National Land & Water Resources Audit

An Initiative of the Natural Heritage Trust

Development of estuarine report cards consistent with the national estuarine environmental condition assessment framework

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Department of Water (Government of Western Australia)

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Helping Communities Helping Australia

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The National Land & Water Resources Audit provides data, information and nationwide assessments of Australia's land, water and biological resources to support sustainable development.

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Summary

This document has been prepared for the National Land & Water Resources Audit (the Audit) by the Water Science Branch of the Department of Water. The Audit is funding the development of a national report card system based on the emerging National Estuarine Environmental Condition Assessment Framework (NEECAF) (Mount and Arundel 2007). This report looks at the process of developing report cards with the intention of integration and translating West Australian data and information into a standard national format.

Particular focus has been placed on the South Coast Region and the South West Region. The estuaries selected experience a wide range of conditions including varied estuary bar characteristics, rainfall and river flow and anthropogenic pressures. They include the Hardy Inlet, Broke Inlet, Wilson Inlet, Beaufort Inlet, Wellstead Estuary, Hamersley Inlet and Stokes Inlet. The upper Swan estuary is used in one example to highlight pressure and vulnerability examples.

This report includes some discussion of the back end process of gathering information on the estuaries, producing condition statements, inventory report cards and using this information to identify conditions of concern and information gaps in the understanding of the ecological processes operating in the estuary. The second part of this report focuses on an assessment of pressure, vulnerability and risk. A summary table is also included of the management objectives, pressures, vulnerabilities and indicators of condition and for targets for specific estuaries.

The production of this document was made possible by funding from the National Land & Water Resources Audit (the Audit).

1. Stage 1 – developing the back end of the report card

This section outlines the process currently followed for producing condition statement reports and inventory report cards. Examples of these reports were included with the first report to the National Land & Water Resources Audit. These reports currently form the first stage of the report card development process.

1.1 Condition statement reports

An estuarine condition statement provides an overview of the information available on the physical and biological character of the estuary or Inlet, the rivers feeding the system and catchment land use. It identifies conditions of concern, information gaps and provides recommendations to assist the decision making process for management.

Conceptual diagrams are an important component of the condition statement report. They attempt to collate the available understanding of the estuary (drawn from the background information and data) to illustrate the current understanding of the system and highlight areas where information is insufficient. Some examples of conceptual models are included in Appendix B.

It is important to note that the ability to adequately define estuarine condition in these reports relies on the information and data available but it is often the case that important process information or pressure information is lacking. For this reason one of the primary recommendations by these reports is to fill these information gaps either through monitoring programs or focused research programs. In the case of the reports so far 'likely' or 'estimated' condition is based on expert opinion, management objectives are not considered at this stage and no attempt is made to score condition against these objectives.

Condition reports have been produced for three estuaries on the South Coast of Western Australia and one estuary on the West Coast, namely the Hardy Inlet. Three other reports are in progress for the Beaufort Inlet, Walpole-Nornalup Inlet and Irwin Inlet.

The diagram below summarises the conceptual process for producing the condition statement reports.

