most common types of illness that have been associated with primary contact are gastrointestinal disorders, respiratory illnesses, eye, nose and throat infections and skin disorders (Whitehead *et al.* 2010).

Direct detection of pathogens is not a feasible option for routine assessments, since they occur intermittently and are difficult to measure in water. For this reason, 'indicator' micro-organisms are generally used to assess the health risks associated with pathogens in recreational waters. Previously, Australia's recreational water quality guidelines used thermotolerant coliforms as the primary indicator of health risks in recreational waters, and enterococci as a secondary indicator. However, not all thermotolerant coliforms are of faecal origin and enterococci are now considered to be a more representative indicator, particularly in marine waters (Whitehead *et al.* 2010).

Australia's most recent national guidelines for recreational water quality (NH&MRC 2005) recommend enterococci as the appropriate indicator in coastal waters, and adopt a risk-based classification of recreational waters that relies on a combination of sanitary surveys and water quality monitoring. Under these guidelines, microbiological water quality risks are determined on the basis of the 95th Hazen percentile enterococci values, a method also adopted as the benchmark by the Tasmanian recreational water quality guidelines produced by the Department of Health and Human Services (DHHS 2007). This method helps to transform bacterial count data into a format that can be compared more directly with trigger levels (Whitehead *et al.* 2010). The state guidelines incorporate trigger levels for resampling and/or poor water quality advisories when enterococci levels are high. These trigger levels are not included in the national guidelines, but have been adopted from New Zealand's recreational water quality guidelines (MFE 2002). These include a trigger level of 140 enterococci per 100 ml for resampling and two consecutive measurements of 280 enterococci per 100 ml as a trigger for advising the public of poor water quality. The state guidelines (DHHS 2007) have also adopted a three-tiered approach to long-term (5-year or 100 samples) water quality classification, based on categorisation of samples as poor, moderate or good water quality.

11.3.2 Recreational water quality monitoring programs

Recreational water quality monitoring of enterococci was conducted at a total of 14 swimming sites (beaches and jetties) by Kingborough Council during the 2000-2012. In the Huon Valley municipality, recreational water quality was initially performed at Huon River sites upstream of the study area until the 2007-2008 summer season, and then was modified to focus on three swimming beach sites in the lower Huon Estuary and Port Esperance for subsequent seasons. The 17 sites collectively monitored by the two councils in the study area are indicated in Figure 66, although it should be noted that not all sites were monitored in all years, as described below in Section 11.3.3.

Sampling frequency was variable between sites and years, occurring primarily during the December to March 'swimming season', although some earlier surveys extended over a longer period. In the most recent surveys, sites in the Huon Valley municipality have been monitored on a fortnightly basis, while those in the Kingborough municipality have been monitored approximately monthly. Sites on Bruny Island have generally only been monitored once or twice during the swimming season.

Figure 66 Recreational water quality monitoring sites (Data source: Kingborough and Huon Valley councils).

11.3.3 Recreational water quality

Table 34 summarises available recreational water quality data for the study area during 2000-2012, including data for the 1999/2000 to 2011/2012 swimming seasons for Kingborough sites and 2008/2009 to 2010/2011 seasons for Huon Valley beach sites. Of the 17 sites monitored, eight in the Kingborough municipality have been consistently monitored for 10 or more swimming seasons, while an additional four sites (two each in the Kingborough and Huon Valley municipalities) have been included in the most recent survey reports available.

Note that the 95th Hazen percentile technique and application of the DHHS (2007) approach to long-term water quality classification as poor, moderate or good, could not be applied here due to the low frequency of sampling and <100 enterococci samples analysed per site. The analysis of results, therefore, involved a simpler assessment of how many times trigger values for recreational water quality were exceeded.

The enterococci trigger levels of 140 per 100 ml and 280 per 100 ml, and associated requirements for re-sampling or poor water quality signage, did not come into effect until 2007. Hence all individual readings of ≥280 per 100 ml are noted in Table 34, rather than occurrences of two consecutive readings, since an initially high reading was not always followed by re-sampling. Similarly, the requirement of re-sampling following a value of ≥140 per 100 ml was not strictly adhered to at all times, including after the introduction of the DHHS (2007) guidelines. For example if the elevated value coincided with heavy rainfall, re-sampling was considered to be discretionary on the basis of potentially short term spikes in bacterial counts associated with stormwater, creek or lagoon runoff (HVC 2009).

Table 34 Summary of recreational water quality monitoring data (Data source: Kingborough and Huon Valley councils).

Site	No. of seasons monitored	Most recent survey	Total No. samples	No. of Samples ≥140	No. of Samples ≥280
Stinkpot Bay - Howden	4	March 2004	31	4	4
Wingara Road - Howden	13	December 2011-March 2012	42		1
Dru Pt - Margate	11	December 2011-March 2012	36	2	3
Snug	12	December 2011-March 2012	39	2	2
Coningham	10	December 2011-March 2012	29		
Tinderbox	11	December 2011-March 2012	25		
Nebraska Beach – Bruny Island	11	December 2011-March 2012	12		
Alonnah Beach – Bruny Island	11	December 2011-March 2012	12		
Simmonds Beach – Bruny Island	7	December 2011-March 2012	8		
Lunawanna Beach – Bruny Island	2	January 2011	2		
Trial Bay	1	January 2001	1		
Kettering	1	November 2001-March 2002	1		1
Woodbridge	11	December 2011-March 2012	30		1
Middleton Beach	7	December 2011-March 2012	23		
Eggs and Bacon Bay *	1	January-March 2009	9	1	
Dover Beach *	3	December 2010-March 2011	28	4	2
Randalls Bay *	2	December 2010-March 2011	21	1	1
TOTALS			349	14	15

* Denotes sites in the Huon Valley municipality; remaining sites are located in the Kingborough municipality.

Out of 349 samples analysed in total, 4% recorded enterococci values of ≥140 per 100 ml, while an additional 4% recorded values of ≥280 per 100 ml. The exceeded values at Howden all occurred prior to 2003, and prior to the establishment of a reticulated sewerage system for that area. At Snug, the elevated readings occurred during the period 2001-2007, while at Margate they were more evenly spread through time and recorded as recently as the 2011/2012 swimming season. Elevated values at Kettering and Woodbridge have not been recorded since the 2001/2002 and 2003/2004 seasons, respectively, whilst the three Huon sites have all recorded more recent exceedances of trigger values. The latter were attributed primarily to high rainfall events, and in one case at Dover (2008/2009 season) resulted in the erection of signs advising the public of health risks due to a large volume of turbid water flowing from a lagoon which had burst its banks (HVC 2009).

There were only two occurrences of two consecutive values ≥280 per 100 ml, although as noted above, re-sampling was not performed within the 48 period designated in the DHHS (2007) guidelines. Two elevated values were recorded one week apart at Howden in the 2001/2002 season, whilst in the same season consecutive elevated values were recorded three weeks apart at Margate. Extremely high enterococci counts of up to 13,000 per 100 ml were recorded at both Snug and Margate at this time following a high rainfall event. No consecutive readings of ≥280 per 100 ml have been recorded at any of the sites in more recent swimming seasons.

The results highlight the vulnerability of some beaches and other recreational sites in the study area to short term spikes in bacterial loads, with primary areas of concern currently including Margate, Snug and sites at the entrance to the Huon Estuary. Increased frequency of sampling would facilitate a more comprehensive assessment of areas most susceptible to recreational water quality risks.

11.3.4 Public information and beach signage

Recreational water quality signage is erected on an as-needs basis in the D'Entrecasteaux Channel and lower Huon Estuary, with an example of signgage provided in Figure 67. The Derwent Estuary Program has developed a signage strategy for the Derwent in conjunction with the DHHS involving permanent signs which contain educational information and indicate the long-term (5 year) recreational water quality classification for the respective site. In the event of poor water quality, part of the sign can be flipped down to display an advisory warning and then folded back up when the water quality improves to acceptable levels (i.e. less than 140 enterococci/100 mL). Such a strategy is not currently directly applicable to the D'Entrecasteaux Channel and lower Huon Estuary since recreational water sampling has not been frequent enough to determine long-term classifications on the basis of DHHS (2007) guidelines.

Figure 67 Beach signage at Dover (Source: HVC 2011).

11.4 Summary of water quality

It is difficult to establish temporal trends in many ambient water quality analytes in the Huon Estuary and D'Entrecasteaux Channel due to the absence of a consistent long-term monitoring program. Individual monitoring programs have typically lasted no more than two years, during which it is difficult to distinguish natural inter-annual variation from longer-term trends. Whilst there has been some overlap in sites between monitoring programs, the highly variable nature of the data combined with other differences between programs complicates direct comparisons. The broader D'Entrecasteaux Channel has been less intensively surveyed than the Huon Estuary and North West Bay, and hence our knowledge of its status may not be representative of all the smaller embayments it contains. Another important issue is the unavailability of system-wide data post-2005, meaning that results presented here may not provide an up to date representation of water quality in the region. The evaluation and assessment of the BEMP described in Section 10.4 will analyse more recent data collected since 2009 and hence should be referred to in conjunction with this report. The current summary focuses on key findings across the major ambient water quality data sets that are available for 1996-2005 and also synthesises comments on longer-term temporal trends where they were assessed.

There are some similar limitations with the recreational water quality, since beach monitoring in the lower Huon Estuary was only initiated as recently as 2007-2008, and sample sites in the D'Entrecasteaux Channel have varied over time. There are eight Channel sites that have now been monitored for at least 10 swimming seasons, although there has been variation in survey frequency between years and sampling stations. The DHHS (2007) technique for developing long-term water quality classifications of 'poor', 'moderate' or 'good' could not be applied due to the low frequency of sampling. This necessitated a simpler assessment of data based on the number of times trigger values for recreational water quality were exceeded.

Data reviewed for this report indicate that the ambient water quality of the Huon Estuary and D'Entrecasteaux Channel is relatively healthy and devoid of signs of significant eutrophication. The D'Entrecasteaux Channel is naturally oligotrophic with very few algal blooms, while the Huon Estuary is mesotrophic with increased primary production and an increased occurrence and density of algal blooms. Nutrient concentrations frequently exceed national guidelines, although primary nutrient sources are considered to be of natural origins. There are however some areas for concern, as described further below. In addition, there is no evidence of chronic long-term contamination at any of the recreational water quality survey sites, with re-occurring problems at Howden during 1999-2002 rectified by installation of a reticulated sewage treatment and re-use system. Occasional elevated values at other sites depict no clear temporal trends and are likely to be associated with levels of rainfall in the period immediately prior to sampling.

Whilst the system-wide ambient water quality studies did not involve detailed investigations of the various tributaries feeding into the study area, an assessment of the Kermandie River indicated that it had inferior water quality compared to the Huon River. This was reflected by high particulate loads, and elevated concentrations of metals and some forms of nutrients, most likely associated with a WWTP outfall in its lower reaches and land-use practices in the catchment around Geeveston. These findings are consistent with earlier data suggesting that other tributaries to the Huon Estuary, such as the Agnes and Nicholls Rivulets flowing into Port Cygnet, also suffer from environmental degradation (Bobbi 1998). Fortunately, the streams with poor water quality have insignificant flows compared with the Huon River, although they may have localised negative effects in neighbouring embayments and inlets (Butler *et al.* 2000).

Temperature, salinity, pH, DO and water clarity

The lower Huon Estuary is unique in being highly stratified, with surface water salinities even in the lower estuary dropping to ~14 ppt during periods of high riverine flows, and contrasting with the typically marine salinities (34-35 ppt) in bottom waters. Water temperature varies widely depending on season, depth and distance along the estuary, with values recorded in the overall range of 7 to 22ºC. The D'Entrecasteaux Channel is less influenced by freshwater, with surface salinities rarely dropping below 30 ppt, and mean temperatures of ~10 to 19ºC. Across the entire study area, lowest temperatures occur in surface waters during winter and are associated with increased freshwater inputs and hence reductions in salinity.

Assessments of pH have been rare, but all values reported are within guidelines for acceptable water quality conditions, with the exception of occasional elevated values at sites strongly influenced by freshwater flows. Measures of particulate matter and water clarity have mostly identified conditions meeting acceptable standards, with the lower Huon Estuary recording highest turbidity levels during winter and reduced levels in the lower estuary relative to its upper reaches. Mean Secchi disk depths suggest that sites at the southern end of the D'Entrecasteaux Channel have more transparent water than those at the northern end of the Channel. High turbidities may occur in shallow embayments proximate to river entrances; for example North West Bay experiences turbidity values far in excess of the upper national guideline value during high flows of the North West Bay River.

Huon Estuary waters are generally well oxygenated (80–100%); however, there are localised and transitory exceptions. Undersaturated conditions (60-80%) and sporadic DO depletions have been recorded in several areas of the lower estuary, with occasional occurrences of values as low as 3.6% recorded during 1997-1998. Subsequent surveying during 2002-2003 recorded values no lower than 74%, but it has been suggested that areas of the lower estuary are prone to low DO and should be routinely monitored, particularly during summer months (Crawford *et al.* 2006). Only a small number of sites have been monitored since 1998, and it is unclear how widespread oxygen depletion is in the lower estuary. Causal factors may also be complex, although the combination of summer temperatures, strongly stratified waters, increased loading of organic matter and high biochemical oxygen demand can trigger events of significant DO depletion (Butler *et al.* 2000). Supersaturation (e.g. up to 160% in Port Cygnet) is also an occasional issue in shallow embayments during algal blooms. The D'Entrecasteaux Channel is typically well oxygenated (~100%), although DO levels in North West Bay are variable and have dipped as low as 58% saturation in bottom waters during summer. In accordance with national guidelines, all of the above DO levels outside the range of 80-110% saturation reflect conditions of poor environmental health.

Nutrients, chlorophyll-a and phytoplankton

Throughout the study area, nitrate, phosphate and ammonium concentrations increase significantly with depth and are sourced primarily from marine offshore waters, while silicate concentrations are highest at the surface and sourced from river inputs. Silicate demonstrates a significant spatial pattern in surface concentrations, occurring at higher levels in the Huon Estuary than the D'Entrecasteaux Channel. Concentrations of N and P reach their highest levels during winter intrusions of nutrient-rich subantarctic waters. Seasonal variation in N:P ratios suggested that levels of nitrogen limited the growth of phytoplankton during summer months. Several chemical forms of N and P exceeded national trigger levels at a system-wide level, and by >50% in some cases. The national guidelines for nutrients are, however, considered too low to be applicable to this region due to large natural sources that cannot be controlled by regional or local reductions in anthropogenic inputs.

While natural sources are the primary contributor to nutrients in the region, indicators of anthropogenic inputs were detected, and the combination of nutrient levels and other conditions highlight risks of eutrophication in some areas. Ammonium concentrations were generally below 1 µM in the Huon Estuary, although they were at times higher in the bottom waters of the lower estuary following large spring and summer microalgal blooms. In conjunction with oxygen depletion, increases in nutrient loads and organic matter can lead to oxygen stress and nutrient release in sediments and bottom waters, with the possibility of increased nutrient loads (Butler *et al.* 2000, Crawford *et al.* 2006). Biogeochemical investigations (see Section 12.2.2) have confirmed this as a possibility, and point to an increased likelihood of algal blooms and eutrophication, highlighting the importance of monitoring organic inputs to the system. Sporadic instances of nutrients exceeding water quality guideline trigger levels were also directly traceable to human activities. However, the full extent of anthropogenic inputs is unlikely to be detected because they are dominated by nutrient forms that are rapidly broken down and assimilated by phytoplankton (Butler *et al.* 2000).

Chlorophyll-*a* concentrations in the Huon Estuary were below the national estuarine guideline of 4 µg/L ~90% of the time; however, they exceeded this value by a factor of greater than four during phytoplankton bloom events. D'Entrecasteaux Channel sites had a lower concentration of chlorophyll-*a*, with mean values consistently below the marine guideline value of 1 µg/L, except in North West Bay. The low chlorophyll-*a* concentration of the Channel, combined with low concentrations of ammonia and relatively high concentrations of DO, depict good environmental health. However these attributes, typical of oligotrophic systems, suggest a high susceptibility to ecological change induced by increased nutrient loading. Some areas, such as North West Bay and Barnes Bay, are at risk from nutrient loading due to high terrestrial inputs of nutrients and reduced flushing times (Thompson *et al.* 2005).

Phytoplankton bloom frequency is higher in the Huon Estuary than in the D'Entrecasteaux Channel. Combined phytoplankton and nutrient data for the Huon suggest a classical temperate plankton cycle: high surface nutrients in winter (when phytoplankton are light-limited), a spring and late summer diatom bloom, and mid-summer to autumn dinoflagellate blooms. The taxa display contrasting distributions, with dinoflagellates such as the toxic *G. catenatum* much more abundant in the Huon Estuary than in D'Entrecasteaux Channel, and diatoms most abundant at the northern end of D'Entrecasteaux Channel. HAB dinoflagellate species occur in the Channel but rarely at high densities. The formation of blooms in this waterway seems likely to occur only through advection and other physical processes that can result in concentration of phytoplankton cells. The dinoflagellate *N. scintillans* is susceptible to concentration by physical processes because of its tendency to accumulate near the surface towards the end of a bloom (Thompson *et al.* 2005).

Blooms of HAB phytoplankton species do not depict any clear longer-term trends and their presence or absence in any one year is at times difficult to explain. The abundance of the dominant toxic dinoflagellate *G. catenatum* has fluctuated enormously, with population lows in 1997 and 2006-2007, and greater abundances during 2002−2005 and 2008-2011 (refer to Sections 11.2.4 and 14.3.1). While nutrient availability is clearly important for bloom formation, triggers for the toxic species *G. catentaum* appear to relate to factors such as temperature, water stratification caused by humic-rich freshwater inputs, and the effects of wind on water column stability. A capacity for strong vertical migration, ability to respond to pulses of N by 'surge uptake', physiological flexibility to utilise a wide range of forms of N, and resting cyst dynamics, are considered likely keys to the success of *G. catenatum* in the Huon Estuary. The non-toxic HAB species *N. scintillans* now appears to be a permanent member of the phytoplankton community in south-east Tasmania and has been recorded widely in the Huon Estuary and D'Entrecasteaux Channel. While blooms of this species have the potential to impact negatively on aquaculture species and natural marine communities through depletion of oxygen, its capacity to feed on *G. catenatum* has the potential for positive effects by minimising blooms of the latter toxic species.

Data indicate a long-term increase in phytoplankton biomass in the region that is consistent with increased nutrient loading. From the limited number of comparable sites surveyed during 1996−2005, a substantial increase by ~200% occurred over this period (Volkman *et al.* 2009). Greatest increases have occurred in dinoflagellates, potentially due to changes in stratification, runoff or nutrients, and ocean influences such as the strengthening East Australian Current.

Metals and pesticides

Relative to the adjacent Derwent Estuary, there has been limited study of metals in the Huon Estuary and D'Entrecasteaux Channel due to reduced contaminant sources. Concentrations appear to be low in the Huon Estuary, and almost comparable to levels recorded in pristine, undisturbed systems. However one tributary surveyed, the Kermandie River, had elevated metal loads that exceeded national guidelines. Pesticides were not detected in the waters of the Huon Estuary, although sampling was limited and some laboratory tests were not sensitive enough to detect levels as low as national guideline concentrations. No system-wide studies of metals or pesticides have been performed for waters of the D'Entrecasteaux Channel, although some surveying has been performed for seafood (14.3.3) and sediments (Section 12.2.4).

Recreational water quality

Recreational water quality was assessed through comparisons to two recommended trigger levels: the first recommending re-sampling (140 enterococci per 100 ml), and the second recommending advising the public of poor water quality following two consecutive measurements (280 enterococci per 100 ml). Out of 349 samples analysed in total across 17 sites since 1999, 4% recorded enterococci values of ≥140 per 100 ml, while an additional 4% recorded values of ≥280 per 100 ml. There were only two occurrences of two consecutive values ≥280 per 100 ml, although re-sampling was not performed in line with current recommendations because the above recommended trigger values were only introduced in 2007. The highest values on record since 1999 were enterococci counts of up to 13,000 per 100 ml at both Snug and Margate following a high rainfall event in the 2001/2002 swimming season.

The primary temporal change observed was the drastic improvement in recreational water quality at Howden following the introduction of a reticulated sewerage and wastewater re-use system in 2002. Following regular exceedances during 1999-2002, no values exceeding the trigger concentrations have been recorded at Howden since that time. Elevated enterococci counts at other sites have demonstrated no clear temporal trends, with exceeded values usually attributed to high rainfall in the period immediately preceding sampling. There is no evidence of chronic long-term contamination at any of the recreational survey sites, however occasional elevated values highlight the vulnerability of some beaches and other recreational sites to short-term spikes in bacterial loads. Primary areas of concern in recent years include Margate, Snug and sites at the entrance to the Huon Estuary. Increased frequency of sampling would facilitate a more comprehensive assessment of areas most susceptible to recreational water quality risks.

12 SEDIMENT QUALITY

Most estuaries and protected marine embayments act as depositional areas, trapping and retaining sediments and organic matter from their catchments, along with associated contaminants such as heavy metals, pesticides and nutrients. These sediments may be transported and redistributed as a result of river flows, tides and currents, eventually settling out in lower energy environments (Whitehead *et al.* 2010). The contaminants associated with sediments may be re-processed through chemical or biological processes or buried, forming part of the sedimentary record. Surface sediments provide an integrated picture of inputs to an environment over timeframes of a few years to decades, depending on sedimentation rates (Butler *et al.* 2000).

The D'Entrecasteaux Channel and lower Huon Estuary have a number of localised land-based and marine sources of sediment contamination, including both historical and contemporary inputs. Land uses within the catchment also influence sediment inputs, grain size and chemistry. Since 1999, studies of sediments in the region have largely focussed on indicators of organic enrichment, since organic matter dominates current discharges to the environment. Heavy metals are of reduced relevance compared to the adjacent Derwent Estuary; however, various sources of heavy metals and additional contaminants such as pesticides exist within the region and have triggered sediment investigations.

The following sections provide an overview of current knowledge concerning sediment quality in the D'Entrecasteaux Channel and lower Huon Estuary.

12.1 Sediment quality guidelines

The National Water Quality Management Strategy (NWQMS) has identified interim sediment quality guidelines (ISQG) for heavy metals and other contaminants, based on a literature review of sediment toxicity testing. The guidelines define ISQG-high and ISQG-low values (Table 35), which represent the lower 10th percentile and 50th percentile of chemical concentrations associated with adverse biological effects. The guideline levels were obtained from studies undertaken on North American biota, with some minor alterations for Australian applications (ANZECC 2000).

A national review of Australian sediment quality guidelines recommended that an alternative approach be used in assessing sediment contamination, based on consideration of multiple parameters including geochemistry, toxicity and biological communities. Work has been initiated to develop this approach for the adjacent Derwent Estuary (Whitehead *et al.* 2010), an area more impacted by heavy metals. The discussion presented here for the D'Entrecasteaux Channel and lower Huon Estuary is based on comparison of field data to the ISQG values in Table 35. Note that the table excludes some additional organic compounds listed in the ANZECC (2000) guidelines which have not been analysed in available recent literature for the D'Entrecasteaux Channel and lower Huon Estuary.

In some instances, no sediment guidelines are specified for parameters of interest, reflecting high levels of natural variation and/or an absence of adequate data for establishing trigger values. These parameters may still be very relevant in monitoring environmental conditions, particularly where sites affected by anthropogenic inputs can be compared to 'control' sites distant from known disturbances. Examples that are particularly pertinent to the D'Entrecasteaux Channel and lower Huon Estuary include indicators of organic enrichment, given that there are significant anthropogenic inputs of organic matter to the region.

Table 35 National sediment quality guidelines (Source: ANZECC 2000).

Contaminant	ISQG low	ISQG high
Metals (mg/kg dry weight)		
Arsenic	20	70
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1	3.7
Zinc	200	410
Metalloids (mg/kg dry weight)		
Arsenic	20	70
Organometallics (µg Sn/kg dry weight)		
Tributyltin	5	70
Organics (µg/kg dry weight)		
Total DDT	1.6	4.6
p.p'-DDE	2.2	27
o.p'-+p.p'-DDD	2	20
Endrin	0.02	8
Dieldrin	0.02	8
Chlordane	0.5	6

12.2 Sediment quality monitoring

Numerous studies of the D'Entrecasteaux Channel and lower Huon Estuary performed since 1999 have involved sediment sampling; however, results summarised here are based primarily on major integrated studies that have surveyed an extensive suite of sites. Results from smaller, or more localised, studies have also been referred to for analytes that have been little studied in the region or to help fill spatial data gaps. A comprehensive list and description of sediment quality data sources compiled for the region since 1999 is provided by Parsons (2012).

The sites surveyed by major studies of sediment quality are displayed in Figure 68, although it should be noted that some analytes were only sampled from a subset of the sites illustrated. As described for water quality in Section 11.2, major studies to date have included a limited number of sites for the main D'Entrecasteaux Channel compared with the Huon Estuary and North West Bay. It should also be noted that none of the major studies referred to in this section include ongoing monitoring of sediments in the region; the surveys referred to were conducted between 1997 and 2006, and hence may not be representative of sediment conditions in 2012. Monitoring of sediment conditions and quality, including measurements of redox potential, total organic carbon, stable isotopes (carbon and nitrogen), particle size distribution and sulphides, is ongoing as part of the Broadscale Environmental Monitoring Program (BEMP) described in Section 10.4.

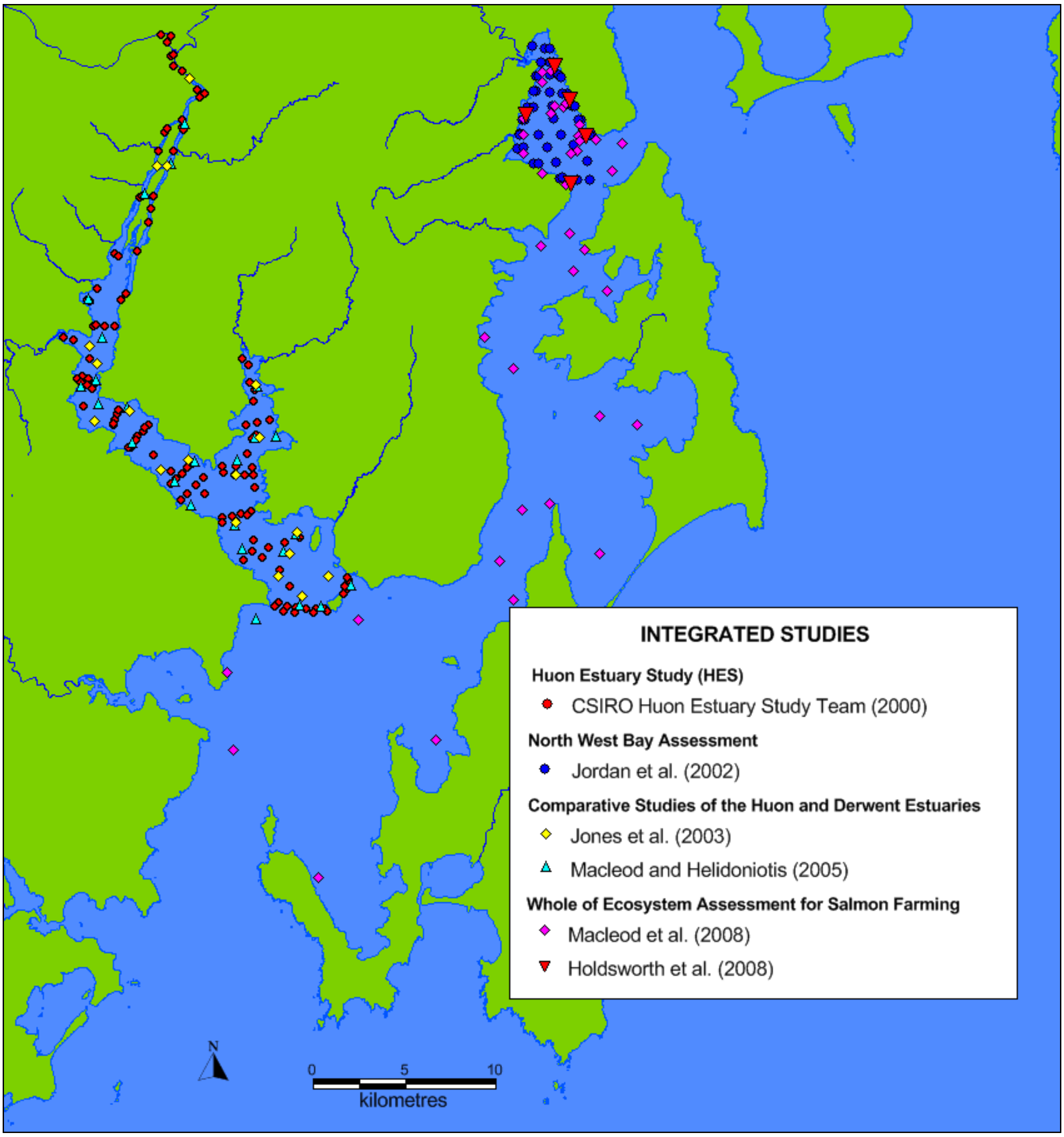


Figure 68 Sediment sampling sites of integrated studies.

12.2.1 Sediment particle size

While sediment particle size (sometimes described as particle 'grain' size) is not a direct indicator of environment health, it is an important contextual parameter that assists with describing the sedimentary environment and interpreting results for indicators of sediment quality. In some situations, it can also help to assess changes associated with anthropogenic disturbance such as discharges of effluent containing a high concentration of particulate matter. Sediment particle size is important in sedimentation and transport processes, affects the depth to which organisms can burrow, and also determines the surface area of sediment that is in contact with the water that fills the voids between particles (i.e. 'pore water') (ANZECC 2000). Finer particles have a greater surface area overall and therefore have a greater capacity to adsorb organic and heavy metal contaminants. Sediment re-suspension can result from wind stirring, tidal currents, dredging and boating, as well as by biological activities ('bioturbation'), leading to particle sorting on the basis of density or size. Particle size analysis is, therefore, frequently used to make qualitative assessments of the strength of currents near the seabed, and hence, the ability of sites to 'flush' if exposed to anthropogenic inputs.

Sediments typically contain particles of a wide range of sizes, and are frequently divided into coarse material, sand and fine clay/silt (or 'mud') fractions on the basis of separations using 2 mm and 63 µm sieves (ANZECC 2000). Many intermediate sieve sizes may be used to divide these particle types into subcategories, such as 'coarse sand', 'medium sand', 'fine sand' and so on. In the natural environment, a dominance of coarse material and sand is generally indicative of high flows and flushing capacity, while a dominance of fine sediments (clay/silt) reflects a lower energy environment and greater potential for retention of contaminants.

Particle size distributions in Huon Estuary sediments have been investigated through several major studies. Sampling in 1997 for the Huon Estuary Study (HES) found that sediment particle size was highly variable, reflecting the changing bottom topography and variable current strengths in the estuary. Sands predominated in the upper reaches and at the mouth, while fine muds were more common in Port Cygnet and the mid-estuary (Butler *et al.* 2000). Consistent results were subsequently recorded in 2004, and identified >90% mud at a large proportion of sites, with the majority containing >50% mud (Figure 69) (Macleod and Helidoniotis 2005). Only sites at the mouth of the estuary and several sites north of Hospital Bay (Port Huon) were described as silty sand, and were associated with either higher current flows or greater levels of exposure. However, the relatively deep channel of the estuary ensures that tidal current velocities are generally low, accounting for the dominance of mud and dark organic-rich sediments.

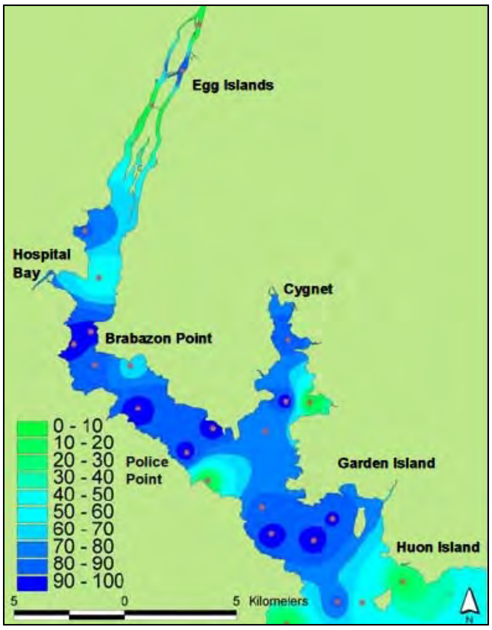


Figure 69 Percentage of silt/clay in sediments of the Huon Estuary (Source: Macleod and Helidoniotis 2005).

Sediment particle size was investigated in the D'Entrecasteaux Channel by Macleod *et al.* (2008a) as part of the Whole of Ecosystem Assessment for Salmon Farming (WoEASF). Sites surveyed at the northern, narrow, end of the Channel were described as predominantly silt/clay, whilst those in the broader middle section were characterised as a mixture of sand and sand/silt. At the southern end of the Channel, there was again a higher occurrence of fine sedimentary material, with sites mostly categorised as silt. These results are consistent with the bathymetry of the Channel (Section 2.4), with the shallower middle section experiencing higher flows and, therefore, coarser sediments. More detailed information is available for North West Bay, where surveys during 2001/2002 found that silt (<63um) was the predominant sediment type and covered around 80% of the bay. A general correlation was observed between silt content and depth, with the deeper areas acting as a deposition zone for fine material (Figure 70) (Jordan *et al.* 2002). Further detailed analysis of particle size data for the broader Channel would be useful to more comprehensively characterise sediments in relation to depth and topographic features.

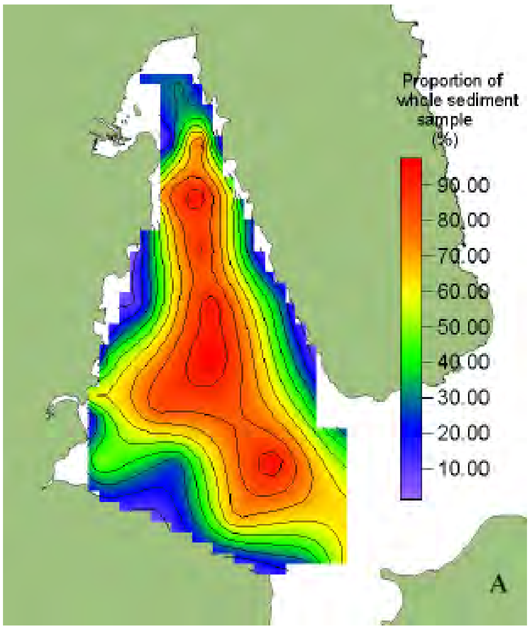


Figure 70 Percentage distribution of silt/clay in sediments of North West Bay (Source: Jordan *et al*. 2002).

12.2.2 Indicators of organic enrichment

Organic matter in sediment consists of carbon and nutrients in the form of carbohydrates, proteins, fats and organic acids. Sediment organic matter is derived from plant and animal detritus, bacteria or plankton formed in situ, or derived from natural and anthropogenic sources in catchments. Fish farms and effluent from sewage treatment plants are examples of organic-rich anthropogenic inputs. The amount of organic matter found in sediments is a function of the amount of various sources reaching the sediment surface and the rates at which different types of organic matter are degraded by microbes (e.g. bacteria). The consequences of organic enrichment in sediments potentially include reduced oxygen levels, toxic levels of sulphides, and impoverished benthic infauna communities. In addition, organic loading of sediments can cause nutrient cycling pathways to be overwhelmed and lead to nutrients being released into the water column. This may increase the likelihood of blooms of algae such as the toxic dinoflagellate *Gymnodinium catenatum*, emphasising the importance of 'healthy' sediments. National guidelines have not been established for indicators of organic content because of high levels of natural variation; hence, interpretation of data relies largely on comparisons with 'baseline conditions' or 'control' sites which are judged to reflect un-impacted levels.

While heavy metals are the primary management issue for sediments in the adjacent Derwent Estuary, organic inputs are the predominant consideration in the D'Entrecasteaux Channel and lower Huon Estuary.

These areas support a major fish farming industry, which is a significant source of organic matter from both uneaten food and fish faeces (Butler *et al.* 2000) (refer to Section 9.2.2). Additional sources of organic matter include domestic and industrial wastes discharged via wastewater treatment plants (WWTPs) and a range of both natural and anthropogenic catchment inputs. Surveys of surface sediments can indicate any localised inputs measured against a system-wide baseline, with data interpretation strongly reliant on a good characterisation of sediment types and their distributions.

Several direct and indirect measures have been used to assess levels and sources of organic enrichment in the D'Entrecasteaux Channel and lower Huon Estuary:

- *Organic carbon and nitrogen content:* measurements of total organic carbon (TOC) are used as an indicator of the amount of organic matter contained within the sediments, and are frequently estimated as % organic content using the 'loss-on-ignition' (LOI) method. Limitations have been documented for the LOI method (e.g. a tendency to overestimate organic content) and hence, some studies have also measured the organic carbon content directly with an elemental analyser because it is considered a better measure of organic carbon (Butler *et al.* 2000). Results of the latter are presented as % dry weight of organic carbon and are usually supplemented by analysis of % dry weight of organic nitrogen.

- *Stable isotopes and lipid biomarkers*: these are used to trace the organic sources of carbon and nitrogen in sediments, for example differentiating between various terrestrial and marine sources of organic matter. Stable isotope analysis is based on assessing carbon and nitrogen 'signatures' that vary between different sources of organic matter. Lipid biomarkers (e.g. fatty acids, fatty alcohols and sterols) are naturally-occurring compounds with a distinctive structure that can be related to a particular source such as phytoplankton, bacteria, marine animals or land plants.

- *Redox potential and sulphides:* inputs of organic matter lead to increased bacterial respiration rates that can translate to a deficiency of oxygen ('anoxia'), or oxygen 'reduction', in the sediments. The oxidation-reduction (redox) conditions in surface sediments can be assessed by measuring the vertical redox potential profile, with negative values indicative of anoxia. Under anoxic conditions, microbes produce compounds such as sulphides as a by-product of organic matter decomposition. Sulphide measurements, therefore, provide an additional indicator of deterioration of sediment quality, while sediment colouration provides a qualitative indicator of the presence of hydrogen sulphide.

- *Benthic infauna:* these fauna have varying tolerances to sediment anoxia, sulphides and organic content, and are frequently used as an indicator of organic enrichment. They are also sensitive to other contaminants such as heavy metals and pesticides, and hence are an indicator of overall sediment health rather than solely organic content. Due to their broader application, information on benthic infauna is included in a separate part of the sediment quality section (see Section 12.2.3).

Note that nutrients associated with sediments have also been studied in the form of nutrient fluxes and porewater analyses, primarily to identify the importance of sediments as a source of nutrients. Studies performed as part of the WoEASF found that loading of sediments with labile (i.e. readily broken down) carbon resulted in nutrient cycling processes being overwhelmed due to increased respiration and reduced oxygen. This resulted in large amounts of ammonium being released into the water column; a process which increases the risk of algal blooms (Thomson 2008).

Organic carbon and nitrogen content

Organic matter has a high affinity for fine-grained sediment, and hence, TOC generally exhibits a positive correlation to the quantity of mud (i.e. fine sediments <63µm) (Jones *et al.* 2003). Assessments of particle size distributions are therefore routinely performed in conjunction with TOC analyses, and are an important consideration in data interpretation.

Jones *et al.* (2003) surveyed %LOI at 18 sites throughout the Huon Estuary during 1997, and recorded values in the range of 16 to 25% in the lower-mid estuary. The reduced nature, black colour and the presence of sulphides recorded from these sediments at the time were attributed to the decomposition of organic matter. For comparative purposes, the HES also presented LOI data which reflected a range in values from 'not detected' to 23.9% (mean 14.4%). Organic carbon (C_{org}) values determined using an elemental analyser indicated that some of the sediments in the Huon Estuary have elevated organic matter contents, consistent with the classification of the estuary as mesotrophic (see Section 11.2.3) (Butler *et al.* 2000). Values of organic carbon were highly variable, ranging from <1% of sediment dry weight near the estuary mouth to values exceeding 8% upstream of the bend at Brabazon Point, while organic nitrogen (N_{org}) ranged from barely detectable in sandy sediments to a maximum of 0.75% (Figure 71). The high variability in organic carbon and nitrogen contents was attributed partly to the wide range of possible sources; however, much of the variability could be explained by the varying proportion of mud. The samples with greater than expected carbon contents on the basis of particle size were all associated with high levels of terrestrial-derived organic matter (see further below).

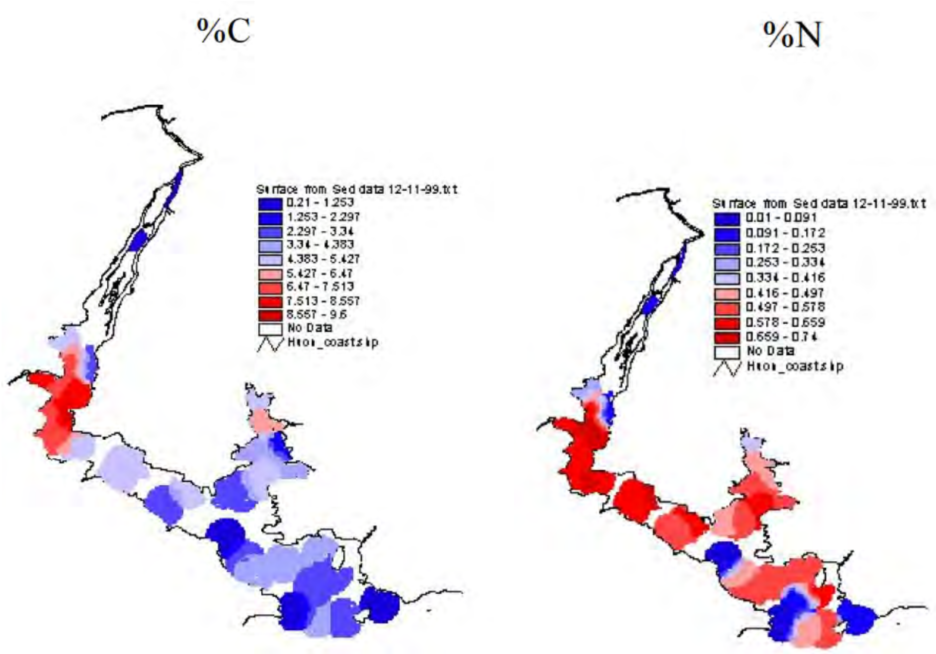


Figure 71 Organic matter in surface sediments of the Huon Estuary (Source: Butler *et al.* 2000).

A subsequent survey of TOC during 2004 recorded similar patterns of spatial variation, with the highest levels (approximately 8%) in the upper estuary, north of Brabazon Point and around the mouth of Hospital Bay, and 4-6% organic content for much of the lower estuary. However, in this study organic carbon content was not strongly correlated with grain size, suggesting that levels were influenced by more than just the depositional nature of the environment. The higher levels in the area around Hospital Bay were attributed to likely wood fibre accumulation from past pulp mill operations (Macleod and Helidoniotis 2005).

TOC was investigated at five sites in North West Bay during 2006 as part of the WoEASF, with low to moderate contents of organic carbon (1.9 to 4.1% by weight) and organic nitrogen (0.06 to 0.43 % by weight) recorded in surface sediments (Holdsworth *et al.* 2008). None of the major studies included assessments of TOC in the broader D'Entrecasteaux Channel; however, some data have been collected in other studies. As part of an investigation of diatoms, Lane (2005) measured TOC at a range of sites in south-east Tasmania. Values at 19 sites in the D'Entrecasteaux Channel ranged from 0.06 to 2.96%, at a mean value of 0.79%. A positive relationship between TOC and the percentage content of mud was also reported.

Stable isotopes and lipid biomarkers

Biomarkers (e.g. organic molecules that can be traced to their biological source) and carbon and nitrogen isotopes used in conjunction with organic carbon:organic nitrogen (C:N) ratios, can be used to distinguish between sources of organic matter, such as terrestrial higher-plant material, phytoplankton and anthropogenic inputs from salmon farms and sewage treatment plants. Another source of terrestrial organic matter relevant to the Huon is the substantial loading of wood waste from forestry operations and historic dumping of pulp fibre from a pulp mill at Hospital Bay (Butler *et al.* 2000). The organic matter from these diverse sources can have very different compositions and degrade at different rates, providing opportunities to quantify contributions from each.

Stable isotope analysis makes use of the fact that different biochemical pathways, and the degree to which carbon and nitrogen have been reworked, will lead to different ratios of ^{13}C and ^{12}C, and ^{15}N and ^{14}N. When the resulting stable isotope signatures of the different sources of organic matter are sufficiently different, it is possible to apportion the sources of organic matter. Isotope values are normally expressed relative to a standard and are given in units of parts per thousand (‰). Lipid biomarkers are naturally-occurring compounds that have a distinctive structure that can be related to particular sources. Some of these compounds are quite stable and can persist for thousands of years in sediments, while others are rapidly degraded and so their presence in sediments can be used as an indicator of very recent inputs (Butler *et al.* 2000).

The HES investigated sources of sedimentary organic matter in the Huon Estuary, with resulting $\delta^{13}C$ values (Figure 72) depicting a range of values from terrestrial (-28.5‰) in the upper estuary to mixed aquatic-terrestrial (-24‰) in the lower estuary. While values reported in the literature are variable for phytoplankton, sediments containing mostly marine (phytoplankton-dominated) organic matter typically give $\delta^{13}C$ values of -19 to-21‰. The proportion of marine and terrestrial organic carbon was estimated by the HES using a simple model based on a terrestrial value of -28.5‰ and an aquatic value of -22‰. A consistent picture emerged of organic carbon in the upper estuary being almost entirely (80%) derived from terrestrial plant material, while substantial inputs of marine sources (55-75%) were detected at the middle and lower estuary sites (Butler *et al.* 2000). The $\delta^{15}N$ values produced similar spatial results (Figure 72), with terrestrial plant matter having a $\delta^{15}N$ value of about 1.5‰ and marine sources having a value of about 7.5‰.

The lipid biomarkers investigated by the HES included fatty acids, fatty alcohols and sterols. The sterols provided additional evidence of terrestrial sources in the upper estuary due to the main sterol produced by terrestrial plants, sitosterol, comprising over 40% of the total sterols. In the Hospital Bay area and adjacent areas of the upper estuary, particularly high levels of sitosterol (Figure 73) may be associated with wood fibres discharged from the former pulp mill. Isotope signatures of the sediments were different from the values obtained for fish feed or fish faeces. In addition, ratios of cholesterol to phytol (from chlorophyll-*a*) suggested that natural aquatic sources, as opposed to fish feed and fish faeces, were the main source of cholesterol at almost all sites sampled. There was one significant exception adjacent to a fish farm in the middle estuary, where a very high cholesterol value (Figure 73) suggested dispersion of fish-farm-derived organic matter off-site. This may have been due to unintentional siting of fish cages outside the lease area in previous years, and the study concluded that while fish farms are a significant source of organic matter, at most sites this is confined within the boundaries of the farm (Butler *et al.* 2000).

Sewage was also traced in HES sediment samples using steroidal compounds found in the faeces of humans and other animals. The sediments in the northern half of the Cygnet arm of the estuary reflected some inputs of human sewage from the Cygnet WWTP, although the inputs were highly diluted. It was concluded that human faecal matter inputs contributed an extremely small proportion of the overall organic matter content (Butler *et al.* 2000).

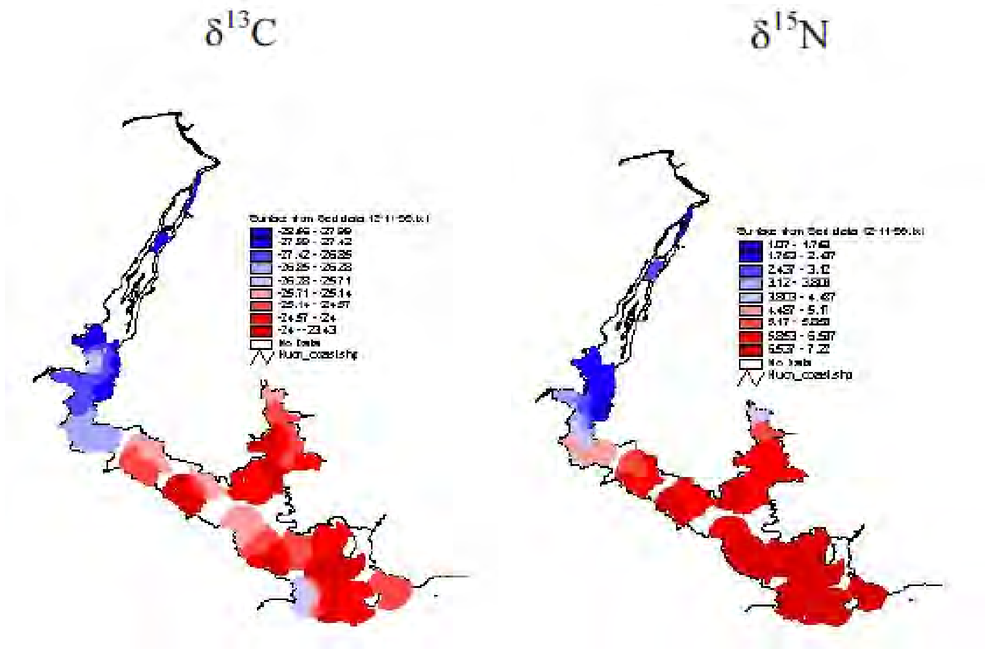


Figure 72 Organic matter δ13C and δ15N values in sediments of the Huon Estuary (Source: Butler et al. 2000).