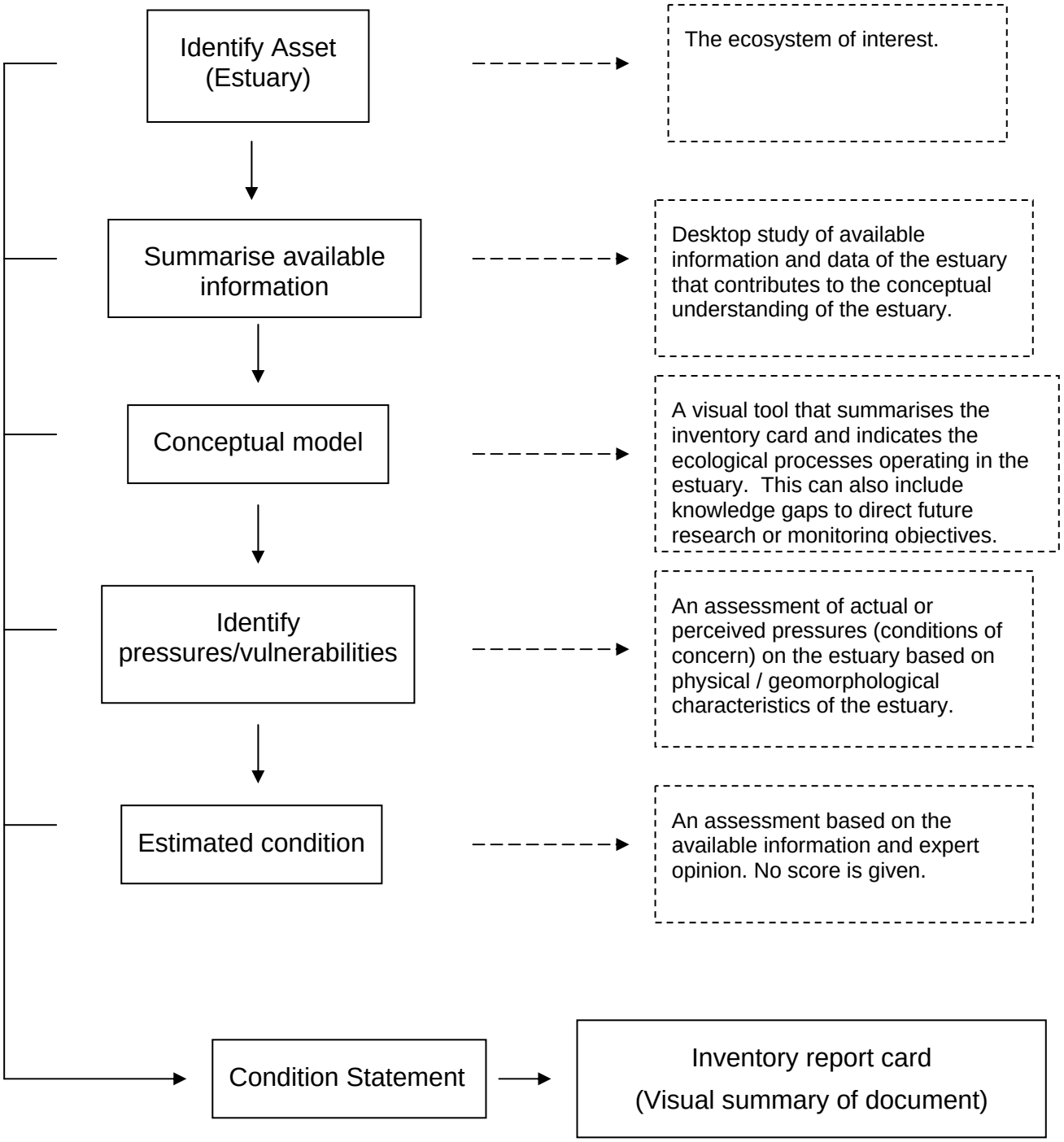

Figure 1 Conceptual process and content in condition statement reports

1.2 Inventory report cards

Inventory report cards are a visual tool, summarising the condition statement report and the available information for a specific estuary. Examples of inventory report cards can be found in Appendix A of this document.

2. Stage 2 – developing the front end of the report card

This section outlines the process currently followed for developing the front end of condition report cards. Management objectives, pressures and the vulnerabilities of each system are identified and used in a simple risk assessment. These are summarised in a table in Appendix C.

2.1 Pressure, vulnerability and risk assessment

The major pressures which act on estuarine ecosystems in the south-west corner of Australia are generally well recognised. These are, in no particular order of importance - catchment clearing, human population density, nutrient trends, the number and extent of contaminated sites and the acid sulphate soil risk. There are others but those listed above may directly or indirectly account for them. For example, high fishing pressure is indirectly covered by population density.

The vulnerability of these estuaries to these pressures are influenced by characteristics such as catchment to inlet surface area ratio, water residence time and bar opening characteristics. A system with a long residence time is likely to be more vulnerable to pressures such as nutrient inputs to the estuary than a system with a short residence time. Similarly, a system with a high catchment to inlet area ratio would be more vulnerable to nutrient inputs. The entrances of many south-west estuaries are seasonally closed which makes them vulnerable to nutrient loading. This vulnerability is captured by the water residence times.

It is important to note that the vulnerability of a system does not distinguish between human and natural pressures.

An explanation of a proposed methodology behind calculating a rating for each of these pressure and vulnerability scores is detailed below.

Pressure scores (an example)

Catchment cleared: The percentage of the catchment cleared is easily defined. The rating of 1 to 5 is assigned as follows:

Table 1 A pressure rating scale for catchment clearing

Catchment clearing	
1	<20% cleared
2	20-40% cleared
3	40-60% cleared
4	60-80% cleared
5	>80% cleared

Other pressures for which scores, as rating from 1 to 5, could be developed could include:

1. Population density
2. Nutrient trends - This pressure would be better defined as a eutrophication index (e.g., US ASSETS index) however we don't yet have these calculated so as an interim it would be our 'expert opinion' on current status and which way things are heading. (e.g., we have good trend info for the Swan, others may just be relative concentrations compared with ANZECC triggers).
3. Number of contaminated sites
4. Acid sulphate soil exposure
5. Fishing pressure - This pressure would also best be defined as a fish index. Murdoch University are currently investigating an approach to use fish as a biotic indicator of estuarine condition. Alternatively, the South African Fish Assemblage Integrity Index (FAII) could be trialled and tested as an approach in the Western Australian context.

Vulnerability scores (an example)

Catchment to inlet surface area ratio: the size of the catchment relative to the inlet area is indication of how sensitive the system is to catchment activities. In the case of the Swan, the ratio is very large and highlights how susceptible the system is to an extensively modified catchment. The Swan has a ratio of 17,000 so the relative ratings were assigned as follows:

Table 2 A vulnerability rating scale for catchment to inlet surface area ratio

Catchment to inlet surface area ratio	
1	< 4,000
2	4,000 – 8,000
3	8,000 – 12,000
4	12,000 – 16,000
5	16,000 – 20,000

**Note that these assignments are likely to change fit the national context.*

Other vulnerabilities for which scores, as rating from 1 to 5, could be developed could include:

1. Water residence time
2. Frequency of bar opening
3. Evidence of deterioration, such as:

a. Frequency of algal blooms

b. Occurrence of toxic species

c. Loss of submerged aquatic vegetation (SAV) habitat

d. Fish kills

Developing tables such as the examples above and determining appropriate ranges and score would allow either a separate pressure score table and vulnerability score table to be developed or alternatively a combined table such as the example below (Table 3).

The overall scores achieved from this assessment could be used as part of the risk assessment.