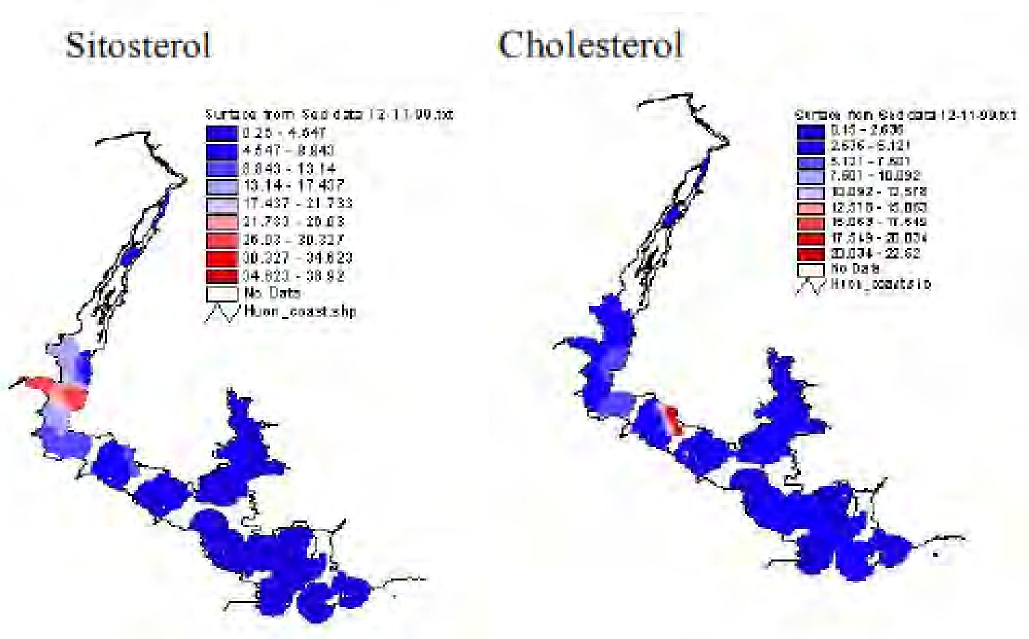


Figure 73 Sterol biomarkers in sediments of the Huon Estuary (sitosterol = higher plant sources; cholesterol = animal sources) (Source: Butler *et al.* 2000).

There have been no studies of stable isotopes or lipid biomarkers in the broader D'Entrecasteaux Channel, however some sampling of North West Bay was conducted as part of the WoEASF. Stable isotope results were consistent with slightly degraded marine organic matter mixed with terrestrial organic matter (Holdsworth *et al.* 2008). Lipid biomarkers displayed a predominance of phytoplankton, higher plant and fauna, while concentrations of terrestrial markers were elevated where the North West Bay River enters. This implied that terrestrial organic matter was derived from the river, probably associated with high runoff events. Sediments in the immediate vicinity of fish farms recorded elevated total lipids and individual levels of coprostanol, cholesterol, and vitamin E, consistent with farm inputs.

Redox potential and sulphides

Whilst not being direct measures of organic content, measurements of both redox potential and sulphides have been used as indicators of levels of organic enrichment. Major studies have focussed on the Huon Estuary, with only localised studies performed in the D'Entrecasteaux Channel.

A survey of the Huon Estuary in 1997 found that, apart from shallow veneers (<1 mm), the sediments were all anoxic and characterised by redox values ranging from –140 mV to –280 mV (Jones *et al.* 2003). The HES recorded similar results for the upper estuary, where oxygen depletion (see Section 11.2.1) was associated with strongly anoxic sediments. However, a subsequent survey in 2004 recorded consistently oxidised conditions (i.e. >0 mV), with the exception of several slightly reduced sites in the lower estuary (Figure 74) (Macleod and Helidoniotis 2005). Sulphide concentrations were generally low throughout the system (<30 µM) (Figure 74), although increased slightly at sites between Hospital Bay and Brabazon Point, an area which also recorded slightly lower redox values. These findings were attributed to former discharges from the Port Huon pulp mill, with the mill reported to have caused an anaerobic blanket of hydrogen sulphide associated with soft, sticky mud in Hospital Bay (Butler *et al.* 2000; see Section 9.7.2). Overall, the 2004 results indicated an improvement since earlier surveys, although changes could be associated with natural variables. The combined redox and sulphide results suggest that while organic content is elevated in parts of the Huon Estuary, it may be largely refractory (i.e. highly resistant to being broken down) and hence not leading to reduced conditions (Macleod and Helidoniotis 2005).

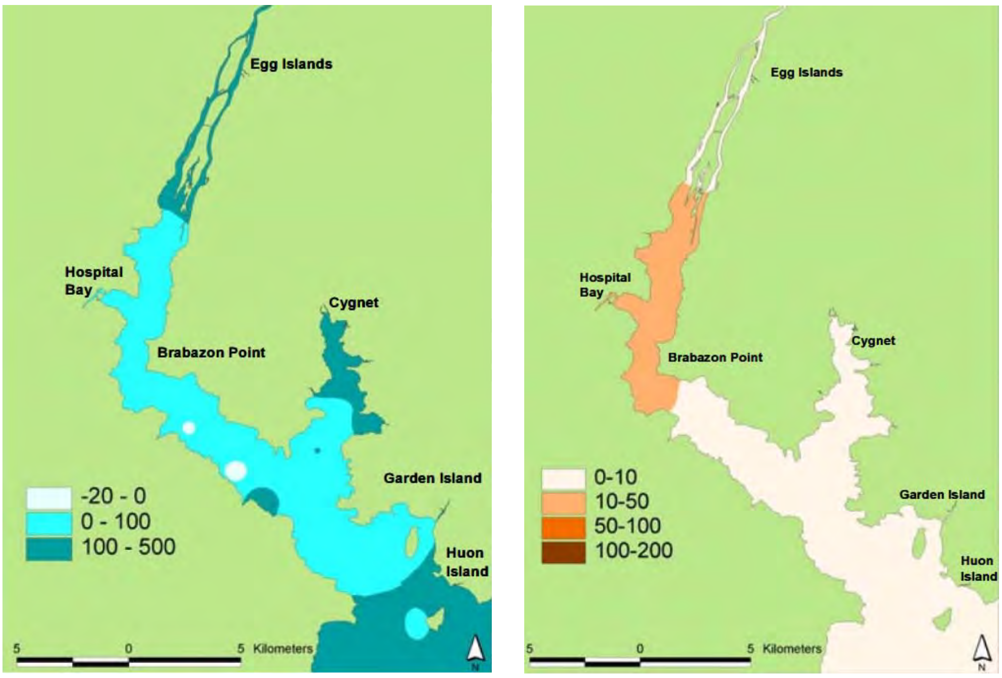


Figure 74 Redox potential (mV) (left) and sulphide concentration (µM) (right) in the Huon Estuary (Source: Macleod and Helidoniotis 2005).

No widespread assessment of redox potential and sulphide concentrations has been conducted in the D'Entrecasteaux Channel; however, surveys have been performed in the vicinity of fish farms and in association with other development applications. In North West Bay, levels of sulphides at reference stations distant from fish cages were very low (less than 20uM), but much higher inside and within 10 m of cages. One month after initiation of fallowing (i.e. removal of fish cages), levels at fish farm sites recorded values around 550-800 µM, although after 24 months they had declined to background levels of <20 µM (Macleod *et al.* 2002). A sediment survey performed at Little Oyster Cove for a dredging proposal found that surface sediments were consistently oxidised, recording mean values of >150 mV (Aquenal 2006b).

12.2.3 Benthic infauna

The benthic infauna are animals living within the sediments on the seabed, with most infauna occurring in the top 10 cm due to oxygen depletion at greater depth. Physical environmental conditions have a major structuring influence on infaunal communities, with parameters such as grain size, current flow, salinity, temperature and oxygen availability particularly important (Macleod and Helidoniotis 2005). Benthic infauna also have varying tolerances to contaminants and other anthropogenic inputs and are, therefore, frequently used as an indicator of sediment health. They are described here rather than in the native species 'benthic invertebrates' section (Section 6.1.5), since in the D'Entrecasteaux Channel and lower Huon Estuary they have been assessed more as an indicator of environmental health than as a measure of natural biodiversity values.

Macleod and Helidoniotis (2005) sampled benthic infauna communities and a range of associated abiotic parameters (i.e. physical and chemical conditions) in the Huon Estuary. Infaunal diversity fluctuated markedly over the length of the system, although overall diversity levels were comparatively high, suggesting that the communities were relatively undisturbed. There was a significant reduction in diversity in the upper estuary compared with other areas whilst diversity at the estuary mouth was significantly increased. Cluster and multivariate analyses suggested that, at an overall similarity level of 20%, the upper estuary sites were clearly differentiated from the rest of the estuary, while at a similarity level of 35%, the mid-lower estuary communities were also divided into three distinct groupings (Figure 75). Despite these differences, there was considerable overlap in the taxonomy and function of the faunal communities throughout the Huon Estuary, and a dominance of euryhaline (i.e. tolerant of a wide range of salinities) and/or estuarine species. The uppermost reaches of the estuary were shallow and, therefore, subject to greater environmental extremes of both temperature and salinity, suggesting that stresses affecting the community composition of this area were largely natural.

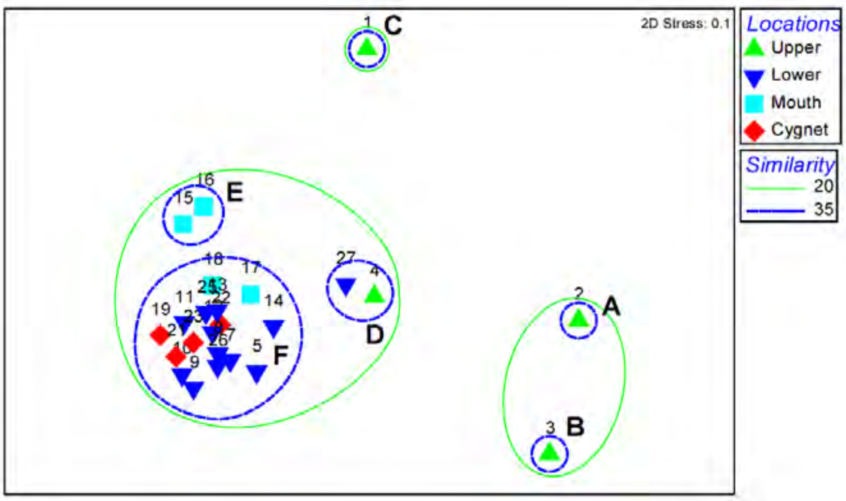


Figure 75 Benthic infauna community groups of the Huon Estuary (Source: Macleod and Helidoniotis 2005).

The distribution of species throughout the estuary seemed to be largely structured according to the prevailing salinity/geographical gradient. No single abiotic factor explained the overall pattern of community distribution. Instead, a combination of factors integrating the changes in organic content, salinity and sediment redox regimes along the estuary best defined the ecological gradient. It was concluded that benthic infauna changes along the Huon Estuary were primarily in response to a gradual change in natural environmental conditions rather than specific human impacts. By comparing known information on the estuary usages, environmental parameters, and the biology and ecology of the dominant fauna, likely impact 'ranks' were assigned to the various community groups within the estuary. The distribution of these impact ranks is shown in Figure 76, with a score of '3' indicative of naturally stressed environments, and readings of 1.1-1.3 reflecting 'normal' upper estuarine through to marine communities. The results of the study provide a baseline ecological reference for future assessments of sediment condition and ecological status (Macleod and Heliodoniotis 2005).

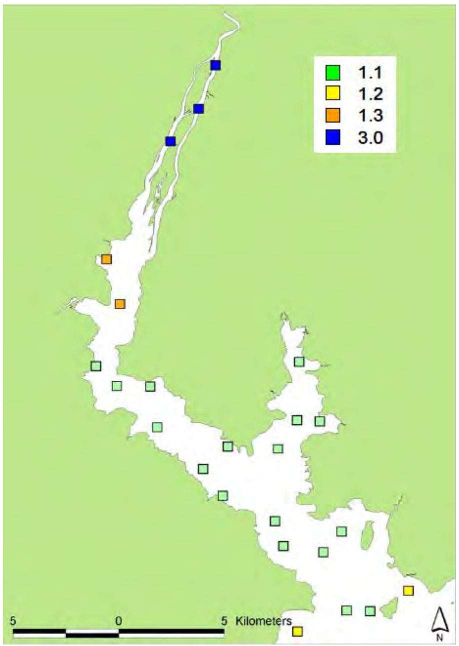


Figure 76 Benthic infauna community impact levels in the Huon Estuary (Source: Macleod and Helidoniotis 2005).

A subsequent study of benthic infauna communities of the D'Entrecasteaux Channel and Huon Estuary was performed by Macleod *et al.* (2008a) as part of the WoEASF. Results suggested a large degree of similarity in benthic communities across these areas, although lower salinity sites were clearly differentiated from fully marine sites. There was a gradation of change throughout the main estuarine region as well as some differentiation of communities associated with embayments. Multivariate analysis at a similarity level of 15% divided sites into five major groupings on the basis of community composition. Consistent with the earlier study above, the most dissimilar sites were in the upper Huon Estuary, where communities lacked key species found elsewhere and recorded a low diversity (groups 'a' and 'b'; Figure 77). The majority of sites (80%), including the lower Huon Estuary, D'Entrecasteaux Channel and most of the deeper sites from North West Bay, were characterised by species common to Tasmanian soft-sediment communities (group 'd'; Figure 77). The remaining two groups primarily included sites in North West Bay which had reduced numbers of species common at other sites, and a marked increase in numbers of several opportunistic scavengers and predators. No clear relationship was detected between benthic infauna communities and depth or sediment type, although sites surveyed did not reflect any major depth or sediment type gradients (Macleod *et al.* 2008a).

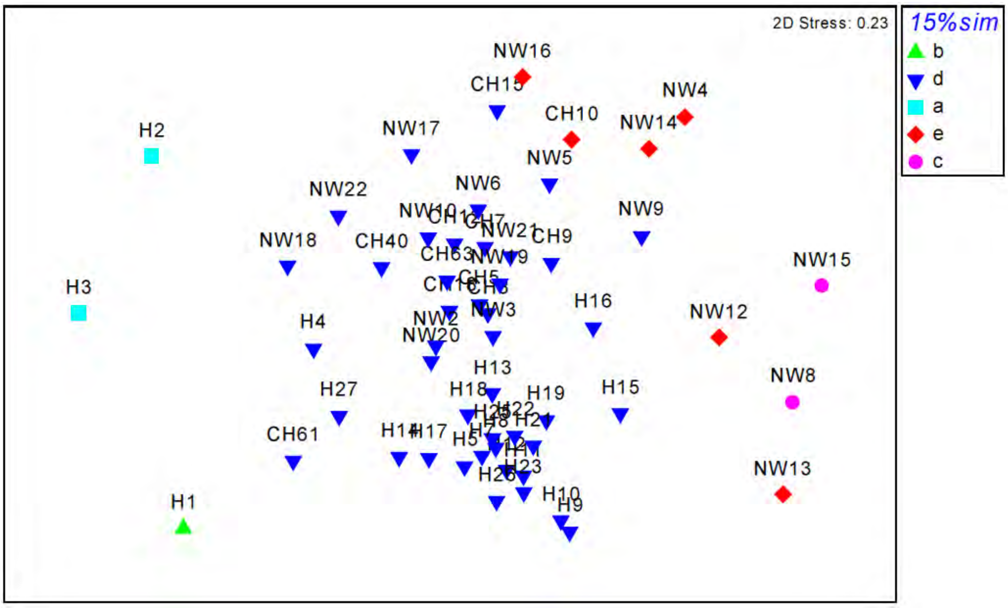


Figure 77 Patterns of benthic infauna community similarity for North West Bay (NW), D'Entrecasteaux Channel (CH) and Huon Estuary (H) sites (Source: Macleod *et al.* 2008a).

Analyses of temporal trends in benthic infauna have not been investigated at system-wide scales, although more localised studies performed during 2001-2003 investigated time-series recovery of communities following exposure to finfish farming activities at Port Esperance and North West Bay. Recovery rates of benthic infauna during fallowing of farm sites varied amongst areas studied, largely reflecting different background conditions. A farming site at Port Esperance investigated over three months showed good recovery and a return of primary ecological functions, however community structure remained dissimilar from reference conditions (Macleod *et al.* 2007). In North West Bay, there was little evidence of recovery in the first few months and the community was dominated by species characteristic of impacted conditions. After 12 months the system had markedly improved, containing a diverse range of species with functional roles similar to those of the reference sites. However, after 36 months of fallowing, communities within 10 m of fish cage sites had still not attained a structure equivalent to that of the reference communities. It was concluded that restoration of system function may be a more useful indicator of generalized recovery from organic enrichment than of community equivalence (Macleod *et al.* 2008b).

12.2.4 Heavy metals

The study area has not supported any major metal processing industries; however, examples of potential sources of heavy metal inputs include contaminated sites, agricultural and urban runoff, discharges from sewage treatment plants, and copper-based antifoulants used at fish farms. Metals are generally not biodegradable, and hence, when entrapped in marine sediments may become a persistent feature of the environment unless they are physically removed or dispersed by natural environmental mechanisms (Macleod and Helidoniotis 2005). Toxic effects on marine organisms are likely when metal concentrations reach threshold levels, while some metals can be concentrated up the food chain via biomagnification (see Section 14.4.3). Heavy metals (including the metalloid arsenic) have been surveyed in the sediments of North West Bay and the Huon Estuary, but there has been no extensive survey of heavy metals in the broader D'Entrecasteaux Channel. Fish farm compliance monitoring has included measurements of copper and zinc levels at farms and neighbouring control sites since 2003 (Macleod and Eriksen 2009).

Heavy metal concentrations in the sediments of the Huon Estuary were investigated during three major studies, with results summarised in Table 36. Analyses for a survey in 1997 lacked the sensitivity needed for comparison with the ANZECC (2000) guidelines for cadmium and mercury; however, concentrations of other metals were below the low guideline in most samples (Jones *et al.* 2003). Occasional exceedances or equivalent values were recorded for arsenic, chromium and nickel, while no values exceeded the high guideline. Correlation coefficient analysis indicated that the zinc, lead and arsenic values were weakly positively correlated with both mud (i.e. fine sediments <63 µm) and organic content. Slightly elevated values at some sites were primarily attributed to higher local background values related to the geology of the Huon catchment. In contrast, pollution effects were identified in Port Cygnet and Hospital Bay, where there were slight increases in zinc content.

Table 36 Heavy metal concentrations in Huon Estuary sediments (units are mg/kg).

Study	Butler *et al.* (2000)	Jones *et al.* (2003)	Macleod and Helidoniotis (2005)	ANZECC (2000) Guidelines	
Sampling date	1998	1997	2004		
No. Sites	6	18	25	ISQG-Low	ISQG-High
Arsenic	1.9-28	4-25	<1-31	20	70
Cadmium	0.02-0.26	<10	<1	1.5	10
Chromium	-	50-80	-	80	370
Cobalt	3.7-12.5	15-35	-	-	-
Copper	3.6-47.0	7-32	3-80	65	270
Iron (%)	0.6-4.3	1.73-4.05	0.5-4.5	-	-
Lead	3.6-29.2	<2-48	2-155	50	220
Manganese	27-87	-	26-129	-	-
Mercury	-	<5	<0.02-0.12	0.15	1
Nickel	5.6-21.9	<2-28	7-41	21	52
Zinc	14-92	<2-66	13-160	200	410

The HES survey during 1998 recorded values that, aside from nickel, were consistently below the ISQG-Low concentrations (Butler *et al.* 2000). Nickel concentrations in Hospital Bay and the lower estuary were around the low trigger value, and additional analysis involving normalising concentrations to iron suggested natural sources. Normalisation procedures also suggested that copper, cadmium, lead, and possibly zinc, were raised by a factor of 2–3 in sediments of Hospital Bay and at the upper end of Port Cygnet, relative to other marine sediments in the estuary (Butler *et al.* 2000). These observations for the two ports were considered to be consistent with previous uses and continued influence of sewage effluents. Note that much higher concentrations of copper, lead and zinc (exceeding the high guideline in the case of zinc) were observed near the previous pulp mill wharf in an earlier study of Hospital Bay (Chesterman 1995), but there have been no subsequent detailed surveys of this area.

A further survey of the Huon Estuary in 2004 reported that metal concentrations in the sediments were generally low (Macleod and Helidoniotis 2005). No metals were recorded above the high guideline values; however, concentrations of copper, arsenic and nickel exceeded low trigger levels in the sediments south of Hospital Bay. Nickel was elevated in most sites south of Egg Islands, while arsenic was slightly elevated at sites between Hospital Bay and the entrance to Cygnet Bay as well as in the centre of the Channel near Garden Island. Although zinc did not exceed trigger levels, it was substantially increased in Hospital Bay. Overall, it was concluded that the primary source of metal contamination was residual input from previous pulp mill operations (Macleod and Helidoniotis 2005), although a decommissioning plan for the mill suggested that no metal based sprays or additives had been used (Chesterman 1995). The plan attributed elevated metals in the area to sewage inputs from Geeveston and/or the extensive former use of metal-based sprays in apple orchards.

A survey of heavy metals in surface sediments of North West Bay recorded values for arsenic, cadmium and copper that were below the recommended low trigger values (Figure 78), suggesting a low risk of adverse biological effects (Jordan *et al.* 2002). However, concentrations of lead and zinc exceeded the low trigger value at 22% of the sites, with 7% also exceeding the high value guideline for zinc. Sites with elevated concentrations were restricted to those with the finest sediments in the deeper basin of North West Bay. Levels of contamination were very low compared to those reported for the adjacent Derwent Estuary (Whitehead *et al.* 2010), representing around 1.5% and 1% of peak Derwent values for lead and zinc, respectively. The general conclusion was that the source of these metals was the local catchment as opposed to the Derwent Estuary (Jordan *et al.* 2002).

While there is – aside from North West Bay – a distinct data gap for sediment metal concentrations in the D'Entrecasteaux Channel, there have been localised surveys at dredge sites and also at fish farms as compliance monitoring for use of copper-based (and, to a lesser extent, zinc-based) antifoulants. A survey of Little Oyster Cove was performed in relation to a proposed dredging operation, and recorded values that were consistently below the ANZECC (2000) guidelines except in the case of tributyltin (see Section 12.2.5). Sediment monitoring of copper and zinc concentrations at Tasmanian fish farms has included surveys in the region, for example at Soldiers Point in the northern Channel. Surveys at Soldiers Point during 2003 and 2010 recorded an increase in copper at cage sites relative to background conditions; however, concentrations were below the ISQG-high guidleline value (DPIPWE 2011e). Results reported at four Tasmanian fish farm sites monitored during 2003-2008 and eight supplementary sites surveyed during 2005/2006-2008 revealed copper values exceeding the ISQG-low guideline at most farms, and measurements exceeding the ISQG-high guideline at four farms. Samples exceeding the ISQG-low guideline for zinc were recorded at five farm sites, while the ISQG-high value was exceeded at only one site. Elevated metal concentrations were generally confined to farm sites, with copper values in excess of the ISQG-low value only recorded at one adjacent compliance station. Results of zinc sampling suggested an alternative source, such as the adjacent Derwent Estuary, in several areas (Macleod and Eriksen 2009).

12.2.5 Tributyltin

Tributyltin (TBT) is an organic additive that was historically used in marine antifouling paints to discourage the growth of fouling marine organisms such as barnacles, tubeworms, mussels, and algae. However it was found that TBT diffused into the marine environment and affected the growth, reproduction and survival of marine organisms in their natural environment. As a result, the use of TBT-based antifouling paints was banned on vessels less than 25m in length in 1991 and then banned for all vessels in Australia in 2008. TBT can enter the waterway through leaching or paint flake dislodgement from the hulls of vessels previously treated with paints containing TBT, hull cleaning and maintenance, or disturbance of contaminated sediments by propellers and dredging. TBT has the potential to cause long-term effects on marine ecosystems where it is stored in sediments and may re-enter the food chain when the sea bottom is stirred up by dredging or other activities.

Contamination of sediments with TBT is most likely to occur in areas regularly used as anchorages or for vessel maintenance activities, such as marinas and slipways. There have been no comprehensive surveys of TBT in these types of environments in the D'Entrecasteaux Channel and lower Huon Estuary. However, some surveys have targeted specific sites in conjunction with proposed dredging activities. Aquenal (2006a) conducted sediment sampling in a proposed dredging zone in Little Oyster Cove, and found that TBT concentrations were below detection level or below the ISQG low trigger value in the majority of the samples. However, from a total of 29 samples analysed, 9 samples recorded values greater than the ISQG-low value (6-50 μg Sn/kg), and one sample recorded a concentration of 170 μg Sn/kg, a value exceeding the

ISQG-high guideline. The results suggested localised spot contamination, and a widespread low level accumulation in the northern half of the dredge area sampled.

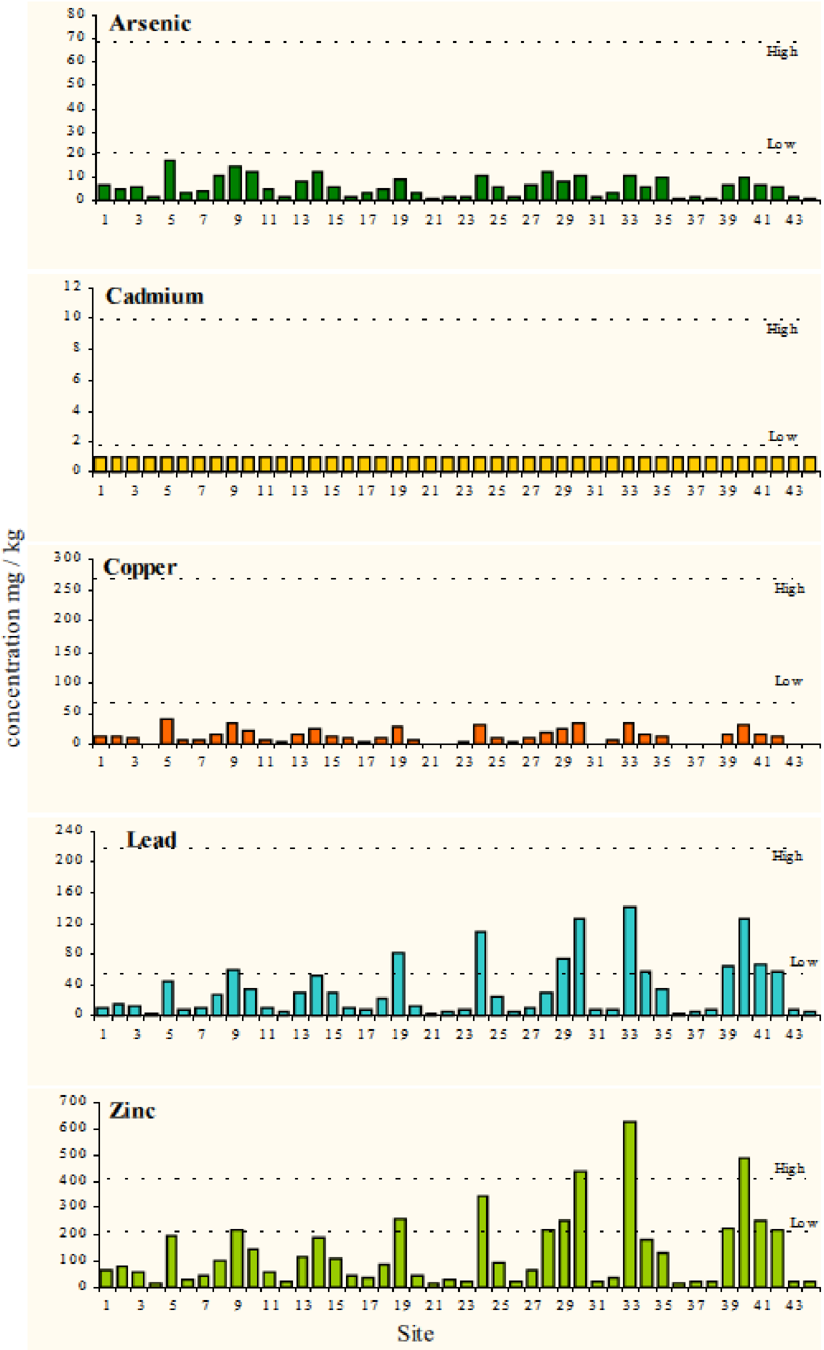


Figure 78 Heavy metal concentrations in North West Bay sediments (Source: Jordan *et al.* 2002).

In another study of a proposed dredge area, GHD (2008) performed a sediment sampling program for a fish processing plant re-development in North West Bay. A total of 12 samples did not detect TBT, although the detection level of 0.01 mg/kg was above the ISQG low value.

Contamination of sediments with TBT is, therefore, likely to be highly localised, but remains an issue where disturbance of sediments is proposed in areas that have historically supported concentrations of recreational or commercial vessels.

12.2.6 Pesticides

Organochlorine pesticides such as DDT, dieldrin and toxaphene are neurotoxins and suspected human carcinogens. Many of the organochlorine pesticides which are now banned were previously used in large quantities and may still occur at high concentrations in sediments because they are not easily metabolised or degraded (Whitehead *et al*. 2010). These compounds are readily stored in fatty tissues and can bioaccumulate to high concentrations through aquatic food chains to secondary consumers, including humans (USEPA 2000). Organochlorine pesticides have gradually been superseded by chemical compounds that are more specific in their action and considered less persistent in the environment. An example is the herbicide atrazine, although even this has shown some level of persistence within Tasmanian aquatic environments. The primary sources of pesticides to aquatic systems of the D'Entrecasteaux Channel and lower Huon Estuary are likely to include agricultural and forestry runoff (Butler *et al.* 2000).

Sampling of pesticides was performed as part of the HES, although no investigations of pesticides in sediments of the D'Entrecasteaux Channel are documented. Concerns about synthetic organic chemicals in the Huon region have centred on pesticides, and it is likely that the horticulture industry concentrated along the banks of the Huon Estuary and its tributaries has probably used pesticides for over a century (Butler *et al.* 2000).

The HES surveyed a suite of 33 pesticides, although only 5 of these have been allocated ISQG values by ANZECC (2000), and many tests lacked sensitivity needed to detect exceedances of these guidelines (Butler *et al.* 2000). None of the pesticides could be measured at or above their limits of detection at any of the sites, with one important exception. The organochlorine pesticides DDT and DDD, which are particularly persistent pesticides, were present in the Hospital Bay sediment sample at 180 mg/kg and 140 mg/kg, respectively. These values far exceed the ISQG-high guidelines, implying a high probability of toxic effects on benthic organisms (Butler *et al.* 2000). The sample was collected from the southern part of the bay, while a separate study collected samples further to the north-west, inside the entrance to the Kermandie River (Aquenal 2006a). From a total of 20 samples spread across eight sites, no pesticides were detected in any of the sediments sampled, although again, many of the laboratory detection levels were higher than ISQG values.

In summary, limited studies to date suggest that there is no widespread contamination by pesticides in the Huon Estuary; however, significant localised contamination was detected in Hospital Bay, Port Huon. Due to a history of sawmilling, pulping and associated discharge or organic material, it is conceivable that sediments in the area have behaved as a 'sponge' for contaminants such as organochlorine pesticides. The HES recommended a more extensive survey of pesticides in Hospital Bay (Butler *et al.* 2000), as well as a more comprehensive survey in the broader Huon Estuary using higher sensitivity analyses and focussing on pesticides known to have been previously used in the Huon catchment. The lack of comparable data for the D'Entrecasteaux Channel suggests that inclusion of sites in this region would also provide a more informative baseline for the region.

12.2.7 Antibiotics

Antibiotics used to treat disease by the salmon farming industry have several environmental implications, and hence monitoring has been performed to measure antibiotic residues in sediments. The main environmental concerns relate to the effects on non-target organisms, environmental persistence and development of resistance. While no data have been reported for specified sites in the Channel and lower Huon Estuary, the primary antibiotic used, oxytetracycline (OTC), has been measured in sediments of two Tasmanian fish farm sites. Concentrations were determined before and after treatment, with samples collected under cages and at varying distances from the cages. The overall level of OTC residue beneath the cages was low, reaching a maximum level 180 µg/kg, but generally averaging less than 50 µg/kg. These levels are very low compared with values recorded in earlier studies of overseas salmon farms, a likely reflection of improvements in aquaculture feed formulation and technology (Macleod and Eriksen 2009).

The distribution of OTC in the sediments was more widespread than has been reported elsewhere, with residues detected up to 500 m from the lease boundary, albeit at low levels (14-53 µg/kg). Results of temporal sediment sampling indicated that OTC residue levels had declined but were still evident 90 days after treatment (DPIPWE 2011e). Current data cannot distinguish between total antibiotic loading and the component that is biologically available and could have an ongoing effect, an issue that has been highlighted for future additional research (Macleod and Eriksen 2009).

12.3 Summary of sediment quality

Sediment conditions and quality have been most comprehensively studied in the Huon Estuary and to some extent North West Bay, with a less extensive network of sites sampled in the main D'Entrecasteaux Channel. Particle size distributions displayed relationships to depth and current flow, with higher percentages of fine particles recorded in deeper areas and sheltered habitats. The majority of the Huon Estuary and North West Bay were dominated by fine (silt/clay) sediments, suggesting a high capacity to adsorb available contaminants.

Some sediments in the Huon Estuary had very high organic matter contents, and TOC values were consistent with the classification of the estuary as mesotrophic. Organic carbon and nitrogen content were highly variable due to a diverse range of sources and variable particle size distributions, with fine muddy sediments associated with increased organic matter. Highest levels of organic matter (approximately 8%) were in the upper estuary, where they were almost entirely derived from terrestrial plant material. Elevated levels around Hospital Bay were also associated with a spike in the terrestrial plant biomarker sitosterol and may be associated with wood fibres discharged from the former pulp mill. Organic content varied between 4-6% for much of the middle-lower Huon Estuary and consisted of mixed aquatic-terrestrial sources.

Organic matter sourced from fish farms was confined within the boundaries of the farms in nearly all cases, while sewage contributed an extremely small proportion of overall organic matter inputs except in the vicinity of Cygnet. Biogeochemical laboratory studies found that organic loading in Huon Estuary sediments can result in nutrient cycling processes being overwhelmed, thus triggering the release of large amounts of ammonium and increased risks of eutrophication (Volkman *et al.* 2009). This highlights the importance of maintaining 'healthy' sediments and monitoring organic inputs.

Redox potential and sulphides provided additional indicators of organic enrichment and displayed improvement in the Huon Estuary between 1997 and 2004 surveys. The earlier survey found consistently reduced conditions (i.e. negative redox values) and black sediments reflecting high levels of sulphides. In 2004, reduced conditions were only recorded in a few localised areas of the lower estuary, with lowered redox levels attributed to accumulated organic material from the former pulp mill and some salmonid farming operations.

By comparison with the Huon Estuary, TOC levels in North West Bay and the broader D'Entrecasteaux Channel were low to moderate (0.06 to 4.1%). Sources of organic matter were only investigated in North West Bay, where slightly degraded marine organic matter was mixed with terrestrial organic matter. Lipid biomarkers displayed a predominance of phytoplankton, higher plant and fauna, with terrestrial biomarkers particularly evident where the North West Bay River entered. Sites studied in relation to fish farming activities in the bay displayed elevated lipids and sulphide levels, although fallowing resulted in significant reduction of observed levels.

Benthic infauna communities exhibited a high degree of similarity across the study area, although communities associated with lower salinity sites were clearly differentiated from fully marine sites. Overall diversity levels were comparatively high, suggesting that the communities were relatively undisturbed, while a combination of factors integrating changes in organic content, salinity and sediment redox regimes best explained patterns in community composition. Studies consistently noted reduced diversity and highly dissimilar communities in the upper Huon Estuary, although this was attributed primarily to natural stresses associated with the upper reaches of a salt-wedge estuary. Some sites in North West Bay were also differentiated although the extent to which this was due to human interference is not known. Localised studies of temporal changes relating to fallowing studies for finfish farms have indicated variable recovery times, and that restoration of system function may be a more useful indicator of general recovery from organic enrichment than of community equivalence.

Sediments of the Huon Estuary were generally low in heavy metals, with most values falling below the national guideline values. However, pollution effects were identified in Port Cygnet and Hospital Bay, where low guideline values were exceeded for some metals and additional analysis suggested concentrations 2-3 times those of sediments elsewhere in the estuary. High levels of localised contamination with the organochlorine pesticides DDT and DDD were also recorded in Hospital Bay, while concentrations of pesticides elsewhere were lower but require a more comprehensive assessment. Overall, results indicated persistence of localised contamination from historic port and industrial activities, although sewage discharges and land-use practices in the Geeveston area are also likely contributing factors (see Section 11.2.5).

Heavy metals in sediments of North West Bay were mostly below national guideline values with the exceptions of lead and zinc which exceeded the low trigger value at 22% and 7% of sites, respectively. These sites were characterised by fine sediments and were located in the deepest part of the bay, with the source of metals suggested to be the catchment rather than the adjacent Derwent Estuary. Copper concentrations at some fish farm sites were elevated relative to background conditions and exceeded the ANZECC (2000) guideline values, while a low level of zinc contamination was also recorded at some sites. Residue of the primary antibiotic agent used in salmonid farming was detected in sediments post-application, although levels were low compared to those recorded in earlier overseas studies. Localised spot contamination and occasional broader areas of low level accumulation were also documented for TBT in marina environments. Identification of contaminants exceeding national guidelines in some areas highlights the need for careful management of activities that may disturb sediments and mobilise associated contaminants.

13 NUTRIENT CYCLING

The cycling of nitrogen and phosphorus in estuarine and coastal systems is complex and linked to many biological, chemical and physical variables, including the type and distribution of biota and sediments, dissolved oxygen and pH levels, water temperatures, and interactions with organic matter (Whitehead *et al.* 2010). Nitrogen and phosphorus enter the Huon Estuary and D'Entrecasteaux Channel via natural sources as well as various anthropogenic sources, as described in Section 9. Their fate is mostly deposition to sediments or transport to coastal waters, however additional sinks include biological uptake and loss to the atmosphere as dissolved gases. As an example, Figure 79 provides a conceptual diagram of nutrient cycling in the Huon Estuary, depicting the primary sources of inputs and processes that affect the transport, assimilation and loss of nutrients (Butler *et al.* 2000). The nitrogen cycle is of primary interest here, and in Australian coastal environments in general, since nitrogen is generally the limiting nutrient for phytoplankton growth in the region.

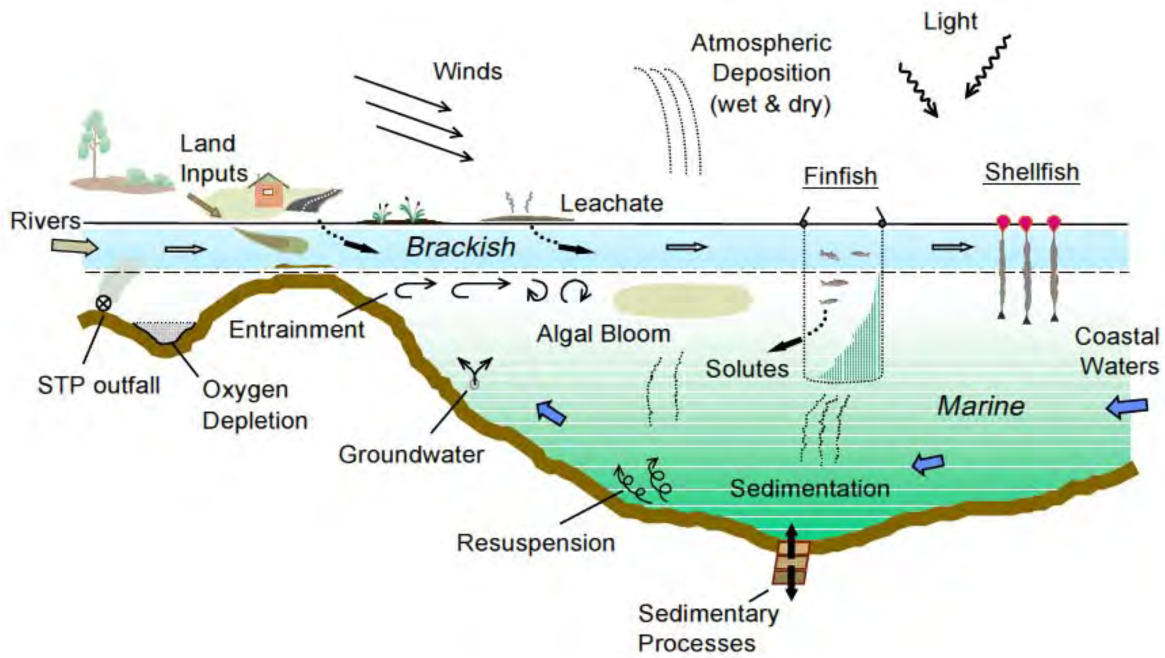


Figure 79 Huon Estuary nutrient cycling processes (Source: Butler *et al.* 2000).

As described in Section 11.2.3, nutrients occur in the environment in many forms which vary in their ability to be broken down and assimilated (i.e. converted by organisms into living tissue), while numerous processes are involved in the transport of nutrients between water, sediment and air. Dissolved organic and particulate forms typically comprise the largest pools of nitrogen in the water column; however, the dissolved inorganic nitrogen (DIN) forms are those most readily available for biological use by groups such as bacteria, phytoplankton, microphytobenthos and seagrass (Jordan *et al*. 2002). Bacteria are the primary mediators of nitrogen processing, while phytoplankton are also particularly important in nutrient cycling, converting inorganic nitrogen to organic matter and biomass production.

Nutrient cycling processes include, for example: denitrification, which converts nitrogen to gas under anoxic conditions, and hence, releases it to the atmosphere; nitrogen fixation, which converts nitrogen from gaseous to organic forms; and ammonification, which results in release of ammonium from organic matter. These and other cycling processes are invariably linked; for example, the conversion of organic nitrogen to gas occurs through a series of steps including ammonification, nitrification and then denitrification (Jordan *et al.* 2002). The cycling of nutrients between the water column and sediment, and from particulate to dissolved forms, is generally not well understood in estuaries and coastal waterways, and yet is essential for understanding the impact of nutrient inputs to these systems.

To improve understanding of the nutrient cycling within the Huon Estuary and D'Entrecasteaux Channel, detailed biogeochemical modelling has been undertaken for the region. Biogeochemical models simulate local processes controlling the cycling of nutrients, and can provide predictions of the possible effects of loads and transport on water and sediment quality and phytoplankton blooms (Butler *et al.* 2000). The coupling of biogeochemical models with hydrodynamic and sediment models provides a powerful predictive tool that can be calibrated and validated against field observations to increase model reliability. Such models are increasingly recognised as a valuable instrument for coastal management. An integral component of the modelling for the region has been the development of nutrient budgets, which define the key input sources and magnitudes, outputs and storage of nutrients in a system. Results are presented below on the basis of the two major investigations conducted – the Huon Estuary Study (HES) and the Whole of Ecosystem Assessment for Salmon Farming (WoEASF).

13.1 Estimates of nutrient loads

Estimates of nutrient loads are needed both as inputs to biogeochemical models and also to assist with the interpretation of nutrient budgets formulated by these models.

The HES estimated nutrients from river flows, sewage wastewater treatment plants (WWTPs), and finfish farms in the Huon Estuary. Inputs from WWTPs were estimated on the basis of discharges at Ranelagh, augmented to include other smaller WWTPs and diffuse loads from non-sewered properties. The result represented an upper bound for inputs due to human waste, as it assumed that all loads from non-sewered properties found their way to the estuary (Butler *et al.* 2000). Fish farm nitrogen loads were calculated as nitrogen in fish feed input minus nitrogen in harvested salmon, and indicated an input in 1997 of 123 tonnes, with 13% estimated to be particulate and 87% dissolved. These estimates were based on the feed conversion ratio applicable at the time, although note that this ratio has subsequently been improved, with less waste of feed (Section 9.2.2). Inputs of nutrients from the catchment were calculated separately for the upper catchment (above Judbury) and lower catchment (below Judbury). Lower catchment inputs were augmented to include estimated loads from agriculture and grazing, based on areas of improved pastures and orchards, cropland and urban development. Annual yields per unit area for these land use types totalled 182 tonnes nitrogen and 8.4 tonnes phosphorus, representing about 20% (nitrogen) and 33% (phosphorus) of total catchment loads (Butler *et al.* 2000).

The WoEASF subsequently provided updated estimates of nutrient loads for the Huon Estuary and expanded the investigations to include the D'Entrecasteaux Channel. Inputs from WWTPs, fish farms and natural marine sources were calculated, while additional work was performed to estimate inputs from the sediments. Combined inputs from sewage were estimated across the nine WWTPs discharging to the Huon Estuary and D'Entrecasteaux Channel, as well as those at Blackmans Bay and Taroona to the north of the Channel. The total average daily flow in 2005 was estimated to be 5.3 ML per day, carrying a total load of 120 tonnes nitrogen per year. Flow was projected to increase to 6.6 ML per day by 2010 (i.e. 25% increase) and 10.3 ML per day by 2030, nearly double the 2005 flow. Note that these values are in fact very large compared to estimated flows for WWTPs in the Huon and Channel regions during 2010-2011 (2.5-3.3 ML/day; see Section 9.1), although the latter excluded inputs from Taroona and Blackmans Bay. The overall conclusion of the WoEASF was that WWTP nutrient loads in the Huon and D'Entrecasteaux were small in comparison to marine, river and fish farm loads into the region (Volkman *et al.* 2009).

At finfish farms, improvements in feed technology and food conversion ratios meant that fish were presumed to consume the vast majority of the supplied food, while it was estimated that 86% of the nitrogen input was in a soluble form excreted by the fish (references in Volkman *et al.* 2009). This soluble waste is dominated by ammonium, the chemical form most available to phytoplankton and many other aquatic plants. The nitrogen input from farm waste in 2002 was estimated to be 843 tonnes across both the Huon Estuary and D'Entrecasteaux Channel, with approximately 120 tonnes in particulate form and 723 tonnes as soluble waste. Modelling was performed to derive projected estimates of inputs by 2009, based on maximum anticipated growth in the fish farming industry. These projected estimates indicated significant increases in nitrogen and phosphorus inputs (see Section 9.2.2), although projected data based on modelling should not be interpreted as actual inputs.

Estimates of catchment inputs via riverine flows were calculated using comparable methods to the HES, while sediment process studies were performed to investigate the role of sediments as a reservoir and source of nutrients recycled back into the water column. These involved calculations of average annual nutrient sediment-water flux across representative sites, with averages then multiplied by the surface area of the waterways to get an estimate of nutrient inputs from subtidal sediments. This approach indicated that the sediments provided approximately 96 tonnes of inorganic nitrogen, 32 tonnes of phosphate and 586 tonnes of silicate, which were very small in the context of other inputs (Volkman *et al.* 2009).

To demonstrate the relative magnitudes of nutrient sources, comparative data were compiled for the Huon Estuary using data compiled from the HES and WoEASF, with results provided in Table 37. These data are based on estimates compiled during 1997-2002 and, therefore, may not reflect current inputs. The major source of dissolved nitrogen and phosphorus was the marine system (Butler *et al.* 2000), which contributed approximately 8-9 times more than the Huon River, the next largest source. Fish farms were the third largest contributor, while inputs from WWTPs and sediments were comparatively minor and the atmosphere accounted for the smallest inputs documented (Volkman *et al.* 2009). While some anthropogenic inputs may have changed since these data were compiled, the relative dominance of natural marine sources is likely to have changed little since 2002.

Table 37 Annual estimated nutrient loadings to the Huon Estuary (tonnes) (Source: Volkman *et al.* 2009).