Table 3 A pressure and vulnerability assessment example for the Upper Swan estuary (severely modified) and Broke Inlet (near-pristine)

	Upper Swan						4.3	**Broke Inlet**						1.0
Rating														
5	5	5												
4			4	4	4	4	4							
3														
2														
1								1	1		1	1	1	1
No info														
	% Catchment cleared	catchment:inlet ratio	Residence time	Population (human)	Nutrient trends	Contaminated sites	ASS risk	% Catchment cleared	catchment:inlet ratio	Residence time	Population (human)	Nutrient trends	Contaminated sites	ASS risk

Risk

Without clearly defined goals and management objectives or a valuation of the asset it limits the ability to do effective risk assessment. At this stage of the assessment, we can determine the relative score for the pressures and vulnerability of estuaries including the natural and human induced pressures acting upon them (as above).

Relating either of these approaches to Table 4 below, the Swan Estuary would score as ‘very high’ and Broke Inlet as ‘low’. This compares well with the OzEstuaries classification of the Swan Estuary as ‘severely modified’ and Broke inlet as ‘near-pristine’.

Table 4 Rating table for risk

Risk	
1	Low risk
2	Moderate risk
3	High risk
4	Very high risk
5	Extreme risk

2.2 Management objectives

Management objectives for south coast and south west estuaries are essentially driven by social values (aesthetics, recreation and tourism) which indirectly encompass ecological values of habitat integrity and biological diversity. In some instances these systems are also being redefined as Marine Parks (e.g. Hardy Inlet) for which management objectives are already defined. This report considers both social and ecological management objectives, but it is recognised that management objectives still need to be defined for many estuaries through an appropriate consultation process.

The table in Appendix C outlines the key management objectives for selected estuaries based on our current understanding and knowledge of social pressures on the estuary.

2.3 Selection of Indicators of condition

The choice of indicators for the assessment of estuarine condition clearly depends upon the values and management objectives associated with each individual location. In Western Australia there is good information on many estuaries which have had regular water quality monitoring studies done for a number of years. However, the management objectives have not necessarily been clearly defined with full stakeholder consultation and/or agreement.

Evidence of estuarine condition (see Appendix C) in most estuaries on the south coast and south west coast is most commonly in the form of:

- Fish kills
- Algal blooms
- HABs (toxic or harmful algal blooms)
- Submerged Aquatic vegetation (SAV) habitat integrity
- Biotic diversity measures
- Fish recruitment and survival

Indicators should be selected to assess these conditions and should be readily measurable, scientifically valid for assessing resource quality, and provide relevant information for management decision making.

The table in Appendix C gives examples of estuarine conditions and the potential indicators that could be used to monitor and manage against to meet the management objectives. To achieve this the selection of indicators depends on a clear identification of a problem for which, by common agreement, improvement is required.

Environmental indicators are often highly variable, and respond to a range of factors in addition to any implemented management actions. For this reason an approach incorporating a well-designed sampling program (when, where, how often, and how you sample), and appropriate data analysis and use of statistical techniques is necessary to set targets and measure against them.

3. Conclusions

This report demonstrates our progress in the development of estuarine condition report cards. Clearly, we are at the beginning stages of the process. Our current objectives are to continue to assess and describe the Western Australian estuaries. In doing so, we will develop or trial (VSSPIR) a pressure/vulnerability assessment tool, and ASSETS (the US eutrophication index). We are not at the point of providing a front end report card. However, in our vision of a report card we hope to include, a description of the system, a conceptual model of process understanding, scores of pressure/vulnerability, and a measures of resource condition indicators appropriate to the estuary. We are also looking into an approach to determine a top level headline assessment of condition (e.g. A – E) consisting of the ecological evidence measured against the management objectives.

Appendices

Appendix A — Inventory report card examples

Hardy Inlet

Hardy Inlet is situated on the southern tip of Western Australia. It is the end point of the Blackwood and Scott Rivers which drains the largest catchment in the southwest. The Blackwood River catchment and the Scott coastal plain are both heavily modified (76 % cleared) by land-use and economic activity, including a diverse suite of agricultural activities, that include, vegetable and fruit production, cut flowers, cropping and stock farming. The Hardy Inlet has been considered to have high social and environmental value to those using or living adjacent to the estuary.

Hardy Inlet is under stress, suffering symptoms of nutrient enrichment from the catchment and the organic rich sediments. As one of the few naturally open estuaries on the South Coast, stratification is a common theme with the presence of salt wedge that extends furth up the estuary with reduced river flow. This can lead to deoxygenation, which has resulted in fish deaths. Although Hardy Inlet is considered macrophytes dominant, the system experiences frequent phytoplankton blooms that in clued harmful blue green species (Lyngbya sp.).

Inlet Summary

Inlet size (km²)	9
Inlet shape	Central basin
OZCOAST classification	Modified, wave dominated
Bar status	Open
Inlet : catchment (km²)	0.0003
Residence time	Days - weeks
Phyto/SAV dominant	SAV
Organic loading	Yes
Eutrophication (ASSETS)	-
Social value	Canoeing, fishing, ecotourism
Environmental value	Birds, fish

Submerged aquatic vegetation

Present	Yes
Coverage (km²)	-
Coverage (% of estuary)	-
Depth limit	1
Dominant macrophyte	Seagrass
Dominant species	*Ruppia megacarpa*
Dominant macroalgae	Green alga (Chlorophyta)
Dominant species	*Chaetomorpha linum*
Habitat value	Fish, Invertebrates

Microalgae

Phytoplankton dominance	No		
Dominant type	Diatoms		
Activity (cells/ml)	674		
	Max	**Min**	**Med**
Chlorophyll a	82	0.5	1.0
Microalgal blooms	Yes		
Harmful algal blooms	Occasional (*Trichodesmium, Lyngbya*)		

Riparian vegetation

Mangrove (% area)	-
Saltmarsh (% area)	-
Other (% area)	-
Weed dominated	-
Flood plain connectivity	Yes

Water quality

Physical			
Temperature (°C)	**Max** 29.5	**Min** 11.0	**Med** 19.7
Salinity (PSU)	46.24	0	23.9
Frequency of hypersalinity	Infrequent		
Dissolved oxygen (mg/L)	15.9	0.1	6.4
Frequency of anoxia	Infrequent		
pH	9.0	6.4	7.7
Secchi (depth m)	6.5	0.2	1.4
	Max		**Ave**
Depth (m)	15		2.4
Nutrients	**Max**	**Min**	**Med**
TN (mg/L)	2.5	0.08	0.4
TP (mg/L)	1.1	0.005	0.03
NO_x (mg/L)	1.4	0.003	0.01
NH_3 (mg/L)	0.33	0.003	0.015
FRP (mg/L)	0.24	0.002	0.005

Sediment

	Max	**Min**	**Med**
Organic matter (%)	22.9	1.2	6.1
TSS	-	-	-
MPB (Chla, µg/g DW)	-	-	-
Porosity (%)	89.2	45.0	74.2
P binding capacity	-		
Denitrification efficiency	-		
Sediment oxygen demand	-		
TCO_2 fluxes	-		
Net respiration	-		
Sedimentation rate (mm/yr)	-		

Fish

Commercial fishing	Yes
Recreational fishing	Yes
Fish Stocks (number)	-
Estuarine species (E)	Yes (Black bream)
Marine species (M)	Yes
Target species	Black bream (E)
Dominant type	Estuarine, Estuarine/Marine
Fish Kills	Yes (infrequent)

Other

Invertebrate diversity	-
Target species	-
Poor system indicator (*C. capitata*)	-

Hydrodynamics

Residence time	Days to weeks
Bar opening frequency	Open
Bar opening duration	Permanent
Opening type	Natural
Frequency of stratification	Frequent, localised
Windmixing	Yes

Catchment summary

Catchment Size (km²)	28000
Cleared land (%)	>80
Riparian zone intact	No
Land use type	Agriculture (Crop & stock)
Main Tributaries	Blackwood River (BR)
Stream salinity	Scott River (SR)
TN	-
TP	-
Colour	Heavily stained
Hydrology	Episodic

Data Coverage

No. of water quality (WQ) sites	11
No. of sediment quality (SQ) sites	9
Frequency of data (WQ)	Fortnightly
Frequency of data (SQ)	Once off
Period data collection	1999-2005

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Swan: Lower estuary

The Swan River estuary flows through the city of Perth. Its lower reaches are relatively wide and deep, with few constrictions, while the upper reaches are usually quite narrow and shallow.

The Swan River drains the Avon and Swan Coastal catchments, which have a total area of about 121,000 km². The Avon River contributes the majority of its freshwater flow. During the summer months the estuary is tidally-driven with a maximum tidal amplitude of 1 metre. There is extreme seasonality of river flow with winter rainfall flushing the upper swan and creating a salt wedge in the lower reaches which slowly progresses upstream in autumn and summer as the winter flows cease. However, the estuary is also subject to barometric pressure changes which can result in the salt wedge moving many kilometres in a period of days.

Inlet Summary

Inlet size (km²)	23.9
Inlet shape	Narrow channel, large basin
OZCOAST classification	Wave-dominated
Bar status	Permanently open
Inlet : catchment (km²)	0.0002
Residence time	-
Phyto/SAV dominant	Phyto & SAV
Organic loading	Yes
Eutrophication (ASSETS)	TBA
Social value	Boating, fishing, passive recreation, diving
Environmental value	Birds, fish, dolphins, benthic habitat

Submerged aquatic vegetation

Present	Yes
Coverage (km²)	Seagrass: 4.61
Coverage (% of estuary)	Seagrass: 20
Depth limit	Seagrass: 2 m
Dominant macrophyte	Seagrass
Dominant species	*Halophila ovalis*
Dominant macroalgae	Rhodophyta
Dominant species	*Gracilaria comosa*
Habitat value	Invertebrates/birds/fish

Microalgae

Phytoplankton dominance	Yes		
Dominant type	Diatoms (Bacillariophyta)		
	Median	Min	Max
Activity (cells/ml)	2189	1	197 354
Chlorophyll a (µg/L)	1.7	0.1	76
Microalgal blooms	Yes - typically spring blooms (harmless)		
Harmful algal blooms	Yes - 2000: *Microcystis aeroginosa* (hepatotoxic blue-green) - 2003/04: *Karlodinium micrum* (ichthyotoxic dinophyte)		

Riparian vegetation

Mangrove (% area)	None
Saltmarsh (% area)	-
Other (% area)	-
Weed dominated	-
Flood plain connectivity	>50% sea wall structures

Water quality

Physical	Max	Min	Med
Temperature (ºC)	-	-	-
Salinity (PSU)	40.3	20.9	34.8
Frequency of hypersalinity	0%		
Dissolved oxygen (mg/L)	10.0	0.2	5.6
Frequency of anoxia	Infrequent		
pH	8.6	7.3	8.0
Secchi (depth m)	0.3	10	3
Depth (m)	Max		Ave
	17		12.7
Nutrients	**Max**	**Min**	**Med**
TN (mg/L)	3.5	0.03	0.28
TP (mg/L)	0.31	0.0025	0.013
NO_x (mg/L)	2.4	0.0025	0.009
NH_3 (mg/L)	0.26	0.0025	0.01
FRP (mg/L)	0.11	0.0015	0.03