Source	TDN	NO_3	NH_4	TDP	Reference
Huon River	966	51	23	142	Wild-Allen *et al.* (2005)
Kermandie River	27	9	8	1	Wild-Allen *et al.* (2005)
WWTP outfalls	28	-	-	9	Butler *et al.* (2000)
Fish farms	268	-	-	25	Wild-Allen *et al.* (2005)
Atmospheric	18	-	-	-	Butler *et al.* (2000)
Marine	7654	-	-	1272	Butler *et al.* (2000)
Sediments	96	91	12	32	Volkman *et al.* (2009)

TDN = total dissolved nitrogen, NO_3 = nitrate, NH_4 = ammonium, TDP = total dissolved phosphorus

13.2 Nutrient budgets and biogeochemical modelling

The Huon Estuary is considered unusual among Australian estuaries in a number of respects. Physically, it is strongly stratified, with a two-layer circulation driven by relatively high freshwater discharge. Nitrate+nitrite (NO_x) and phosphate concentrations in deep water at the mouth of the estuary (in the D'Entrecasteaux Channel) are also high year-round. This, combined with the two-layer circulation, results in a large influx of NO_x and phosphate into the estuary in bottom waters in winter and summer (Butler *et al.* 2000). The key

environmental issues in the Huon Estuary are associated with the effects and fate of nutrient and organic matter loads from the catchment, from the marine boundary, and from activities in the estuary, especially fish farming. Previous experience in other coastal systems has shown that in order to understand and address these issues, the estuary needs to be assessed as an integrated system in which both physical and biogeochemical influences on nutrients are investigated (Butler *et al.* 2000).
The HES used both an inverse hydrodynamic model and a biogeochemical process model to analyse nutrient cycles in the Huon Estuary. The inverse modelling combined the estimates of physical exchanges in the estuary with nutrient distributions observed on spatial surveys, while the biogeochemical modelling estimated horizontal fluxes and local sources and sinks of nutrients. The combined approach was based on a simple model of nutrient cycling and phytoplankton biomass in estuaries, which represents the cycling of nitrogen through dissolved inorganic, phytoplankton and detrital pools (Butler *et al.* 2000). This model was used to develop nutrient budgets for the Huon Estuary to provide an overall picture of nutrient sources, sinks and transformations.

Based on model simulations for 1996-1998, net fluxes at the marine boundary indicated that the Huon Estuary was a substantial sink for nitrogen (1240-1270 tonnes) and phosphorus (133-270 tonnes), suggesting burial in sediments or loss as gas to the atmosphere through denitrification. Modelling suggested that about two-thirds of this internal sink was supplied by marine nitrate, with the remainder split primarily between agricultural and fish farm contributions. In winter, the natural influx of nitrogen passed through the estuary unutilised, while in spring, summer and autumn, phytoplankton converted DIN into organic matter, at times reaching bloom proportions. The upper Huon catchment was a very small source of DIN, but delivered a large load of dissolved organic nitrogen. Fish farm inputs were only estimated for the calendar year 1997; however, the model indicated a significant increase in estimated farm loads (by ~30%) over the two years of the study. The observed composition of DIN in bottom waters during summer and autumn was a concern, and suggested local regeneration from water or sediments and increased sensitivity of the estuary to anthropogenic nutrient loads (Butler *et al.* 2000).

The WoEASF developed a more complex biogeochemical model simulating the cycling of carbon, nitrogen and phosphorus through dissolved and particulate organic and inorganic forms in the water column and surface sediments (Volkman *et al.* 2009). The model was expanded to include both the Huon Estuary and D’Entrecasteaux Channel, and was dynamically coupled to a high resolution three-dimensional hydrodynamic model and a multilayer sediment model. The coupled model simulated the seasonal cycling of organic and inorganic carbon, nitrogen, phosphorus and oxygen through multiple phytoplankton, zooplankton, nutrient and detrital pools and was validated against field observations collected in 2002. A regional nitrogen budget was developed using the model, with the major conclusion being that the combined Huon and D’Entrecasteaux Channel waterway was a substantial net exporter of nutrients, with estimates for 2002 indicating export of 758 tonnes of nitrogen into adjacent waters (Figure 80).

Most of the nitrogen in 2002 was contributed from the surrounding marine waters (60%; mostly delivered in winter), with reduced and similar contributions from the Huon River (23%) and fish farms (17%). However, the chemical form of nitrogen varied amongst sources, with almost all of the fish farm-derived nitrogen being labile (i.e. readily broken down, biologically available) and most of the river-derived nitrogen being refractory (i.e. resistant to being broken down, biologically unavailable) (Figure 81). The study area was divided into sub-regions for the purpose of assessing the fate of nutrients imported into the system. Small amounts of nutrients imported were retained within the region (up to ~5%) or lost as gas to the atmosphere through denitrification (8-15%), however the vast majority of nutrients were flushed from the system at marine boundaries (78-91%) (Figure 82).

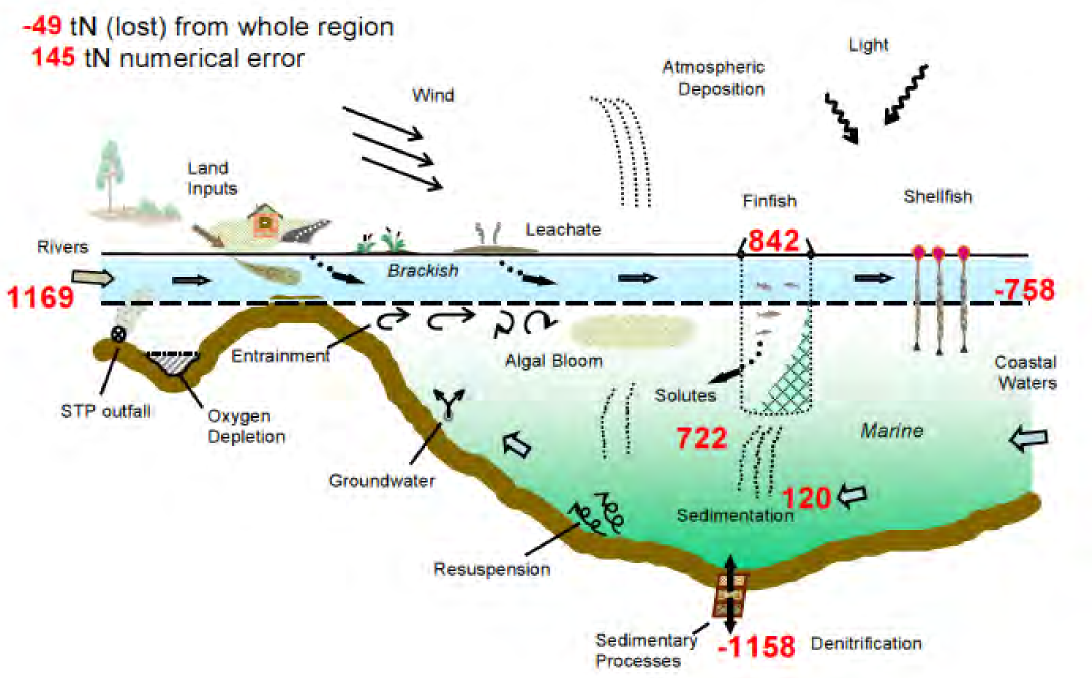


Figure 80 Modelled nitrogen budget for the Huon Estuary and D'Entrecasteaux Channel (Source: Volkman *et al.* 2009).

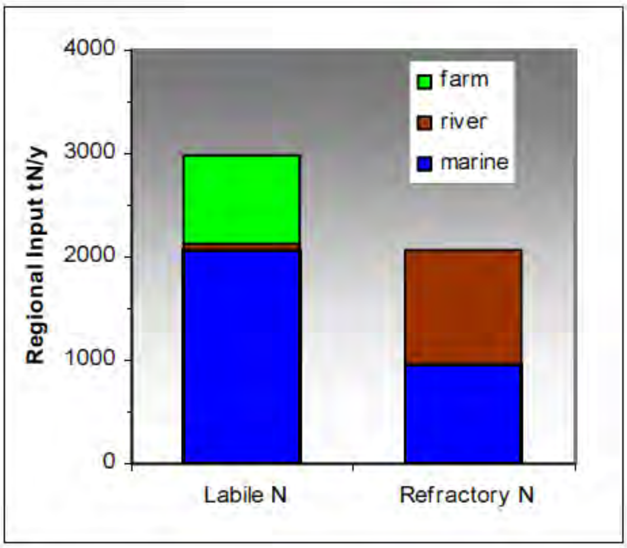


Figure 81 Contributions of labile (biologically available) and refractory (biologically unavailable) nitrogen (Source: Volkman *et al.* 2009).

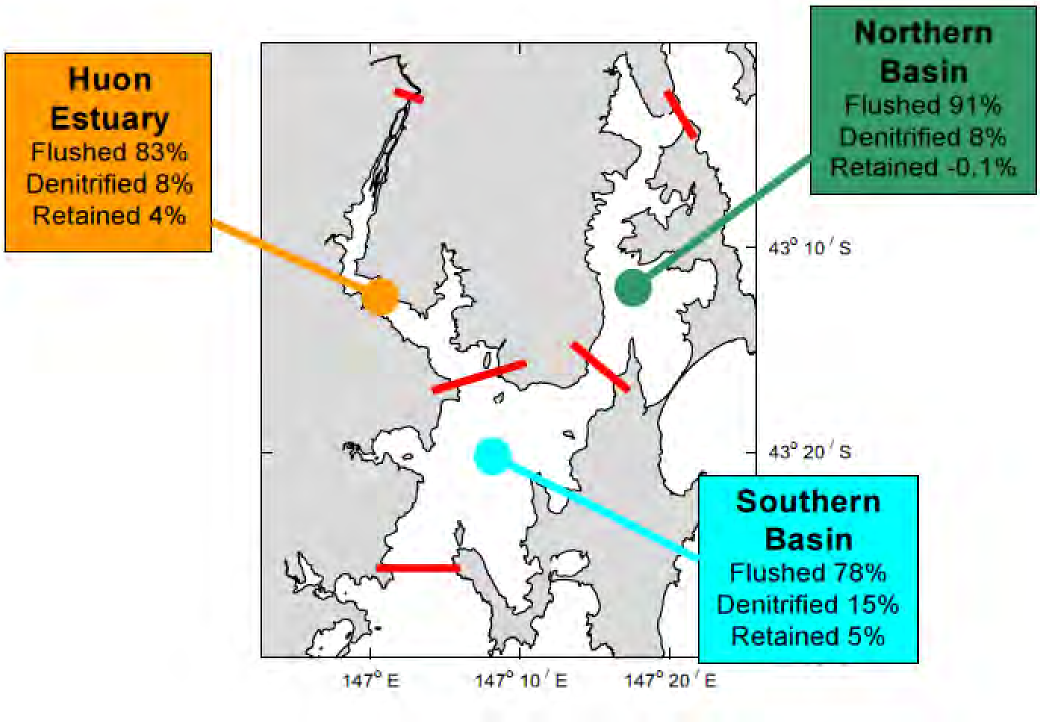


Figure 82 Estimates of proportions of nitrogen flushed, denitrified (lost to the atmosphere) and retained (Source: Volkman *et al.* 2009).

The data included in the model demonstrated that the biogeochemical dynamics of the region were highly variable both spatially and temporally due to a complex interaction of coastal morphology, hydrodynamics, local weather, opaque river water and a range of nutrient sources. The model was considered to provide an adequate simulation and explanation of the seasonal dynamics of nutrient cycling and phytoplankton abundance in the D'Entrecasteaux Channel, but poorer agreement for the Huon Estuary due potentially to unresolved aspects of dinoflagellate dynamics (Volkman *et al.* 2009). There is the potential for model accuracy to be increased through additional calibration and improved information on nutrient inputs.

13.3 Effects of changes in fish farm inputs

A major objective of both the HES and WoEASF were to improve understanding and prediction of the capacity of the waterways to sustainably support fish farming activities. Both studies used their respective models to run a series of simulations investigating the consequences of expansions to the salmonid farming industry. The assimilation capacity of the Huon Estuary and D'Entrecasteaux Channel will essentially determine their carrying capacity for finfish farms, and is clearly a key issue for both farmers and regulators in managing the industry (Butler *et al.* 2000). There is also recognition that where many fish farm lease sites are established in an estuary or embayment, their potential impact must be assessed in terms of the combined nutrient loads on the system as a whole.

The HES performed model simulations with farm loads set at 0, 2, 4 and 10 times the loads documented for 1997. These multipliers were chosen arbitrarily to explore the model estuary's response, and were not based on scenarios provided by industry or managers (Butler *et al.* 2000). The predicted effects of changes in farm loads depended on season, and according to the model, doubling 1997 finfish farm loads carried some risk of increased frequency or density of summer blooms. Quadrupling loads would put the system on the brink of nitrogen saturation, with a predicted trebling of DIN, doubling of chlorophyll, and a substantially increased risk of prolonged algal blooms. Increasing loads by a factor of 10 would completely change the nature of the system, producing elevated DIN and large blooms throughout summer months (Butler *et al.* 2000).

The WoEASF subsequently applied several model scenarios based on levels of fish farming, including no fish farm inputs, fish farm inputs as documented for 2002, and projected inputs for 2009 based on proposed maximum anticipated expansion of the industry (Volkman *et al.* 2009; see Section 9.2.2). Figure 83 illustrates predicted monthly fish farm inputs for 2009 relative to 2002 fish farm and riverine inputs. While fish farm inputs were smaller than those from rivers for most of the year during 2002, projected maximum 2009 fish farm inputs exceeded the 2002 riverine sources during nearly all months.

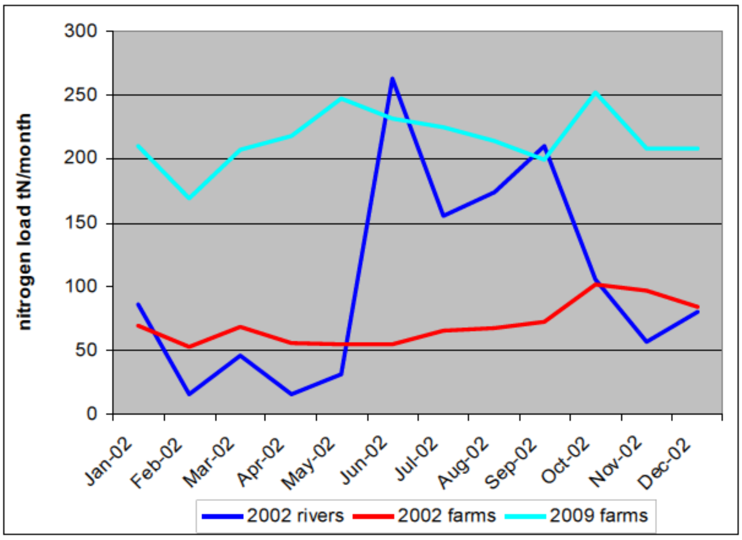


Figure 83 Nitrogen inputs: fish farm and riverine inputs in 2002, and maximum projected fish farm inputs in 2009 (Source: Volkman *et al.* 2009).

The 2009 'worst case' scenario simulation resulted in larger, more prolonged and wider spatial impacts of farm loads represented as increased concentrations of nutrients and chlorophyll and reduced bottom water oxygen saturation compared with 2002. Associated with these changes was a predicted shift from oligotrophic (i.e. low in nutrients) to mesotrophic (i.e. moderate nutrients) conditions in many areas. In 2002, 21.9% of the region could be classified as mesotrophic, while in the 2009 scenario, the area of mesotrophic classification had increased to 54% of the total region (Figure 84). There was no evidence of eutrophic conditions in any model simulation. In general, projected farm discharges had greatest impact on the nutrient and phytoplankton fields in summer and autumn when riverine and marine inputs of nutrients to surface waters were comparatively small (Volkman *et al.* 2009).

	oligotrophic	mesotrophic	eutrophic
No Farms	90.2	9.8	0.0
2002	78.1	21.9	0.0
2009	46.0	54.0	0.0

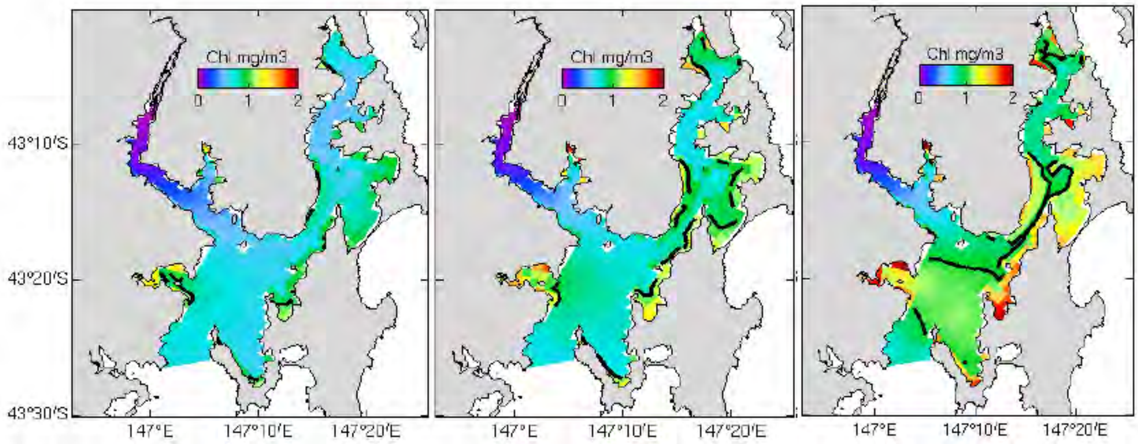


Figure 84 Percentage trophic status by area under three fish farm input model scenarios, and corresponding mapped chlorophyll concentrations: no farms, 2002 and maximum projected 2009 inputs (left to right) (Source: Volkman *et al.* 2009).

The above projections are subject to uncertainty arising from limitations in the models and underlying knowledge, and hence modelled impacts should not be interpreted as representing 'actual' impacts. Based on feed input and water quality data, the evaluation and assessment of the Broadscale Environmental Monitoring Program (BEMP) described in Section 10.4 will assess the response of the system to changing nutrient inputs from fish farms and other sources.

13.4 Changes from 1996–1998 to 2002–2003

The HES produced a nitrogen budget for the Huon Estuary only, while the budget produced by the WoEASF also incorporated the D'Entrecasteaux Channel, thus complicating direct comparisons between the two studies. Furthermore, 2002-2003 experienced approximately 50% greater river flows than the 1996-1998 HES period, while nutrient concentration data in 2002-2003 were sparse but also suggested rises from previous years (Volkman *et al.* 2009).

Within the above limitations, some general comparisons can be made. The estimated total annual nitrogen input from freshwater rose to ~1,169 tonnes in 2002-2003, from ~600 tonnes in 1996-1998. Other annual nutrient inputs also increased due to increased population in the expanded region (by ~100 tonnes nitrogen) and increased salmon production (by ~82 tonnes nitrogen). On an annual basis, the HES reported the Huon Estuary to be a substantial sink for nitrogen (about 1250 tonnes) during 1996-1998. In contrast, due to the dynamics of the Channel, the WoEASF reported the combined Huon Estuary and D'Entrecasteaux Channel region to be net exporter of nitrogen (758 tonnes) during 2002-2003 (see Figure 80) (Volkman *et al.* 2009).

14 SEAFOOD SAFETY

14.1 Toxicants of concern

A number of chemicals are known to accumulate in shellfish and finfish that are harmful to humans. Bivalve molluscs such as oysters and mussels are filter feeders that accumulate contaminants directly from the water column or via ingestion of contaminants adsorbed to phytoplankton, detritus and sediment particles. Bivalves are efficient bioaccumulators of heavy metals and organic contaminants such as pesticides, and may reflect local contaminant concentrations more accurately than more mobile crustacean or finfish species (USEPA 2000). Bivalves are also very effective at accumulating poisons from toxic microalgal species which may periodically form blooms in the water column. Ingestion of affected shellfish by humans, and other organisms, can in turn cause Paralytic Shellfish Poisoning (PSP) or other types of shellfish poisonings, which may result in severe health issues or even death.

Bottom-dwelling fish such as flathead may accumulate high concentrations of contaminants from direct physical contact with contaminated bottom sediments or through ingestion of contaminated prey species (Whitehead *et al.* 2010). Pelagic fish species (occurring in the water column) are less at risk of contamination via sediments, but may still accumulate chemicals contained within their prey, with concentrations increasing at each successive level of the food chain. This issue does not apply directly to farmed fish such as Atlantic salmon which are fed on food pellets administered to each fish cage, and hence are not exposed to contamination via prey ingestion.

The primary toxicants of concern in the D'Entrecasteaux Channel and lower Huon Estuary are PSP toxins derived from blooms of toxic microalgae, and in particular, the dinoflagellate *Gymnodinium catenatum*. The risk of PSP toxins in shellfish is a primary focus for monitoring activities, while additional monitoring is conducted for faecal pathogens (*Escherichia coli*), heavy metals and pesticides in shellfish. Unlike the nearby Derwent Estuary, which has incurred significant heavy metal contamination, heavy metals are considered a minor risk to seafood in the D'Entrecasteaux Channel and lower Huon Estuary. Available data on heavy metal concentrations in marine organisms are nevertheless presented here and have been collected primarily to monitor 'background' levels for comparison with Derwent Estuary sites.

14.2 Seafood safety guidelines

Food safety guidelines, including those prescribed for seafood, are provided by Food Standards Australia New Zealand (FSANZ), within the Joint Australia New Zealand Food Standards Code. The code uses a combination of maximum permitted levels (MLs) and generally expected levels (GELs). MLs have been set only for those foods that provide significant contributions to total dietary exposure for a given contaminant, and are based on human health risk calculations. In contrast, GELs were developed for those contaminant/commodity combinations with a low level of risk to the consumer and where adequate data were available; these provide a benchmark against which to measure contaminant levels in food. It should be noted that some GELs did not incorporate Tasmanian data and may not be entirely appropriate to this region (Whitehead *et al*. 2010). Current guidelines for human consumption of seafood include MLs for shellfish poisons derived from toxic microalgae and *E. coli* (an indicator species for faecal pathogens) in bivalve molluscs (Table 38), and a mixture of MLs and GELs for heavy metals in various seafood types (FSANZ 2011) (Table 39).

Table 38 National food guidelines for shellfish poisons and *E. coli* in bivalve molluscs (Source: FSANZ 2011).

Maximum Permitted Levels				
Amnesic shellfish poisons (ASP) (mg/kg)	Diarrhetic shellfish poisons (DSP) (mg/kg)	Paralytic shellfish poisons (PSP) (mg/kg)	Neurotoxic shellfish poisons (NSP) (MU/kg)	*E. coli* * (No./g)
20	0.2	0.8	200	7

MU = Mouse Units relating to a standard mouse bioassay method; * the *E. coli* maximum permitted level applies to bivalve molluscs except scallops.

Table 39 National food guidelines for heavy metal levels in seafood (Source: FSANZ 2011).

Seafood Category	Maximum Permitted Levels (mg/kg)				Generally Expected Levels (median/90 percentile) (mg/kg)	
	As #	Cd	Hg	Pb	Cu	Zn*
Fish	2	no set limit	mean level of 0.5 for most fish mean level of 1 for large/predatory fish	0.5	0.5/2	5/15
Molluscs	1	2	0.5 (mean)	2	5/30	130/290
Crustaceans	2	no set limit	0.5 (mean)	?	10/20	25/40

relates to inorganic arsenic only; * GELs for zinc in shellfish relate to oysters only.

It should be noted that shellfish monitoring in the region is primarily based on water quality indicators, with monitoring of shellfish flesh only performed if water quality trigger levels are reached. Trigger levels leading to testing of shellfish flesh and closure of shellfish growing areas are indicated in Sections 14.3.1 and 14.3.2 below.

14.3 Shellfish sanitary surveys

The Tasmanian Shellfish Quality Assurance Program (TSQAP) conducted by the Department of Health and Human Services (DHHS) has been in place since the mid-1980s and is aimed at reducing food safety risks associated with shellfish consumption. In carrying out its role, the TSQAP implements the objectives and strategies of the Australian Shellfish Quality Assurance Program. The basis of this program is to ensure that shellfish are only harvested from waters that are shown to be free of harmful contaminants.

Following the introduction of the toxic dinoflagellate *Gymnodinium catenatum* around 1980, a biotoxin monitoring program was set up to routinely test for levels of biotoxins in shellfish in bloom affected and other farms around Tasmania. A Biotoxin Management Plan was also developed to protect shellfish consumers from the effects of biotoxin poisoning, and also to provide an early warning of impending shellfish farm closures to marine farmers (TSQAP 2012). As part of this plan, each growing area has undergone a risk assessment based on historical data of algae identified in water and cysts identified in sediments, with particular attention paid to the history of the toxic dinoflagellate *G. catenatum*. Farming areas are each categorised as high, medium or low risk of harmful algal blooms (HABs). The frequency of sampling varies according to risk status and the biotoxin history of each growing area, while uniform statewide criteria have been developed for farm closure on the basis of biotoxin risk (TSQAP 2012).

The shellfish growing areas in the D'Entrecasteaux Channel and lower Huon Estuary study area that are monitored as part of the TSQAP sanitary surveys are illustrated in Figure 85, while monitoring performed in relation to biotoxin risk is indicated in Table 40. Risks of contamination with poisons derived from toxic microalgae have been monitored primarily on the basis of water quality sampling of HAB species. Additional surveys of salinity and thermotolerant coliforms are also conducted to monitor risks associated with pathogens. Analyses of shellfish meat include heavy metals and pesticides approximately every three years, as well as bacteria (*E.coli*) and biotoxins when certain water quality 'trigger' (or 'alert') levels are reached. Environmental farm closure 'criteria' have been developed specific to each growing area and relate to a range of indicators, including rainfall, salinity, river flow and densities of *G. catenatum* cells in the water and shellfish flesh.

Figure 85 Locations of shellfish growing areas monitored in sanitary surveys (Data source: TSQAP).

Table 40 Sanitary survey biotoxin monitoring in shellfish growing areas (Source: TSQAP 2012).

Growing area	Year monitoring initiated	Biotoxin risk	Microalgal sampling frequency*
Deep Bay	1988	high	monthly in winter/fortnightly in summer
Great Bay	1988	medium	monthly sampling
Port Esperance	1983	high	monthly in winter/fortnightly in summer but weekly from mid-February to mid-May
Fleurtys Point	1985	medium	monthly sampling
Gardners Bay	1991	high	monthly in winter/fortnightly in summer
Little Taylors Bay	1988	medium	monthly sampling

* Baseline frequency only; monitoring frequency increases if toxic cells are found at any site.

14.3.1 Toxic algal blooms

Toxic algae – and particularly dinoflagellates such as *Gymnodinium catenatum* – can pose a significant risk to human health as they contain potent neurotoxins. During blooms these microscopic algae occur in high concentrations throughout the water column, while a resting stage (cysts) may occur in sediments all year (Whitehead *et al.* 2010). Different microalgal species produce a range of toxins, such as paralytic shellfish poisons, amnesic shellfish poisons and diarrhetic shellfish poisons. Numerous animals feed on microalgae, including filter-feeding bivalves and zooplankton, with the potential for neurotoxins from toxic algae to accumulate and be passed along the food chain.

Blooms of the toxic dinoflagellate *G. catenatum* have resulted in regular and sometimes prolonged closures of shellfish farms in growing areas of the D'Entrecasteaux Channel and Huon Estuary. Major blooms of *G. catenatum* occurred in 1986 and 1993, and were associated with several cases of human poisoning resulting in mild and temporary symptoms being experienced. Subsequent monitoring has shown that the Huon Estuary remains the area most affected by toxic *G. catenatum* blooms in Tasmania, and shellfish are no longer farmed on the Huon River other than at Port Cygnet where harvesting over the high risk summer/autumn period is avoided. The other area of major concern is Port Esperance, where two shellfish farms continue to grow mussels and oysters (TSQAP 2012).

Water quality monitoring performed by TSQAP is used to detect and implement management action for HAB species on the basis of 'alert levels' for individual species. The phytoplankton alert levels are included in the TSQAP Biotoxin Management Plan and are reviewed each year, with 2012 alert levels presented in Table 41. These levels are based on shellfish quality assurance regulatory issues and human health issues. Shellfish meat is tested when certain alert levels are reached rather than being monitored routinely at a set temporal frequency.

Table 41 Phytoplankton alert levels* (Source: TSQAP 2012).

Microalgal species	Type of toxin	Alert Level for TSQAP to be contacted (cells/L)	Alert Level to initiate flesh testing (cells/L)	Alert Level to initiate closure pending flesh testing results (cells/L)
Alexandrium catenella	PSP	100	200	500
Alexandrium minutum	PSP	100	200	500
Alexandrium tamarense	PSP	100	200	500
Alexandrium ostenfeldii	PSP	100	200	500
Gymnodinium catenatum	PSP	200	1000 (mussels) 2000 (other)	5000
Dinophysis acuminata	DSP	200	1000	
Dinophysis acuta	DSP	200	1000	
Dinophysis caudata	DSP	500	1000	
Dinophysis fortii	DSP	200	1000	
Prorocentrum lima	DSP	500	500	
Pseudo-nitzschia seriata group (*P. multiseries* & *P. australis*)	ASP	50,000	50,000	500 000

* Refer to TSQAP (2012) for further guidelines on application of these alert levels.

Data on *G. catenatum* counts in water samples for the period 2001-2011 are presented in Figure 86 for shellfish growing areas of the D'Entrecasteaux Channel and lower Huon Estuary (TSQAP, unpub. data). Available data included more than 600 cell counts from a mixture of fixed depth (usually 0.2-0.3 m) and integrated (0-10 m) samples, with samples below the detection level of 100 cells per L excluded from analysis. The resulting data show considerable variation between sites and years with a notable reduction in *G. catenatum* cell density during 2006 and 2007.

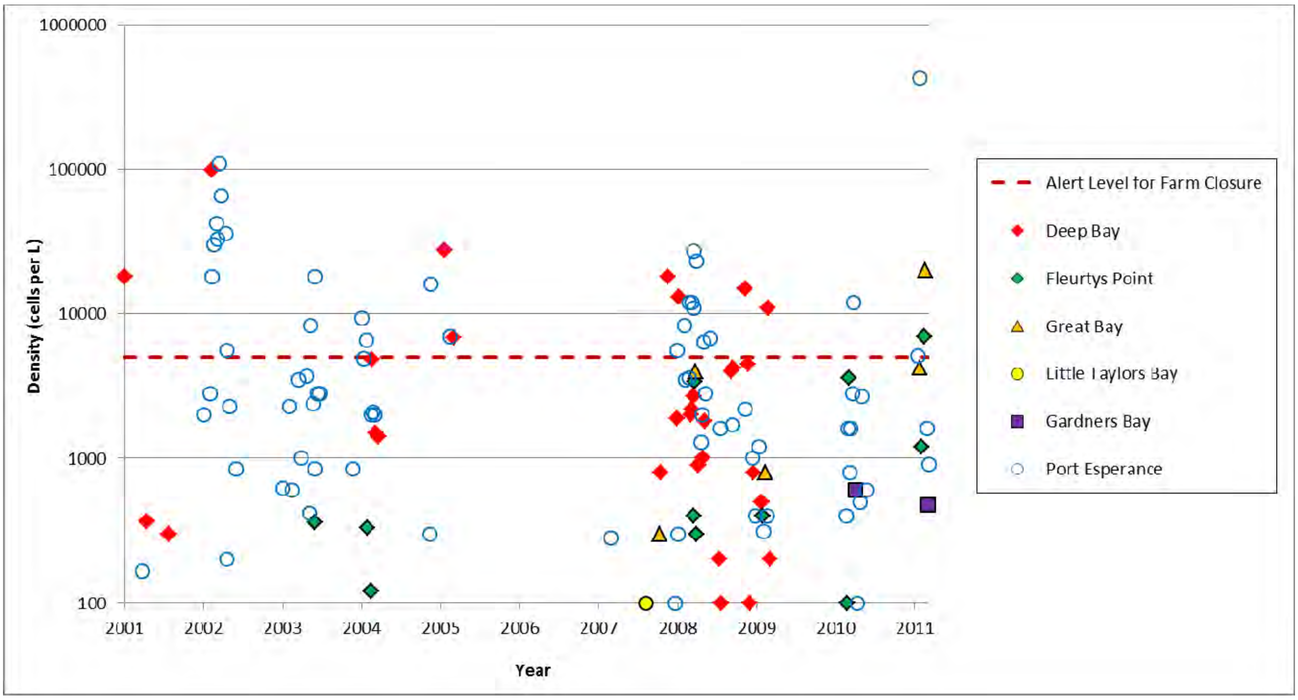


Figure 86 *Gymnodinium catenatum* density in shellfish growing areas (Data source: TSQAP).

The mean cell count for *G. catenatum* across all samples was 2110 cells per L, while mean values in growing areas during 2001-2011 varied as illustrated in Figure 87. It should be noted that sampling ceases when cell counts are very high, introducing potential bias to the data set (A. Turnbull, TSQAP, pers. comm.). Within these limitations, the data reveal the highest mean count of *G. catenatum* cells at Port Esperance, followed by Deep Bay, whilst counts were considerably lower in other growing areas. The alert level to initiate farm closure (5000 cell/L) was frequently reached at Port Esperance and Deep Bay, and it was also reached on individual occasions at Great Bay and Fleurtys Point during 2011.

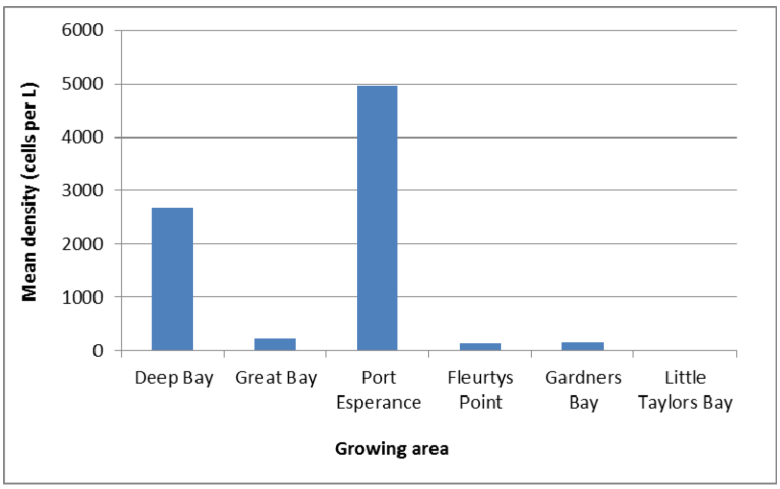


Figure 87 Mean cell counts of *Gymnodinium catenatum* during 2001-2011 (Data source: TSQAP).

Farm closure data also provide a useful indicator of temporal trends in biotoxin risk, with annual days of closure due to HABs illustrated in Figure 88. Note that as a result of high biotoxin risks, the growing area in Deep Bay is only sporadically farmed and its default operational status is 'closed'.

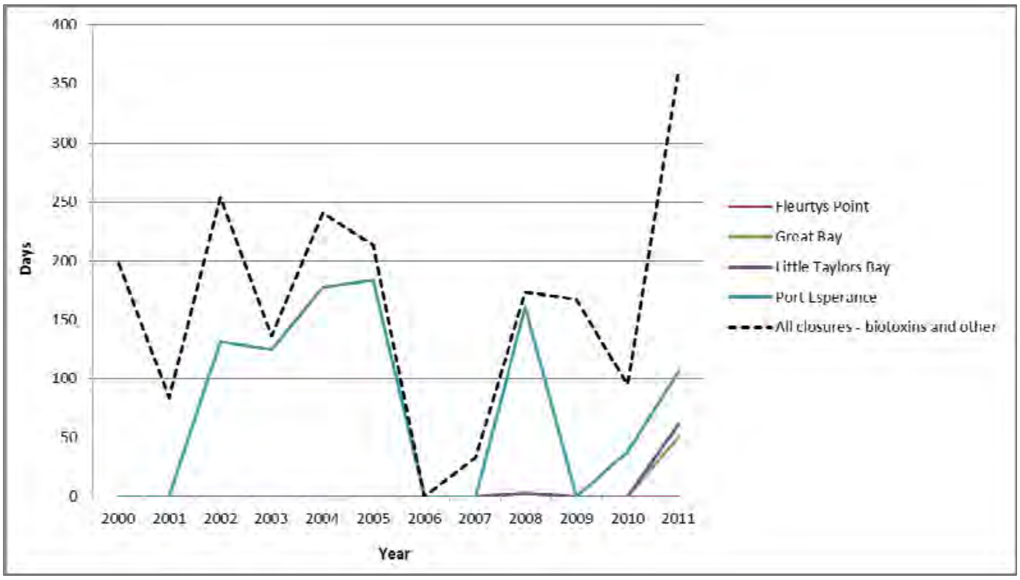


Figure 88 Number of days that biotoxins resulted in the closure of shellfish growing areas (Data source: TSQAP).

Gardners Bay is also restricted, but for microbial reasons; it harvests year round but must relay stock to another area for purging (A. Turnbull TSQAP, pers. comm.). Monitoring of these areas has therefore also become sporadic, and hence they have been excluded from the analysis of instigated farm closures. Total days of biotoxin-related closure for the remaining four growing areas during 2000-2011, based on adding days of closure for each area, ranged from none to 219 days (in 2011) at a mean of 87 days. The majority of closures were at Port Esperance, with the only other significant closures recorded at Great Bay and Little Taylors Bay during 2011 (Figure 88). Biotoxins were the primary contributor to farm closures during 2003-2005, 2008 and 2011, and also accounted for ~50% of closure days in 2002. Across all years, the total number of days of biotoxin-related closure for the four growing areas was 1046 days.

The marine farming industry collaborates with TSQAP in monitoring biotoxin risk. Shellfish farmers perform collection of water quality samples for TSQAP microalgal analyses, while the finfish farming companies operating in the region, Tassal and the Huon Aquaculture Company, also perform weekly sampling of densities of HAB species in the water column. Data sharing is performed on an as-needs basis and particularly where densities reach the alert levels indicated in Table 41.

14.3.2 Faecal bacteria

The risk of contamination of shellfish via faecal bacteria is also monitored on the basis of water quality sampling and indicators of catchment runoff such as rainfall and riverine flows. Events of elevated bacterial counts and high catchment inputs have triggered closures of shellfish growing areas in the D'Entrecasteaux Channel and lower Huon Estuary during the 2000-2011 period. In the case of faecal bacteria, farm closure is triggered most frequently by indicators relating to rainfall and river flows, while a median value of 14 thermotolerant coliforms/100ml in water samples is an additional trigger. Sampling of bacteria (*E.coli*) in shellfish flesh is also conducted during periods of degraded water quality.

Data on closures due to faecal bacteria and associated catchment indicators is summarised in Figure 89. Total days closure across the four growing areas varied from none to 198 (in 2000) at a mean of 141 days. The largest total number of days closure during 2000-2011 was at Fleurtys Point, followed by Port Esperance, while Great Bay and Little Taylors Bay had few closures. Concerns about faecal bacteria were the primary contributor to farm closures during 2001-2002, 2007, and 2009-2010, and also accounted for ~50% of closure days in 2002. Across all years, the total number of days of closure recorded across the four growing areas was 914 days, slightly less than for biotoxins (Section 14.3.1).

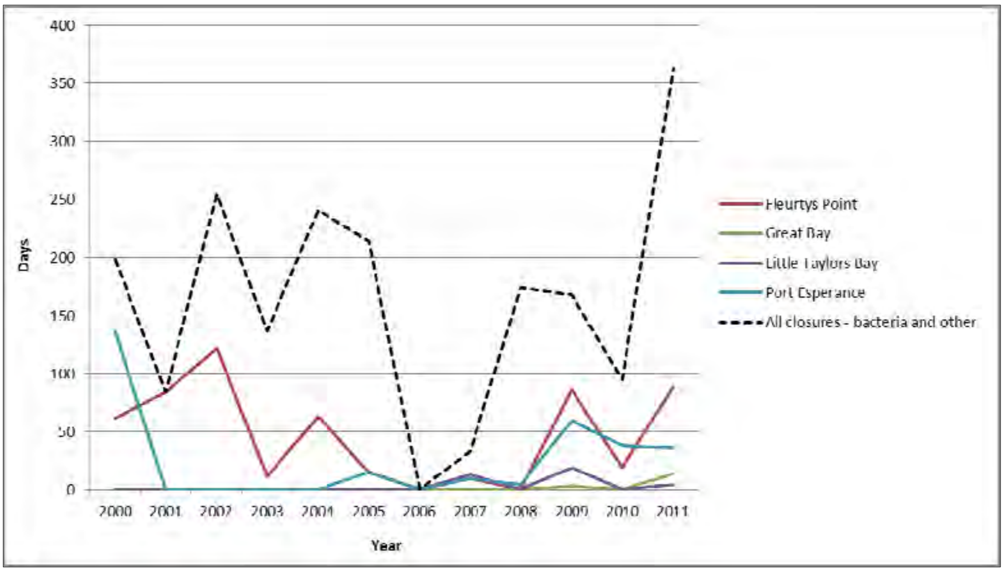


Figure 89 Number of days that pathogen indicators resulted in the closure of shellfish growing areas (Data source: TSQAP).

When biotoxins and faecal bacteria/associated indicators were both taken into consideration, the total number of days farm closure ranged from none (2006) to 362 (2011) at a mean of 163 days, with 1960 days of closure recorded in total across the four growing areas during 2000-2011. The worst affected was Port Esperance with 1223 days closure at an annual mean of 102 days, while Fleurtys Point had 565 days closure at a mean of 47 days. Little Taylors Bay and Great Bay were the least affected, with 101 and 71 total days of closure, and annual means of 8 and 6 days closure, respectively.

Faecal bacteria data for TSQAP water samples during 2000-2011 are summarised in Figure 90, including the number of times the trigger value (median of 14 thermotolerant coliforms/100ml) was exceeded, and the mean thermotolerant coliform count during these exceedances, in each growing area. By frequency, elevated bacterial counts were highest at the Deep Bay and Gardners Bay sites near Cygnet, while Great Bay was least affected by bacterial contamination. The highest level of contamination, as measured by mean thermotolerant counts during exceedances of the trigger value, was recorded at Gardners Bay. While this growing area was more susceptible to bacterial contamination than most other growing areas, it was noted in 2002 that water quality in Gardners Bay had improved since a sewage upgrade in Cygnet and fencing of the foreshore (TSQAP 2008). Port Esperance also recorded relatively high levels of contamination, although less frequently.

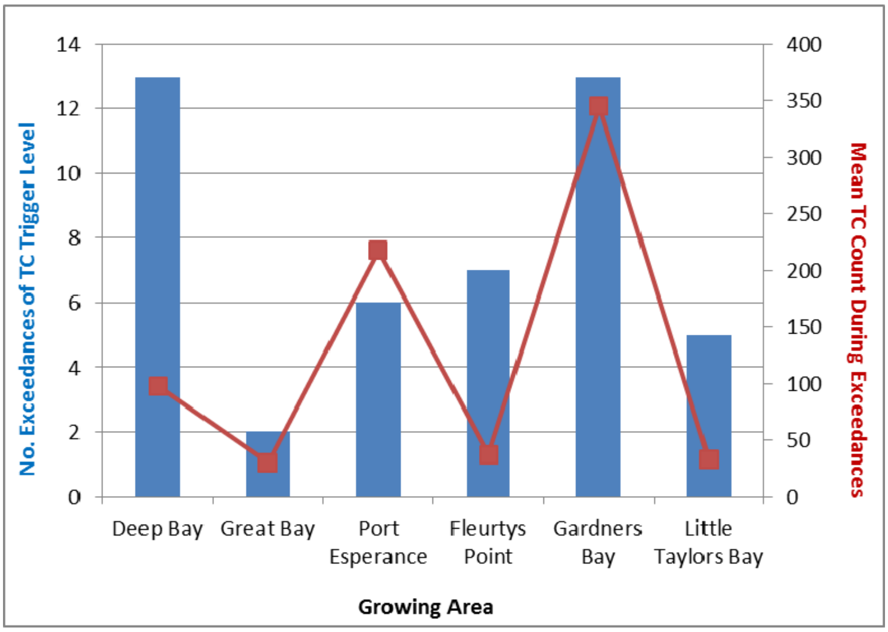


Figure 90 Exceedances of the thermotolerant coliform (TC) trigger level for shellfish growing areas during 2000-2011 (Data source: TSQAP).

14.3.3 Heavy metals and pesticides

Heavy metals and pesticides were also monitored in shellfish growing areas by TSQAP, although monitoring was conducted less frequently and was based entirely on samples of shellfish flesh. The two shellfish types tested, oysters (Pacific oyster *Crassostrea gigas*) and mussels (blue mussel *Mytilus galloprovincialis planulatus*), generally exhibit different responses to heavy metal uptake. Oysters accumulate zinc to a higher degree than mussels, while mussels tend to preferentially accumulate lead (Whitehead *et al*. 2010).

A summary of the TSQAP results is provided in Table 42 for metals that have been allocated MLs or GELs by FSANZ (2011), with concentration ranges given for comparison to MLs (arsenic, cadmium, mercury, lead), and median and 90th percentile values provided for comparison with GELs (copper, zinc). Note that the ML for arsenic (As) relates to the inorganic component only, while the TSQAP measurements relate to total arsenic and are subsequently divided by ten to estimate the inorganic fraction. With that in mind, the MLs for As, cadmium (Cd), mercury (Hg) and lead (Pb) were not exceeded in any growing areas, while the median GEL for copper (Cu) was exceeded in all growing areas where oysters were tested and the 90th percentile GEL was only exceeded for oysters at Port Esperance on one occasion. The latter was attributed to practices within the bay which have now been revised (A. Turnbull, TSQAP, pers. comm.). The median GEL for zinc (Zn) was exceeded in all oyster samples except those from Port Esperance, while the 90th percentile GEL was not exceeded in any of the growing areas.

National guidelines have not been set for permissible levels of pesticides in shellfish; however, the current default is that any detection is not acceptable. To date, no pesticides have been detected in the shellfish of the D’Entrecasteaux Channel and lower Huon Estuary sampled through the sanitary surveys of TSQAP (A. Turnbull, TSQAP, pers. comm).

Table 42 Heavy metals data for Pacific oysters and mussels (Data source: TSQAP).

Growing area	Years monitored	Species	As (total)	Cd	Hg	Pb
Deep Bay	2005, 2008	Mussels	1.5	<0.1 to 0.1	<0.02 to 0.019	<0.1 to 0.1
Fleurtys Point	2002, 2008	Oysters	1.8	nd to <0.5	nd to <0.02	nd to <0.5
Gardners Bay	2002, 2005, 2008	Oysters	1.1 to 2.1	nd to 0.1	nd to 0.019	nd to 0.09
Great Bay	2001, 2004, 2005, 2008	Oysters	1.8 to 2.0	nd to <0.5	nd to 0.03	nd to <0.5
Little Taylors Bay	2002, 2008	Oysters	1.7	<0.5	nd to <0.02	nd to <0.5
Port Esperance	2005, 2008	Mussels	0.8 to 3.1	<0.1 to 0.1	<0.02 to 0.02	<0.1
	2003, 2006, 2008	Oysters	0.8 to 7.3	<0.1 to <0.5	<0.02 to 0.03	<0.1 to <0.5
		FSANZ MLs	***1 (inorganic)***	***2***	***0.5 (mean)***	***2***
Growing area	**Years monitored**	**Species**	**Cu median**	**Cu - 90th percentile**	**Zn median**	**Zn - 90th percentile**
Deep Bay	2005, 2008	Mussels	0.85	1.05	11.35	11.87
Fleurtys Point	2002, 2008	Oysters	14.05	17.61	150	194.8
Gardners Bay	2002, 2005, 2008	Oysters	22.3	23.58	166	212.6
Great Bay	2001, 2004, 2005, 2008	Oysters	16.5	25.7	220	264
Little Taylors Bay	2002, 2008	Oysters	13.2	14.16	145.5	165.1
Port Esperance	2005, 2008	Mussels	2	3.32	13	16.4
	2003, 2006, 2008	Oysters	28.3	51.6	90	179.6
		FSANZ GELs	***5***	***30***	***130***	***290***

nd = not detected

14.4 Additional heavy metals surveys and monitoring programs

In addition to the TSQAP sampling, monitoring of heavy metals in seafood has been conducted as part of the Nyrstar Hobart zinc smelter monitoring program for the Derwent Estuary. Several Bruny Island sites in the D'Entrecasteaux Channel have been included in this monitoring program to provide 'background' (or 'control') data for comparisons with the more heavily contaminated sites of the Derwent Estuary. The primary control site sampled is Mickeys Bay at the southern end of Bruny Island, while wild shellfish are also sampled at Aikens Point in Simpsons Bay, and Apollo Bay and the Barnes Bay Ferry Terminal at the northern end of the island. The program includes the following monitoring components, which are summarised in the sections below:

- Mercury levels in flathead - monitored since 1984.
- Heavy metal levels in wild oysters and mussels - monitored since 1992.
- Heavy metal levels in caged oysters - experiments conducted since 2004.