Sediment

	Max	Min	Med
Organic matter (%)	1	0.6	-
TSS	80	1	2.2
MPB (Chla, mg/g DW)	-	-	-
Porosity (%)	60	25	-
P binding capacity	-		
Denitrification efficiency	50-100		
Sediment oxygen demand	-		
TCO_2 fluxes	20-100		
Net respiration	-		
Sedimentation rate (mm/yr)	-		

Fish

Commercial fishing	-
Recreational fishing	Yes
Fish Stocks (number)	-
Estuarine species (E)	-
Marine species (M)	-
Target species	-
Dominant type	-
Fish Kills	Yes

Other

Invertebrate species richness	-
Target species	-
Poor system indicator (*C. capitata*)	-

Hydrodynamics

Residence time	-
Bar opening frequency	Permanently open
Bar opening duration	Permanently open
Opening type	Artificially dredged
Frequency of stratification	6 months - winter and spring saltwedge
Windmixing	Yes

Catchment summary

Catchment Size (km²)	121,000
Cleared land (%)	-
Riparian zone intact	-
Land use type	Agriculture, urban, industrial
Main Tributairies	Swan-Avon and Canning Rivers
Stream salinity	-
TN	-
TP	-
Colour	-
Hydrology	Winter-spring brackish flow

Data Coverage

No. of water quality (WQ) sites	2
No. of sediment quality (SQ) sites	4
Frequency of data (WQ)	Weekly
Frequency of data (SQ)	Sporadic
Period data collection	1995-2006

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Appendix B – Conceptual model examples

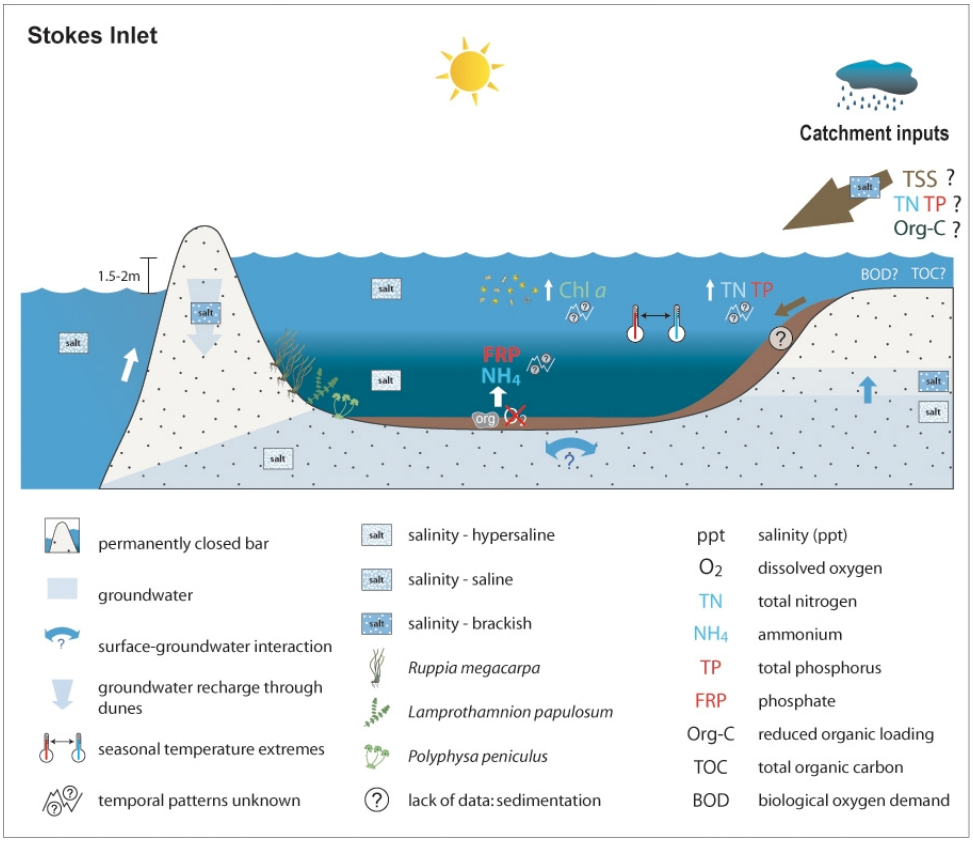

Figure 2 A conceptual model of the ecological processes operating in the estuary and data availability for Stokes Inlet.