14.4.1 Mercury levels in flathead

The southern sand flathead *Platycephalus bassensis* is considered to be a good bio-indicator for mercury as it is a bottom-feeding species, lives year round in the D'Entrecasteaux Channel and is relatively territorial. Twenty flathead are caught at Mickeys Bay during spring each year and analysed for total mercury. A range of different fish sizes are targeted to allow for an assessment of size versus mercury concentration; however, analyses provided here are based on mercury levels in legal-sized fish (i.e. ≥300 mm in length) only. Note that median values are presented in line with current accepted methods that use median mercury levels to estimate the maximum number of serves that can be consumed per week (Whitehead *et al*. 2010). Median mercury concentrations during 2002-2010 fluctuated from year to year, with no distinct temporal trend (Figure 91). None of the median values (nor mean values) recorded exceeded the recommended FSANZ guideline of 0.5 mg/kg. This contrasts with results for the Derwent, where the guideline was exceeded in various parts of the estuary (Whitehead *et al*. 2010).

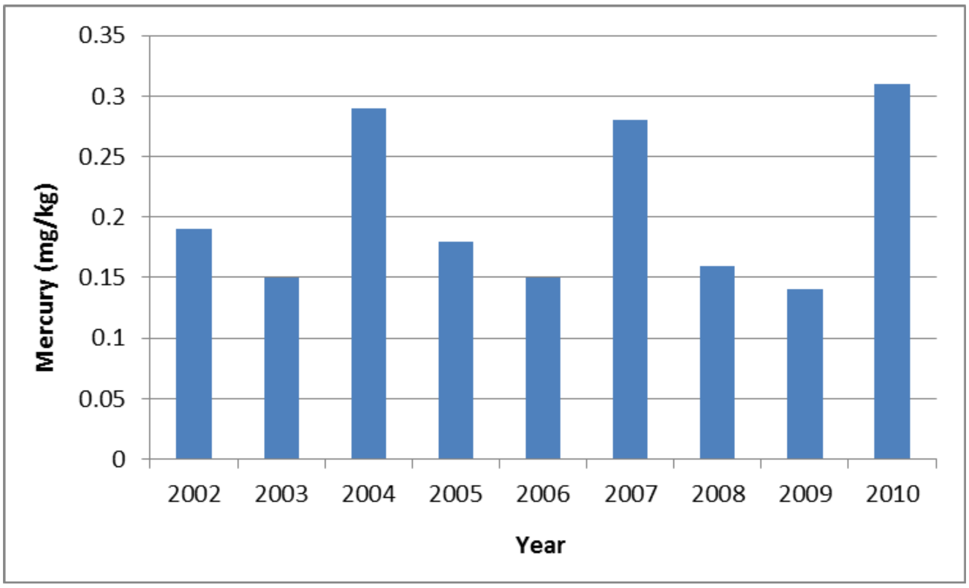


Figure 91 Median mercury levels in flathead of Mickeys Bay, Bruny Island (Data source: Nyrstar).

In 2008, Nyrstar Hobart commissioned a statistical review of their flathead data, with a focus on temporal changes in mercury levels in flathead between 1991 and 2007 (Macpherson 2008). Mean mercury concentrations at Mickeys Bay over this period ranged from 0.1 to 0.3 mg/kg, with no distinct temporal trend in values. There was strong evidence of a decrease in the average length in flathead across the whole Derwent/D'Entrecasteaux Channel study region, with this change particularly evident in the D'Entrecasteaux Channel. During the 1990s, the average size of flathead from the Channel was clearly larger than in the Derwent Estuary, however size declined and was comparable to some of the Derwent Estuary sites by 2007. This finding is likely to be related to fishing effects rather than heavy metals, but is nevertheless a useful long-term observation from this monitoring program.

14.4.2 Heavy metals in oysters and mussels

Nyrstar surveys of heavy metals in wild growing oysters and mussels were conducted annually from 1991 to 2002 and then three-yearly since 2002. Wild oysters included both the native flat oyster *Ostrea angasi* and the introduced Pacific oyster *Crassostrea gigas*, while the blue mussel *Mytilus galloprovincialis planulatus* has also been surveyed. As noted above, the oyster and mussel species can exhibit different responses to heavy metal uptake, and hence it is useful to monitor both. Median heavy metal levels have been calculated by combining data from surveys at four D'Entrecasteaux Channel sites during 2002-2011 and are presented in Table 43. None of the FSANZ MLs were exceeded in wild oysters or mussels; however, the median values for copper and zinc in oysters exceeded the FSANZ GELs. Note that in contrast to the Derwent Estuary, levels of lead in mussels were not higher than those in oysters, which may simply be a reflection of the low availability of lead in the water column. Elevated zinc levels in the D'Entrecasteaux Channel were also previously reported on the basis of same Nyrstar dataset by Whitehead *et al.* (2010), who suggested that this may reflect regional zinc contamination from the Derwent Estuary.

Table 43 Median metal levels in wild shellfish (Data source: Nyrstar).

Seafood Category	Maximum Permitted Levels (mg/kg)			Generally Expected Levels (median) (mg/kg)	
	Cd	Hg	Pb	Cu	Zn*
Molluscs	2	0.5 (mean)	2	5	130
	Median Values D'Entrecasteaux Channel 2002-2011				
Oysters	0.28	0.03	0.2	29	547
Mussels	0.2	0.02	0.2	1.1	26.8

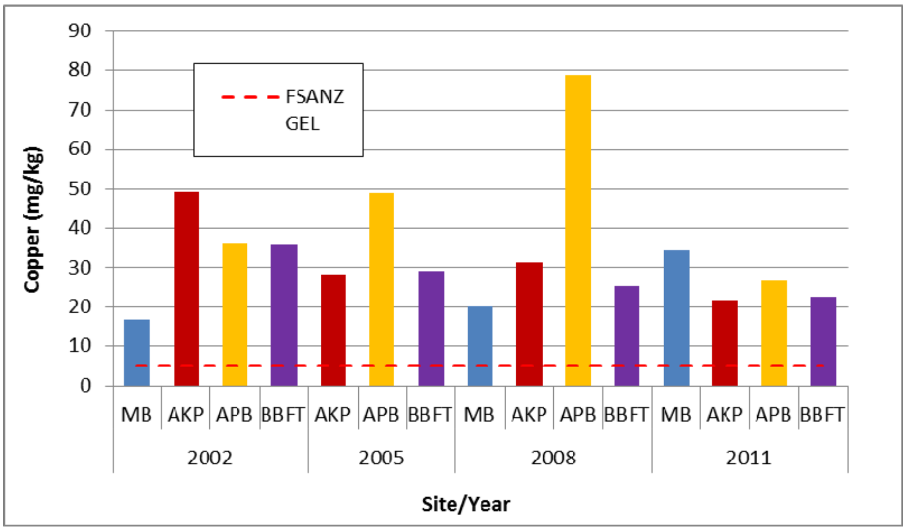
* GELs for zinc in shellfish relate to oysters only.

Copper and zinc values for individual sites and years are presented for wild oysters in Figure 92, and indicate that values exceeding the FSANZ median GEL were consistent across all sites and years. While no consistent temporal trend is evident, values of both copper and zinc in 2011 were on average lower than recorded during previous surveys. Apollo Bay and Aikens Point recorded higher mean values than either Mickeys Bay or the Barnes Bay Ferry Terminal.

The Nyrstar monitoring program has also conducted caged oyster experiments since 2003/2004, involving the deployment of uncontaminated, cultured Pacific oysters at various sites in the Derwent Estuary and also Mickeys Bay in the D'Entrecasteaux Channel. The aim has been to quantify metal uptake rates and investigate accumulation factors in oysters of known age, in order to eliminate the age-related variability encountered in the wild oyster surveys (Whitehead *et al*. 2010). Results from the oyster experiments during 2004-2005 to 2008-2009 indicate that within six weeks, oysters deployed at Mickeys Bay had accumulated levels of copper and zinc that exceeded the FSANZ median GELs. Accumulation of lead was negligible, while concentrations of cadmium and mercury also remained below the FSANZ ML guidelines (Whitehead *et al.* 2010).

14.4.3 Heavy metals in other species and food-web pathways

There have been limited studies of heavy metal concentrations of other marine flora and fauna species in the D'Entrecasteaux Channel and lower Huon Estuary. Swadling and Macleod (2008) sampled zooplankton, macroalgae and invertebrates from the Huon Estuary to provide a basis for comparisons with similar samples collected from the Derwent Estuary. The study also analysed specimens of sharks and skates collected from the southern end of Bruny Island to assess metal concentrations in top-predators. Benthic (sediment-dwelling) species in the Huon Estuary recorded lower heavy metal concentrations overall than species in the middle Derwent Estuary, but levels were more comparable to those of the lower Derwent Estuary. The picture was more complicated for higher trophic levels, with the sharks and skates from Bruny Island recording amongst the highest levels of some metals compared with lower trophic level species feeding in similar environments. The study concluded that the lower order trophic specimens did not provide a clear explanation of the metal loading in higher order species. Further analyses of diets of key species, coupled with detailed stable isotope analyses to assign trophic level, were recommended to develop a better understanding of metal biomagnification through the food web (Swadling and Macleod 2008).



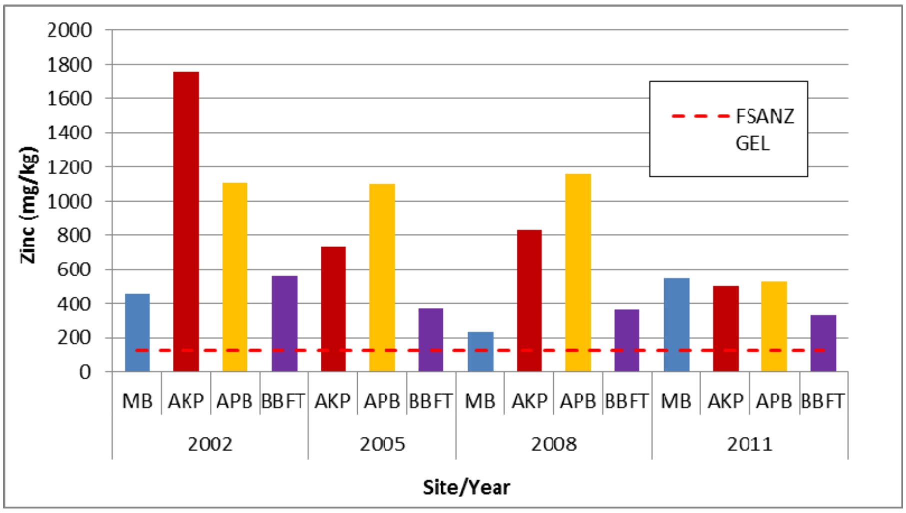


Figure 92 Copper (top) and zinc (bottom) concentrations in wild oysters at four D'Entrecasteaux Channel sites (Data source: Nyrstar).

14.5 Antibiotics

Antibiotics are used at salmon farm sites during outbreaks of disease (see Section 9.2.2), and are generally administered in the fish feed. Hence, there is the potential for wild fish to accumulate detectable levels of antibiotic residue following consumption of uneaten medicated feed pellets by pelagic species, such as slimy mackerel and dogfish shark, or benthic foraging species such as flathead. There is also the possibility of an escape of treated Atlantic salmon prior to the completion of its withholding period. Antibiotic residues have been detected in wild fish caught within fish farm lease areas and at some control sites, with rate of decline in concentration over time predicted to be similar to that in farmed species (DPIPWE 2011e). Food Standards Australia and New Zealand (FSANZ) was engaged by the Tasmanian DHHS in 2007 to undertake a risk assessment to determine whether levels of the primary antibiotic used, oxytetracycline (OTC), observed in wild fish and medicated Atlantic salmon could pose a risk to human health if consumed. FSANZ concluded that there are no health risks associated with the consumption of medicated escapee Atlantic salmon or wild fish caught near fish farms.

14.6 Summary of seafood safety, and health advice

Sanitary surveys are performed to monitor risks of seafood contamination in six shellfish growing areas of the D'Entrecasteaux Channel and lower Huon Estuary, using a combination of water quality monitoring and catchment indicators (e.g. rainfall, river flows). Closure of shellfish farms is instigated where water quality and catchment indicators reach trigger levels. Sites in the lower Huon Estuary are at very high risk from biotoxins associated with the toxic dinoflagellate *Gymnodinium catenatum*. As a result, one farm located in Port Cygnet is now inactive for much of the year. This farm, and an additional farm which is restricted due to high risks of microbial contamination, are monitored sporadically and were, therefore, excluded from analyses of data on shellfish farm closures. The growing area at Port Esperance, where two shellfish farms continue to grow mussels and oysters, is also significantly at risk from biotoxins, while areas in the broader D'Entrecasteaux Channel are less affected. Closures due to faecal bacterial indicators have in contrast been recorded more frequently at Fleurtys Point in the Channel, although Port Esperance has also experienced many days of closure due to this risk. During 2000-2011, biotoxins and faecal bacteria/associated indicators of degraded water quality contributed almost equally to total days of closure for shellfish farms, with slightly more closure days attributed to biotoxin risk.

While water quality and farm closure data revealed no clear temporal trends in relation to biotoxins and faecal contamination, it is clear that risks to shellfish safety are not diminishing. In fact, 2011 recorded the largest number of days of shellfish farm closure during 2000-2011, and was the first year for this period during which significant farm closures were instigated for some Channel growing areas as well as Port Esperance due to biotoxin concerns. A water quality sample taken from Port Esperance during 2011 recorded the highest count of *G. catenatum* documented for the period, while this area continues to be affected by toxic algal blooms in 2012 (A. Turnbull, TSQAP, pers. comm.). Closures due to risks of faecal contamination across the study area were also elevated during 2009 and 2011, as previously recorded during 2000-2002, due to rainfall and river flow triggers.

Shellfish flesh testing in the region has consistently not detected pesticides, while metal concentrations have been below nationally prescribed maximum permitted levels (MLs). MLs have not been set for copper and zinc due to a lower consumer risk, with generally expected levels (GELs) instead used to provide a benchmark against which to measure contaminant levels. On the basis of data compiled during 2001-2008, median GELs for copper and zinc were exceeded in oysters from all growing areas of the region, with the exception of zinc at Port Esperance. Consistent with this, a separate monitoring program for four sites in the D'Entrecasteaux Channel also recorded exceedances of the GELs for copper and zinc. It should be noted however that some GELs developed nationally did not incorporate Tasmanian data and may not be entirely appropriate to this region (Whitehead *et al*. 2010). Exceedances of median GELs do not have direct implications for seafood safety and require no further investigative action (A. Turnbull, TSQAP, pers. comm.).

Metals in native finfish have not been monitored extensively in the D'Entrecasteaux Channel and lower Huon Estuary; however a long-term monitoring program has assessed mercury levels in flathead collected at Mickeys Bay, southern Bruny Island. Mercury concentrations recorded during 1991-2010 were consistently below the maximum permitted level. In a separate study, top-level predators such as sharks and skates from Bruny Island recorded high concentrations of metals, consistent with biomagnification through the food web. The lower order specimens did not provide a clear explanation of the metal loading in higher order species and hence transfer of metals through the trophic levels requires further investigation. Wild fish and escaped Atlantic salmon may contain antibiotic residue after marine farm treatment events, however an assessment has indicated that this does not pose a risk to human health.

The DHHS has issued a statewide recommendation that eating wild shellfish can be a high risk activity in unmonitored areas and that poor water quality due to heavy rainfall or algal blooms may influence the quality of shellfish. It has indicated that it remains safe to buy and eat shellfish from approved retail outlets at any time in Tasmania due to the TSQAP monitoring program. A general recommendation is that wild shellfish not be consumed following heavy rainfall, while it is also recommended that wild shellfish not be consumed from:

- marinas or other areas potentially subject to boat discharges
- adjacent to sewage, industrial or stormwater outfalls
- areas where septic tanks may be failing
- areas impacted by toxic algal blooms

In addition to the above general health warning, specific alerts recommending against the consumption of wild shellfish are applied periodically to the D'Entrecasteaux Channel and lower Huon Estuary, or parts thereof, during periods of algal blooms or other degraded conditions. There are currently no prescribed limits regarding consumption of finfish in the D'Entrecasteaux Channel and lower Huon Estuary.

15 SUMMARY AND RECOMMENDATIONS

15.1 Environmental status and trends

Previous environmental studies have identified the waterways of the D'Entrecasteaux Channel and lower Huon Estuary as remaining 'substantially natural' — meaning that they have not changed dramatically from their historic baseline. Compared to the adjacent more developed Derwent Estuary, they are considered a useful baseline of relatively un-impacted conditions which provide a reference for measuring the extent of impact in the Derwent. Environmental quality of the waterway is highest in the Channel, while both the Channel and Huon Estuary benefit from relatively small regional populations and a lack of heavy processing industries on their shores. However, as described below, a number of trends suggest increasing pressure on the D'Entrecasteaux Channel and lower Huon Estuary coast and waterways, and risks of these areas experiencing increasing environmental degradation. Several management initiatives have helped to reduce inputs to the waterway, while additional measures are planned that are likely to have future beneficial environmental outcomes. The environmental characteristics and status of the region are summarised under the headings below.

Anthropogenic inputs

Point sources of anthropogenic inputs include 9 wastewater treatment plants (WWTPs), 3 fish processing plants and 20 operational finfish farming leases. Diffuse non-point sources include stormwater drains, septic and other urban runoff, tips and contaminated sites, quarries, catchment inputs carried by the major rivers and other rivulets and creeks (e.g. forestry and agricultural runoff), and wastes associated with marinas and other boating activities. Data indicate that catchment inputs via river waters and fish farms remain the largest sources of anthropogenic nutrient inputs to the D'Entrecasteaux Channel and lower Huon Estuary region. Smaller inputs occur via sewage and industrial WWTPs, and septic system leakages in several areas are contributing locally to pollutant loads. Inputs via stormwater outlets cannot currently be quantified, but are also likely to have local effects. There is evidence of environmental legacy issues at two former heavy industrial sites at Port Huon and Electrona, although pollutants in Port Huon sediments may be contributed by a number of sources, and measures have been implemented at Electrona to mitigate impacts on the waterways.

The estimated total average daily flow from all sewage WWTPs in 2011 was 3,279 kL/day; an estimate far smaller than projected in earlier system-wide studies due largely to different calculation methods. A major improvement since 1999 was the introduction of reticulated sewage at Howden, 100% of which is being re-used. Little can currently be deduced about temporal trends in total WWTP inputs, since flow data are only available for 2009/2010. Even though continued population growth is expected in the region, direct inputs to the Channel from sewage WWTPs may decline in the future due to proposals to divert effluent from Electrona and Margate to Blackmans Bay. Land-based industrial inputs are greatest at a fish processing site at Dover, although a WWTP upgrade planned for this site in 2012/2013 will help to reduce emissions. Organic inputs at fish farms are likely to have increased, as indicated by a 130% increase in production during 2010 relative to 2000. Caps have been placed on levels of nutrient inputs from fish farms, and a survey program has been instigated to monitor the cumulative effects of fish farming activity on the environment. Use of antibiotics at fish farms has declined to very low levels in recent years, and a proposed phasing-out of the use of copper-based antifoulants on fish cage nets at depositional sites by 2015 will help to reduce metal inputs. Cleanup programs have been instigated by salmon and shellfish growers and community groups to address concerns about marine debris.

Water quality

System-wide water quality data reported publicly since 1999 were collected during 1996-2005 and therefore reflect conditions during that period. More recent data (2009 to present) have been collected as part of the Broadscale Environmental Monitoring Program (BEMP) and are currently being evaluated, but were not available at the time of preparing this report. Assessments of temporal trends in water quality are hindered by the absence of long-term monitoring based on consistent sites, sampling frequency and methods. Available data suggest that, as of 2005, the ambient water quality of the Huon Estuary and D'Entrecasteaux Channel was relatively healthy and devoid of signs of significant eutrophication. Although nutrient concentrations frequently exceed national guidelines (particularly during winter months), primary nutrient sources are considered to be of natural origins, related to nutrient-rich subantarctic water masses. Heavy metal concentrations have been investigated in the Huon Estuary and are low in most areas. In addition, water quality conditions are generally suitable for primary recreational activities, with poor conditions at Howden during 1999-2002 rectified by installation of reticulated sewage, and other spikes in bacterial loads short term in nature and associated with high rainfall.

There is some evidence of anthropogenic impacts on water quality, primarily in the Huon Estuary and North West Bay. However, it should be noted that sampling has been less intensive in the broader D'Entrecasteaux Channel. Elevated heavy metals and suspended solids occur in some tributaries of the Huon, while highly turbid waters occur periodically in shallow embayments proximate to river entrances, such as North West Bay. The waterways are generally well oxygenated (80–100%); however, localised oxygen depletion has been recorded in the lower Huon Estuary and North West Bay. Chlorophyll concentrations are generally below the national guidelines, but in the Huon Estuary they may exceed the estuarine guideline by a factor of greater than four during phytoplankton bloom events. A combination of field data and laboratory experiments suggests that organic loading in the Huon Estuary may be causing sediments to release nutrients into the water column, a process which increases the likelihood of algal blooms and eutrophication. Data indicate a long-term increase in phytoplankton biomass in the region (~200% during 1996−2005) that is consistent with increased nutrient loading. Blooms of the toxic dinoflagellate *Gymnodinium cataenatum* remain a high priority concern for water quality of the region.

Sediment quality

Levels of organic matter are very high in some sediments of the Huon Estuary, although primarily reflect natural sources, while being low to moderate in North West Bay and the broader D'Entrecasteaux Channel. Distribution of anoxic (i.e. oxygen deficient) sediments, indicative of organic loading, declined in the Huon Estuary between 1997 and 2004 suggesting an improvement in health, although this may be due to variation in river flows and other natural factors. Organic matter sourced from fish farms is confined within the boundaries of the farms in nearly all cases, while sewage is an extremely small contributor to organic loads except potentially in the vicinity of Cygnet. Organic loading in the Huon Estuary can potentially trigger the release of ammonium from sediments and increase the risks of eutrophication of the surrounding water. This highlights the importance of maintaining 'healthy' sediments and monitoring organic inputs.

Benthic infauna are a useful indicator of sediment health, with relatively high diversity levels suggesting a low level of disturbance in most areas of the Huon Estuary and D'Entrecasteaux Channel. Localised impacts on benthic infauna occur at finfish farms; however, system function, although not community equivalence, can be restored through fallowing. Sediments in Hospital Bay adjacent to Port Huon are generally in poor health, with a high organic content and elevated metal and pesticide concentrations. This may be due to discharges from a former pulp mill, sewage discharges from Geeveston and runoff from agricultural lands. Heavy metals are also elevated in sediments at Port Cygnet and in deep, silty areas of North West Bay, but are low in most other areas surveyed. Elevated levels of copper, and less commonly zinc, occur at some fish farm sites. Residues of antibiotics administered to farmed fish may also be detectable post-application, but at lower levels than recorded in earlier studies of similar farming operations overseas. Localised contamination with tributyltin, a compound previously used in vessel antifoulant paint, occurs in some marina environments.

Seafood safety

During 2000-2011, biotoxins and faecal bacteria-degraded water quality contributed almost equally to total days of closure for shellfish farms in the region, with slightly more closure days attributed to biotoxin risk. Sites in the lower Huon Estuary and Port Esperance are at high risk from biotoxins associated with the toxic dinoflagellate *Gymnodinium catenatum*, while areas in the broader D'Entrecasteaux Channel are usually less affected. There are no clear temporal trends in biotoxin and faecal contamination impacts on shellfish safety; however, it is clear that risks associated with both are ongoing. For example, 2011 recorded the largest number of days of shellfish farm closure during 2000-2011, and was the first year within this period to record significant farm closures for some Channel growing areas due to biotoxin concerns.

Shellfish flesh testing in the region has not detected pesticides, while metal concentrations have been below nationally prescribed maximum permitted levels. Prescribed 'generally expected levels' are exceeded for copper and zinc in oysters, but these levels were developed in the absence of Tasmanian data and may not be directly applicable to the region. As such, they are not considered to have implications for seafood safety. Metals in native finfish have not been monitored extensively, although long-term monitoring of flathead at a southern Bruny Island site indicates mercury concentrations consistently below the maximum permitted level. There are currently no prescribed limits regarding consumption of finfish in the D'Entrecasteaux Channel and lower Huon Estuary, however periodic alerts recommend against eating wild shellfish and it is generally recommended that eating wild shellfish can be a high risk activity in unmonitored areas.