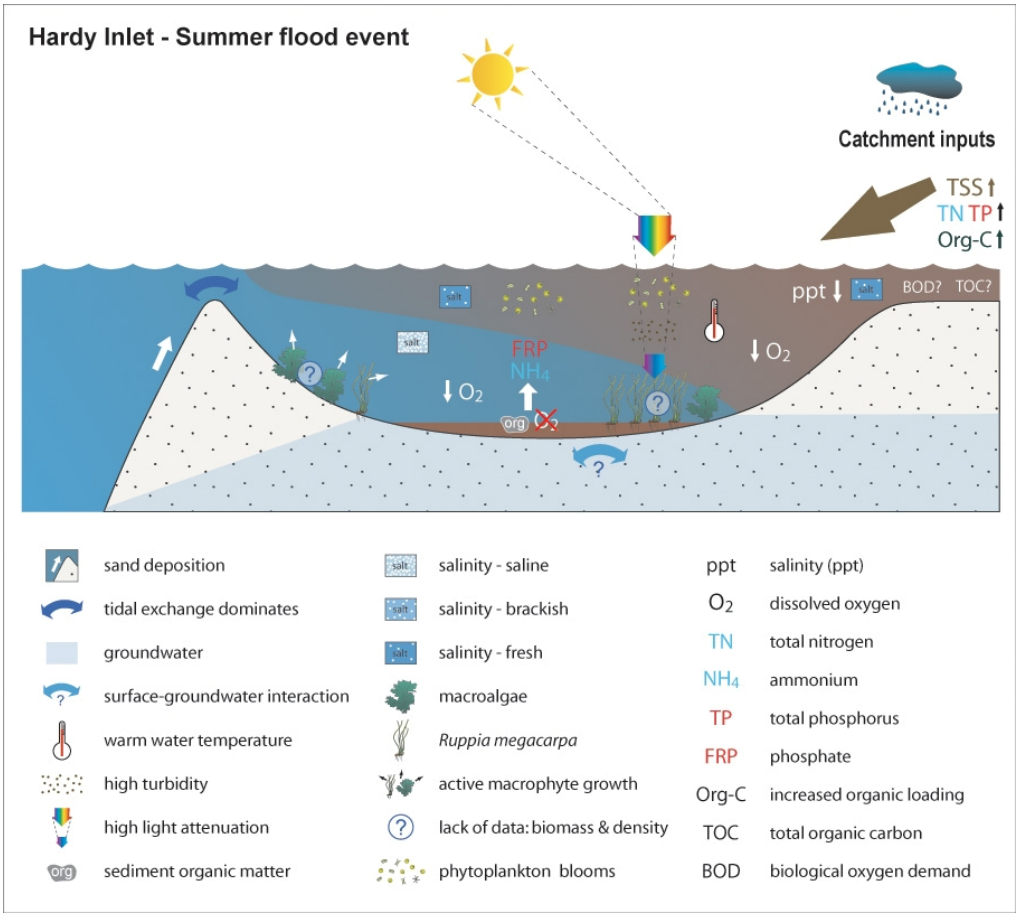

Figure 3 A conceptual model of the ecological processes operating in the estuary and data availability for Hardy Inlet focusing on atypical summer flood conditions.

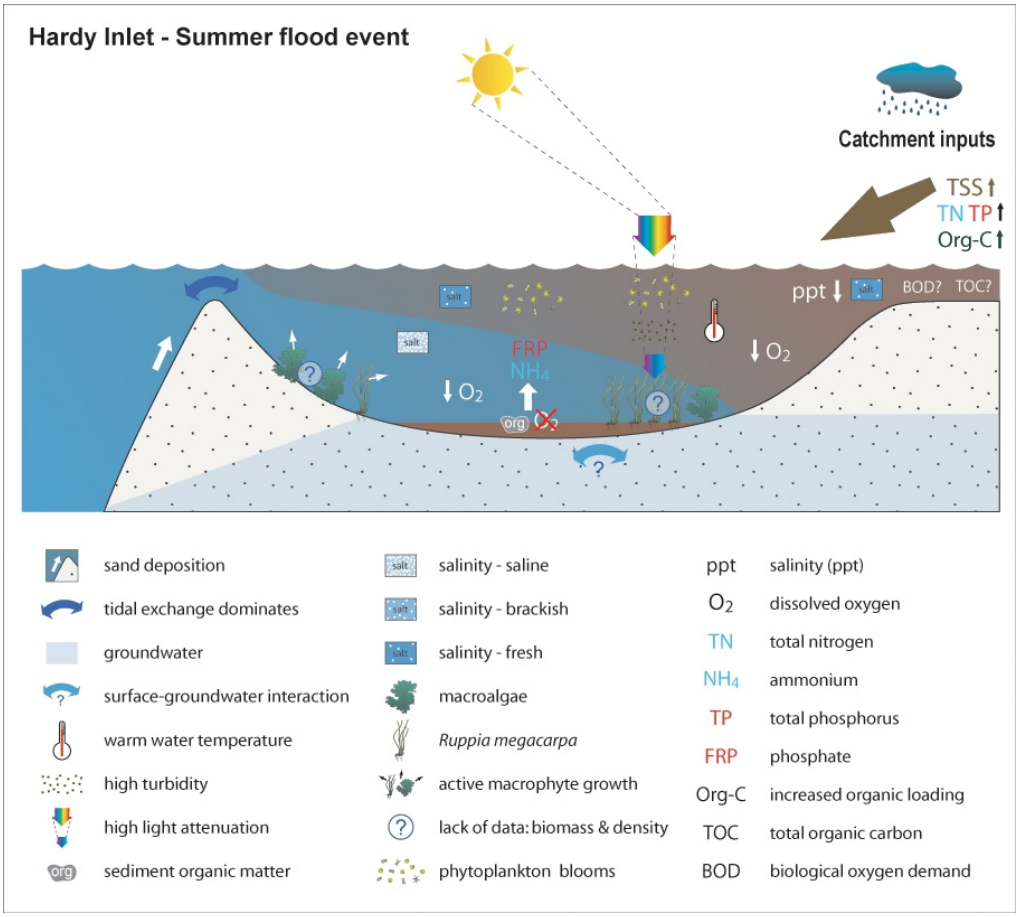

Figure 4 A conceptual model of the ecological processes operating in the estuary and data availability for Hardy Inlet focusing on atypical summer flood conditions

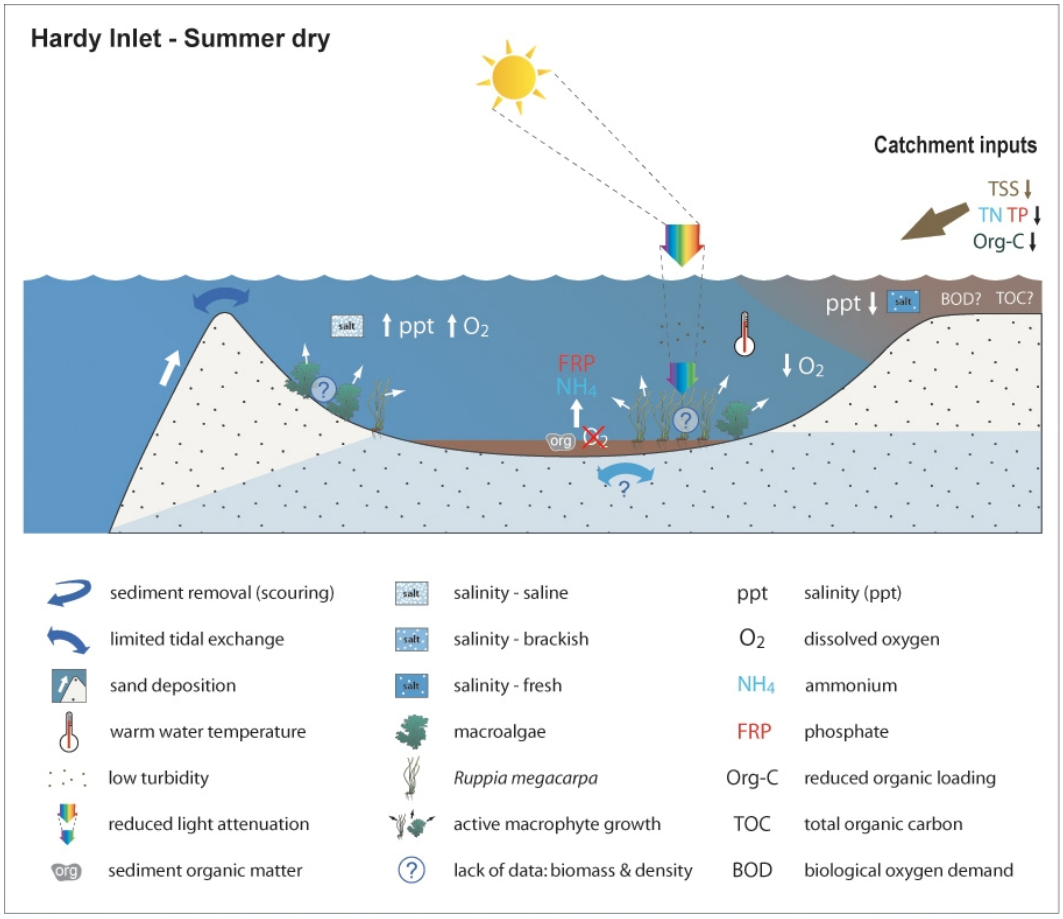

Figure 5 A conceptual model of the ecological processes operating in the estuary and data availability for Hardy Inlet focusing on typical summer conditions

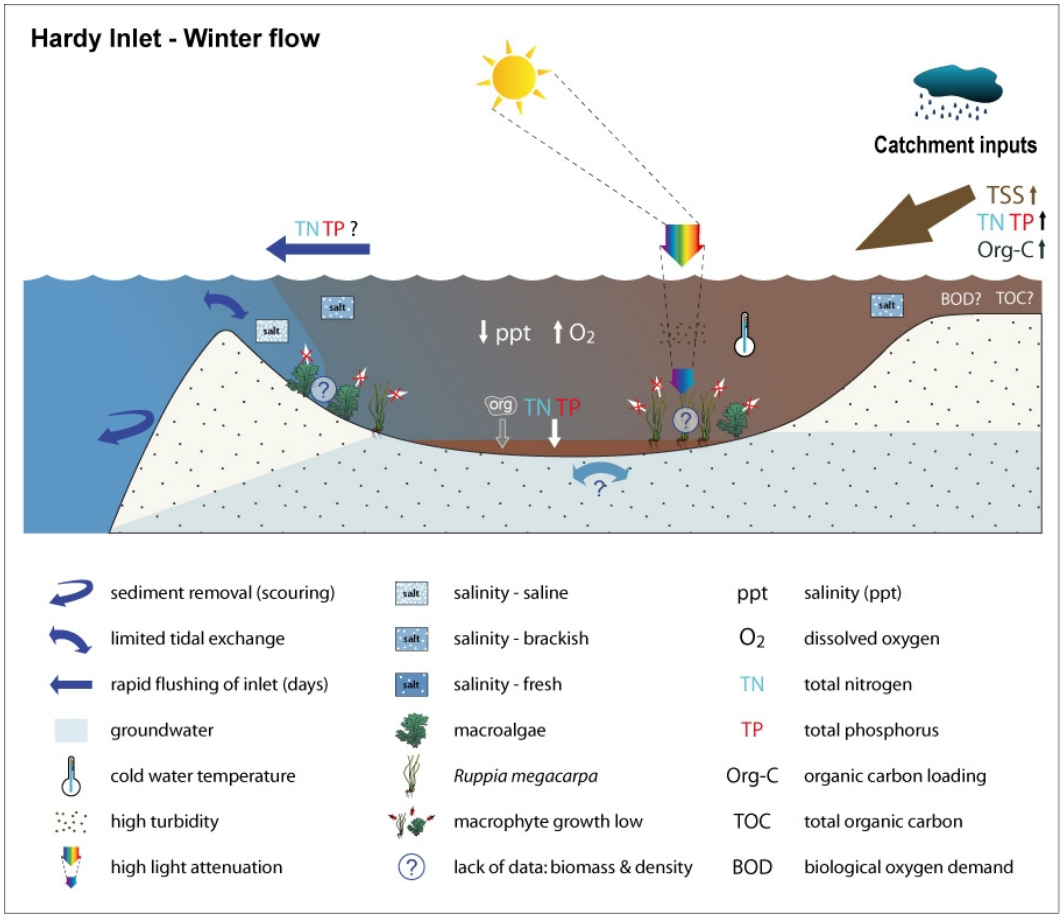

Figure 6 A conceptual model of the ecological processes operating in the estuary and data availability for Hardy Inlet focusing on typical winter conditions