Nutrient sources and modelled impacts

A coupled biogeochemical, hydrodynamic and sediment model was used to simulate local processes controlling the cycling of nutrients, and predict the effects of anthropogenic and natural inputs on water and sediment quality and phytoplankton blooms. The major source of nutrients to the waterways is the natural marine system, with the remainder primarily contributed by the above anthropogenic inputs, supplemented by small inputs from the sediments. Modelling conducted in 2002 indicated that 60% of nitrogen was sourced from marine waters, 23% from the Huon River and 17% from fish farms. While the chemical form of nitrogen varies amongst sources, large portions of the oceanic and fish farm-derived nitrogen are biologically available to phytoplankton and other organisms, while most of the river-derived nitrogen is biologically unavailable.

A modelled scenario based on maximum projected fish farming inputs by 2009 predicted that fish farm inputs of nitrogen would eventually surpass those from riverine sources. The 2009 'worst case' scenario simulation resulted in larger, more prolonged and wider spatial impacts of farm loads, represented as increased concentrations of nutrients and chlorophyll and reduced bottom water oxygen levels compared with 2002. Associated with these changes was a predicted shift in many areas to mesotrophic (i.e. moderate nutrients) conditions, although there was no indication of conditions becoming eutrophic (i.e. high nutrients). The 2009 projections are subject to uncertainty arising from limitations in the models and underlying knowledge, and hence modelled impacts should not be interpreted as representing 'actual' impacts. The BEMP evaluation and assessment (see Section 10.4) will assess the extent to which actual changes in fish farm inputs and water quality conditions have occurred in the region.

Foreshore environment

Only a very small percentage of the foreshore within the region is categorised as 'very highly modified' or under 'extreme pressure'. However, 90% is categorised as being under some pressure from human disturbance, and more than 40% is moderately or highly modified. The geomorphological condition of the foreshore has been partly to significantly disturbed along 80% of the study area coastline, suggesting that only a small portion of the coast remains in a natural state. Consistent with this, only 18% of the foreshore vegetation of the study area is structurally and floristically intact, with vegetation in the remaining areas considered to be unviable (i.e. not self-sustaining) or at risk of becoming so. Further analysis of data by area indicates that 34% of the foreshore has been completely cleared of native vegetation and consists predominantly of urban and rural land or exotic vegetation. In contrast to the neighbouring Derwent Estuary, there are no major sites of reclamation, although a few areas have been significantly modified by former heavy industrial activity.

In excess of 300 structures have been recorded along the foreshore of the study area, including a large number which are unauthorised and in varying states of disrepair. Growth in the marine farming industry has led to a need for additional foreshore facilities, and expansions of on-shore seafood processing plants. The very high and increasing levels of recreational fishing, motor boating and yachting have led to increased pressure on foreshore facilities. Population growth in the region is also concentrated along the coast, leading to greater usage of the foreshore for recreational activities. This highlights the need for careful planning to facilitate the sustainable use of coastal environments.

Values, habitats and species

Many areas of high natural, cultural heritage and geoconservation value occur in the D'Entrecasteaux Channel and lower Huon Estuary, with 45 state reserves occuring within the region. Aquatic habitats are dominated by unvegetated soft sediments but also include highly productive seagrass and kelp beds and saltmarshes. Declaration of new and expanded marine protected areas in 2009 saw their extent grow to comprise 11% of the waterway, compared with <1% previously. However, only 16% of the MPAs, by area, is protected within 'no-take' zones, with recreational fishing permitted elsewhere. Threatened species include 23 fauna and 45 flora, while seven threatened vegetation communities also occur in the study area. Threatened fauna species include eight birds, two terrestrial invertebrates, three marine invertebrates, three fish, three terrestrial mammals and four marine mammals. Many threatened species are endemic (i.e. unique) to Tasmania, south-east Tasmania or even the study area. The region contains all 12 endemic Tasmanian bird species, is a hotspot for marine endemic species including the spotted handfish, seastar species and highly restricted algae, and is widely valued for its orchid diversity.

The status of many species is largely unknown, although recent surveys suggest major declines or population losses of two endemic fauna (forty-spotted pardalote, chaostola skipper) and localised reductions in orchid diversity and abundance. There have been few recent surveys of marine threatened species, although a sediment coring study during 2000-2002 reported a 75% decline in mollusc species diversity and abundance in the region over the previous 120 years. Declines in marine threatened species and overall biodiversity have been attributed largely to historic scallop dredging, and also to siltation of habitats, nutrient inputs and spread of introduced species. Fishing activities are influencing the structure of marine reef communities, resulting in fewer large fish and lobsters, but more grazers such as urchins and seastars. Giant kelp beds may not have declined to the same extent as observed in neighbouring and more northern parts of Tasmania, due most probably to nutrient inputs and strong influences of cool, nutrient-rich waters of the Southern Ocean. A temporal assessment of seagrass extent is available only for North West Bay and indicates irregular and frequent changes over time, with total seagrass extent in decline over the past 60 years. During 2008-2010, the seagrass beds in North West Bay appeared to be in a growth phase, with the seagrass recolonising areas it had previously occupied. There are no major seal haul out or breeding colonies in the study area. Fur seal numbers, however, are increasing around fish farms and posing a threat to fishers and salmon farm workers. There has been some evidence of initial recovery of southern right whale populations, although the intensive use of the waterway and large amount of marine and coastal infrastructure is considered a threat to this recovery. Declines and population losses of little penguins have also been reported, while in contrast, numbers of silver and kelp gulls are artificially high due to supplementary feeding at tips and fish farms; a behaviour encouraged by degradation and loss of natural island habitats.

The majority of the foreshore is rated as moderate to high geoconservation value and contains a total of 24 listed sites, including several classified nationally as geological monuments. At least 600 Aboriginal heritage sites have been identified, and are concentrated along the coast. Some have been degraded by erosion, diverted runoff, walking tracks and trampling. Approximately 65 state-listed and numerous additional locally-listed European heritage sites also occur on the coast and at the sites of historic shipwrecks.

Introduced species

There are currently 49 known introduced and cryptogenic (= potentially introduced) marine species in the study area, including six 'target' introduced pest species. This represents a significant increase since 1999, but may largely be a reflection of improved data availability. Blooms of the toxic dinoflagellate (microalga) *Gymnodinium catenatum* are continuing to pose risks to shellfish safety, while the New Zealand screwshell *Maoricolpus roseus* occurs at densities of up to 2000 per m^2 and is impacting on benthic habitats, and the abundance and condition of commercial scallops. This species and the northern Pacific seastar *Asterias amurenis* have become dominant members of the community, with the seastar expanding its range and density over time. There is evidence suggesting increasing densities of other benthic introduced species, with their proportional abundance increasing by 2-3% per annum relative to the total benthic community during 1998-2003. The introduced Japanese seaweed *Undaria pinnitifida* exhibited increases in cover during ten yeas of MPA monitoring at Tinderbox.

Foreshore mapping to 100 m from the high water mark has revealed 31 dominant weed species, including 10 declared weeds and 6 Weeds of National Significance (WoNS). Weeds are present in nearly 60% of foreshore areas surveyed, with common species including blackberry, radiata pine, montpellier broom, Spanish heath, gorse, boneseed, briar rose and marram grass. Records extending to 1 km inland of the coast indicated the presence of an additional 17 declared weeds including 2 WoNS; hence a total of 27 declared species, incorporating 8 WoNS, were documented for the D'Entrecasteaux Channel and lower Huon Estuary foreshore and coast.

Climate change

Future climate change will impact upon the natural environment, infrastructure and heritage values of the D'Entrecasteaux Channel and lower Huon Estuary. Most recent modelling suggests that by 2100, the region will experience an air temperature rise of 1.6 to 2.9 °C, a sea surface temperature rise of up to 3.5 °C, sea level rise of up to 80 cm, and increased annual rainfall and surface runoff. Shoreline erosion, flooding and landward recession due to sea level rise are primary concerns, with geomorphological mapping indicating that many areas of the study area are highly vulnerable, particularly around Margate, Snug, Great Bay, Bruny Island Neck and mid-Channel tertiary shores. The frequency and severity of storm surge events relative to current sea level and coastal infrastructure locations are predicted to increase, while saltmarshes and other coastal habitats could be lost where there are no suitable environments for their retreat.

Other impacts are associated with changes to water temperatures and chemical properties that influence the composition of marine and estuarine biological communities. Changes already evident include range expansions of species such as the long-spined sea urchin *Centrostephanus rodgersii* and microalga *Noctiluca scintillans*. Both have the potential to negatively impact on fisheries and natural communities, although no significant impacts have been reported in the study area to date. Other potential impacts include reduced biodiversity due to loss of kelp beds and other cold-adapted species, and reductions in growth and survival of a range of wild and farmed fisheries species. Of the fisheries species at highest risk to climate change impacts in south-east Australia, the southern rock lobster, commercial scallop, Pacific oyster and blue mussel are of primary significance for the region. Atlantic salmon are rated as having a moderately high sensitivity, with risks of increased disease and reduced suitability of available sites.

15.2 Data gaps and water management issues

There has been a very large improvement in the availability of environmental data for the D'Entrecasteaux Channel and lower Huon Estuary since 1999. In particular, several system-wide studies have contributed greatly to our understanding of the water and sediment dynamics of the region. In fact, the combined D'Entrecasteaux Channel and Huon Estuary arguably now rates as one of the most intensively surveyed and modelled waterways in Australia. This provides a very solid basis for developing ongoing management strategies and prioritising areas for future study. There is also improved availability of data for assessing foreshore condition, recreational water quality, WWTP inputs, marine farming influences, introduced marine species threats, vulnerability to climate change, and seafood safety. In particular, there has been a large focus on the assessment of salmonid farming impacts, and hence more data is available to address this topic than any other anthropogenic influence. Other anthropogenic inputs have generally attracted fewer studies, and are less commonly referenced in the current report, but remain important management issues and areas for future investigation.

Despite the above major improvements in data availability, many data gaps remain, and review of existing data reveals a number of management issues that require further investigation or action to achieve environmental sustainability. Collaborations between diverse stakeholder groups are required to address both data gaps and management concerns. The sections below summarise key management issues, describe data gaps, and list potential investigations to address these gaps, with a focus on the status of the waterway and associated communities. It should be noted that some of the listed management issues are already being addressed by various government, industry and community initiatives. Hence, those listed should not be interpreted as 'outstanding' issues yet to be addressed, but rather as being elements within the broader management issues identified for the waterways. Data gaps identified are based on primary issues of concern, rather than providing an exhaustive list of all types of information currently not available. It is unlikely that all listed potential investigations can be implemented in the immediate future; however, the information provided is intended as a basis for ongoing planning and prioritisation of activities of the broader D'Entrecasteaux Channel Project.

Anthropogenic inputs

While a broad range of inputs may have local influences on water quality, the major point source inputs are of primary concern for system-wide water quality. Inputs of organic matter and nutrients are recognised as the most significant threat to the ecological functioning of the D'Entrecasteaux Channel and the lower Huon Estuary ecosystems.

Key management issues include:

- Monitoring catchment inputs, with poor quality runoff unmonitored in some areas.
- Sewage and industrial WWTP inputs, given population and production increases, respectively.
- Organic inputs via fish feed at salmonid farms.
- Unmonitored stormwater flows, and septic system failures.
- Potential residual contamination associated with historic secondary industrial activities.
- Potential inputs from metal-based antifouling treatments used at fish farms.
- Wastes associated with boating activities.
- Litter and marine debris.

Data gaps for anthropogenic inputs include:

- Absence of reliable, continuous water quality monitoring data for rivers and streams, and lack of regular monitoring in some degraded tributaries, such as the Kermandie River; both potentially reducing the accuracy of estimates of catchment inputs.
- Inconsistency in methods used to estimate catchment inputs, hindering temporal assessments.
- As also described for ambient water quality below, a lack of consistency in the chemical forms of nutrients analysed, and potential for different results based on contrasting analytical techniques; both potentially hindering comparisons of nutrient sources and integration with water quality data.
- Lack of information on locations of stormwater outlets and stormwater quality.
- Lack of knowledge about, and methods for estimating, inputs from boating activities.
- Lack of quantitative information about sources and volumes of litter and marine debris.

Potential investigations include:

- In the face of statewide downscaling of catchment water quality monitoring, aim to retain and where possible enhance catchment monitoring; review catchment monitoring to develop a 'catchment to waterway' strategy, whereby the catchment monitoring program complements marine monitoring and better informs assessments of relative inputs from different sources.
- In conjunction with the point above, resolve the most accurate methods for estimating catchment inputs and determine how current monitoring can be improved.
- Compare projected fish farm inputs presented in the current report with updated estimates provided by the BEMP evaluation and assessment, once available.
- Ascertain which are the most important chemical forms of nutrients in assessments of waterway health; promote the inclusion of these in analyses for all inputs to facilitate comparisons of nutrient sources and interpretation of ambient water quality data.
- Document locations and flow capacities of stormwater outlets, and prioritise based on considerations such as flow volume, presence of industrial runoff and proximity to recreational areas and shellfish and finfish farms. Establish a monitoring program for high priority outlets to gauge stormwater inputs, and monitor the effectiveness of new urban stormwater systems in the treatment and removal of faecal contamination and other pollutants.
- Investigate strategies to monitor and better manage boat wastes, such as surveys, educational activities and improved waste receiving stations.
- Conduct surveys to quantify the distribution, sources and volumes of litter and marine debris.

Ambient water quality

Ambient water quality in the region is important for health of natural communities and farmed species, and for protection of human consumers of finfish and shellfish.

Key management issues include:

- Determining anthropogenic influences on nutrient levels against a background of high natural levels.
- Blooms of the toxic dinoflagellate *Gymnodinium catenatum*, primarily in the Huon Estuary, and other potentially harmful microalgae, such as the dinoflagellate *Noctiluca scintillans*.
- Seasonally high elevations in bottom water ammonia in the Huon Estuary, suggesting potential nutrient release from sediments.
- Areas with oxygen depletion in bottom waters, particularly in the Huon Estuary.
- High turbidities at some river entrances following heavy rainfall.

Data gaps for ambient water quality include:

- The absence of available system-wide water quality data since 2005, such that water quality data reviewed in this report may not provide an up-to-date picture of environmental status.
- The absence of a long-term, system-wide water quality monitoring program which samples a standard suite of sites based on a consistent frequency of sampling and uniform set of analytical methods; thereby hindering assessments of temporal trends.
- The apparent non-applicability of some national water quality guidelines to this region; for example, nutrient guidelines are exceeded by natural concentrations alone.
- A lack of consistency in the chemical forms of nutrients measured or reported, and in the units of measurement for nutrients and oxygen levels; hindering comparisons of water quality data.
- Inconsistencies in results provided by different laboratories due to contrasting analytical techniques (e.g. ammonia), complicating comparisons of results.
- A limited understanding of the extent of bottom-water oxygen depletion in the Huon Estuary.
- Unresolved aspects of conditions triggering blooms of the toxic dinoflagellate *G. catenatum*.
- An absence of system-wide monitoring of heavy metals and pesticides in waters of the D'Entrecasteaux Channel, and lack of pesticide data suitable for comparisons with national guidelines in the case of the Huon Estuary.

Potential investigations include:

- Collaborate with relevant stakeholders to determine if existing, targeted water quality monitoring may contribute to the development of a long-term monitoring program of the general environmental status of the waterways.
- Support activities to refine regionally-based guidelines and trigger values for water quality parameters that may provide more appropriate indicators of anthropogenic impact than the national guidelines.
- As also described above for anthropogenic inputs, ascertain which are the most important chemical forms of nutrients in assessments of waterway health, and promote the inclusion of these across all water quality monitoring activities.
- Further investigate the potential for contrasting nutrient analytical methods to hinder comparisons between water quality monitoring datasets, and also between ambient and effluent monitoring data; document methods used for major datasets, and assess how any discrepancies are best overcome.
- Document primary types and patterns of use of pesticides in the region and identify sampling and analytical methods needed to establish the status of pesticide levels against national guidelines.
- Investigate the feasibility of monitoring heavy metals in collaboration with other existing sediment monitoring activities.
- Determine in consultation with CSIRO the data needed for additional calibration of the coupled biogeochemical, hydrodynamic and sediment models used to simulate nutrient dynamics; facilitate additional work to improve the accuracy of simulations and hence enhance the functionality of the models as a coastal management tool.
- Determine investigations needed to address unresolved aspects of toxic dinoflagellate blooms, with a potential focus on the distribution of resting cysts and seasonality of their germination.

Recreational water quality

Protection of water quality is important for a diverse range of primary and secondary recreational uses, most notably swimming, scuba diving, kayaking and surfing.

Key management issues include:

- Effects of sewage and industrial WWTP discharges on recreational areas.
- Management of sewage overflows and septic system failures.
- Identification of high risk areas during heavy rainfall.

Data gaps for recreational water quality include:

- Inconsistency in the suite of sites sampled each year, and hence unavailability of data for some sites and years.
- A low frequency of sampling which prevents application of standard water quality classifications developed for Tasmania, and hence also prevents the application of standard beach signage denoting water quality status.

Potential investigations include:

- Conduct a risk analysis for primary contact recreational areas, and use findings to consolidate sites selected for consistent surveying.
- Assess and apply the level of survey frequency needed to meet requirements for standard water quality classifications.
- Consider options for future development of beach signage in line with determined water quality classifications.

Sediment quality

Sediment health is integral to the biodiversity and condition of benthic communities and also has implications for water quality through potential re-mobilisation of stored nutrients and contaminants.

Key management issues include:

- Elevated organic content in some areas, and relative contributions from anthropogenic and natural sources.
- Potential for organically loaded sediments to release nutrients into the water column and contribute to water quality degradation.
- Oxygen depletion, most notably in areas of the lower Huon Estuary.
- Poor sediment health in Hospital Bay, as reflected by elevated organic content, metals and pesticides, and elevated metals in Port Cygnet and deeper areas of North West Bay.
- Fish farm fallowing regimes and level of recovery of sediments from organic inputs.
- Copper and zinc contamination at fish farm sites associated with use of metal-based antifoulants, although noting that the salmonid farming industry is aiming to phase out the use of these antifoulants at depositional sites by 2015.
- Localised contamination of marina environments with tributyltin, a compound previously used in vessel antifoulant paint.

Data gaps for sediment quality include:

- Available sedimentary data reported since 1999 were collected primarily between 1997 and 2006, and hence may not provide an up-to-date account of environmental status.
- Paucity of data on heavy metals in the broader D'Entrecasteaux Channel.
- Absence of data on pesticides in the broader D'Entrecasteaux Channel, and lack of pesticide data suitable for comparisons with national guidelines in the case of the Huon Estuary.
- Gaps in knowledge about the bioavailability and impact of copper and zinc occurring in the sediments of fish farms.
- A general paucity of data for the broader D'Entrecasteaux Channel, particularly regarding level and source of organic matter and other chemical indicators of organic enrichment (e.g. redox potential, sulphides); also, particle size data for this region have been collected through several studies but not yet fully analysed and reported.
- Lack of readily available sediment quality data in the vicinity of most sewage outfalls.
- Lack of ongoing monitoring data for assessing the long-term recovery of Hospital Bay sediments from former pulp mill discharges.

Potential investigations include:

- Collaborate with relevant stakeholders to determine if existing, targeted sediment quality monitoring may contribute to the development of a long-term monitoring program of the general environmental status of the sediments.
- Conduct an up-to-date assessment of sediment health in Hospital Bay, including as a minimum a visual survey and analyses of organic content, heavy metals, pesticides, and benthic infauna. Where possible, resolve the sources of degradation based on historic and continuing activities.
- Conduct surveys of heavy metals in sediments of the broader D'Entrecasteaux Channel, and determine potential collaborations with existing heavy metal monitoring programs.
- Conduct a more comprehensive survey of pesticides across the region which enables comparisons with national guidelines.
- Consolidate and analyse existing sedimentary data, for example on particle size distributions, for the broader D'Entrecasteaux Channel.
- Compile available data for sediments at sewage outfalls and identify any targeted surveys needed to better assess sediment health.

Marine and estuarine habitats and species

Habitats and associated communities have been under increasing pressure from human activities and have experienced structural modifications and declines in diversity.

Key management issues include:

- Impacts of nutrient inputs on seagrass beds and other benthic communities.
- Spread and increased abundance of introduced marine species.
- Impacts of fish farming inputs on algal communities and community structure of benthic faunas.
- Siltation and modification of foreshore habitats.
- Impacts of intensive boating activity and high density of marine and coastal structures on whales.
- Impacts of recreational fishing on reef community structure.
- Degradation of coastal habitats used as feeding and nesting sites by shorebirds.
- Protection of habitats of threatened species and unique communities.

Data gaps for habitats and species include:

- A paucity of recent data on the status of threatened and other rare marine and estuarine species; some work has been initiated by the Institute for Marine and Antarctic Studies (IMAS) but data are not yet analysed, and surveys to date have excluded intertidal species.
- A paucity of information about rare algae and unique invertebrate communities associated with tannin environments, some of which occur outside MPAs and are endemic to the region.
- An absence of temporal data on seagrass beds outside North West Bay, and limited recent surveys of giant kelp beds in the region.
- An absence of recent data on fishing impacts, given that reported MPA reef monitoring data for fished and non-fished areas were collected during 1992-2002.
- Lack of recent monitoring data for nesting shorebirds across much of the region, hindering assessments of temporal changes.
- No risk assessment for potential spread of introduced marine species to the region.

Potential investigations include:

- Facilitate completion of the IMAS study of rare marine and estuarine species, and extend work to intertidal environments.
- Using the current Seamap habitat mapping as a base, compile an atlas that also includes the locations of rare species and habitats and identify key management considerations for mapped values.
- Extend shorebird monitoring surveys (e.g. little penguins) to assess temporal changes, and identify key shorebird habitats requiring rehabilitation works or other measures to reduce disturbance.
- Collaborate with relevant stakeholders to determine if any existing, targeted biological monitoring may contribute to the development of a long-term monitoring program of the general biological health of the waterways; establish a long-term monitoring program for other habitat and biological indicators (e.g. seagrass and giant kelp beds, threatened and other rare species, biodiversity).
- Identify educational strategies aimed at increasing community awareness about marine issues; for example, minimal impact fishing and boating practises, whale and dolphin viewing guidelines, understanding of native species and habitats, and applying measures to prevent the spread of introduced species.
- Monitor the abundance and distribution of key introduced marine species, and assess the potential for data to be collected and made available through existing monitoring programs.
- Conduct a review of existing and potential vectors for spread of introduced marine species to the region, including potential spread from the Derwent Estuary and other locations.

Climate change

Future climate change will impact on the values of the D'Entrecasteaux Channel and lower Huon Estuary, highlighting the need to plan for potential changes and take measures to increase the resistance of the natural environment.

Key management issues include:

- Foreshore erosion, flooding and recession.
- Potential loss of saltmarsh and coastal shorebird habitats where development or natural physical barriers prevent recession.
- Impacts on coastal values and infrastructure.
- Increased upstream penetration of the Huon Estuary salt wedge.
- Impacts on biodiversity and community structure associated with ocean warming and other climate change processes, for example through range extensions of species not formerly identified in the region.
- Potential future impacts on health and viability of wild and farmed fisheries species.

Data gaps for climate change include:

- Lack of coastal hazard mapping and assessment for areas within the Huon Valley municipality.
- Absence of data to monitor long-term changes in shoreline position.
- Other than recent work on saltmarshes, a lack of region-wide information on potential impacts and recession pathways for other key coastal habitats (e.g. nesting shorebird habitats) in vulnerable areas.
- Lack of long-term biological monitoring programs to detect changes in species composition and biodiversity.

Potential investigations include:

- Extend the techniques applied in the recent saltmarsh 'futures' assessment to other coastal habitats at risk from recession and flooding (e.g. expand on initial shorebird habitats work conducted by Birdlife Tasmania for Bruny Island).
- Monitor shoreline position along highly vulnerable shorelines.
- Extend the soon to be completed assessment of coastal hazards in the Kingborough municipality to the adjacent Huon Valley municipality.
- As also outlined for marine and estuarine habitats and species above, develop a long-term monitoring program for marine and estuarine habitat and biological indicators to detect changes in community structure and biodiversity.

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