Appendix C - A summary table identifying management objectives, and pressures and vulnerability scores for estuaries

Table 5. A summary table identifying management objectives, and pressures and vulnerability scores for estuaries

Estuary	Management objectives	Pressures	P (1-5)	Vulnerability Assessment	V (1-5)	(PxV)/2 (1-5)	Indicators of condition	Indicators for targets
Stoke Inlet *(Modified)*	• Aesthetic amenity • Lies partially within National Park (NP) • Ecotourism and tourism • Fishing amenity (recreation)	• Reduced flows (climate) • Catchment pressures: o clearing (70%) o salinity o sediment loading o organic loading • Fishing (low)	**2**	• Bar mostly closed • Long residence time (months to years) • Existing hypoxia and anoxia • Evidence of deteriorating condition: o phytoplankton blooms o harmful algal blooms (HAB) o fish kills	**3**	**2.5** **(Moderate)**	• Fish kills • Algal blooms • HABs (toxic) • SAV habitat integrity • Biotic diversity measures • Fish recruitment and survival	• Disoolved oxygen • Nutrients • Chla • Algal cell counts • % HAB • Dead fish • Fish stocks (target species
Hammersley Inlet *(Largely unmodified)*	• Aesthetic amenity • Manage as Marine Park (MP) • Lies totally within NP • High conservation value • Ecotourism and tourism • Fish amenity (recreation & commercial)	• Reduced flows (climate) • Catchment pressure (low): o Clearing 0% o Saline catchment o Minimal agriculture input • Internal organic loading • Fishing	**1**	• Bar mostly closed • Long residence time (months to years) • Existing hypoxia and anoxia • Evidence of deteriorating condition: o phytoplankton blooms o harmful algal blooms (HAB)	**2**	**1.5** **(Moderate)**		
Wellstead Estuary *(Modified)*	• Aesthetic amenity • Borders Fitzgerald River NP • Recreation • Ecotourism and tourism • Fish amenity (recreation)	• Urbanisation (minor) • Sewage issues • Reduced flows (climate) • Catchment pressure (high): o clearing (80-90%) o agricultural run-off o saline • Internal organic loading (high aquatic plant biomass)	**3**	• Bar mostly closed • Long residence time (months) • Evidence of deteriorating condition: o phytoplankton blooms o harmful algal blooms (HAB) o loss of SAV habitat o fish kills	**3**	**3** **(High)**		
Beaufort Inlet *(Modified)*	• Aesthetic amenity (locals) • Recreation (low) • Tourism (low) • Fish amenity (recreation & commercial)	• Reduced flows (climate) • Catchment pressure: o clearing (80%) o agricultural run-off • Fishing	**2**	• Bar mostly closed • Long residence time (months) • Evidence of deteriorating condition: o phytoplankton blooms o fish kills	**3**	**2.5** **(Moderate)**		

Table 5 cont. A summary table identifying management objectives, and pressures and vulnerability scores for estuaries

Estuary	Management objectives	Pressures	P (1-5)	Vulnerability Assessment	V (1-5)	(PxV)/2 (1-5)	Indicators of condition	Indicators for targets
Wilson Inlet *(Modified)*	• Aesthetic amenity • Recreation • Ecotourism and tourism • Fisheries (recreation & commercial)	• Urbanisation • Sewage issues • Reduced flows (climate) • Catchment pressure: o Catchment clearing (60%) o Agricultural run-off • Aquaculture • Fishing • Internal organic loading (high plant biomass) • Dredging	**4**	• Bar open annually • Poor bar opening can limit flushing • Long residence time (months) • Stratification • Evidence of deteriorating condition: o increased algal epiphytic growth o phytoplankton blooms o harmful algal blooms (HAB) o fish kills	**3**	**3.5** **(High)**	• Fish kills • Algal blooms • HABs (toxic) • SAV habitat integrity • Biotic diversity measures • Fish recruitment and survival	• Disoolved oxygen • Nutrients • Chla • Algal cell counts • % HAB • Dead fish • Fish stocks (target species
Broke Inlet *(Near pristine)*	• Lies within National Park (NP) • Aesthetic amenity (locals) • Recreation (low) • Tourism (low) • Fish amenity (recreation & commercial)	• Reduced flows (climate) • Catchment pressure (low): o Catchment clearing (5%)	**1**	• Bar mostly closed • Long residence time (months)	**1**	**1** **(Low)**		
Hardy Inlet *(Modified)*	• Marine Park • Aesthetic amenity • Recreation • Ecotourism and tourism • Fisheries (recreation & commercial)	• Urban expansion • Sewage issues • Reduced flows (climate) • Catchment pressure: o Catchment clearing (75%) o Agricultural run-off (high) o Saline catchment • Fishing • Dredging	**3**	• Narrowing of entrance channel • Existing hypoxia and anoxia • Evidence of deteriorating condition: o increased algal epiphytic growth o phytoplankton blooms o harmful algal blooms (HAB) o *Lyngbya* sp. o fish kills	**4**	**3.5** **(High)**		