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REPORT NO. RDM/WMA16/04/CON/0613, Volume 2

RESERVE DETERMINATION STUDIES FOR THE SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE GOURITZ WATER MANAGEMENT AREA

PROJECT TECHNICAL REPORT 6, VOLUME 2

ESTUARY RDM REPORT – DESKTOP RE-EVALUATION OF THE 2008 EWR STUDY ON THE KEURBOOMS ESTUARY

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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
CSIR	Centre of Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category / Electrical Conductivity
EcoSpecs	Ecological Specifications
EFZ	Estuary Functional Zone
EHI	Estuarine Health Index
EWR	Ecological Water Requirement
GPS	Global Positioning System
GRDS	Gouritz Reserve Determination Study
MAR	Mean Annual Runoff
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NBA 2011	National Biodiversity Assessment 2011
NTU	Nephelometric Turbidity Units
NWA	National Water Act (1998)
PES	Present Ecological Status
REC	Recommended Ecological Category
RDM	Resource Directed Measures
REI	River Estuary Interface
SA	South Africa
SANBI	South African National Biodiversity Institute
SC&A	Scherman Colloty & Associates cc
TPC	Threshold of Potential Concern
UNEP	United Nations Environmental Programme
WIO	Western Indian Ocean
WMA	Water Management Area
WQ	Water Quality
WRC	Water Research Commission
%ILE	Percentile

1 BACKGROUND

For the Preliminary Reserve determination studies on the estuaries of the Gouritz Water Management Area (WMA), a "best attainable" approach was adopted to assess as many estuaries as possible within the available budgetary framework. It was also decided to exclude systems for which Ecological Water Requirement (EWR) studies were conducted previously, e.g. the Keurbooms Estuary. The detail at which the ecological template for a specific system is determined depends on the availability of **appropriate** data. The more data available on a particular system, the more accurate the Recommended Ecological Category (REC), the recommended ecological flow scenario, as well as Ecological Specifications (EcoSpecs) can be set. However, in instances where the absence of certain data sets pose uncertainties, a precautionary approach should be adopted, i.e. the REC, recommended flow scenario and EcoSpecs should be set conservatively. In 2008 a Rapid level EWR assessment was conducted on the Keurbooms Estuary. While it was referred to as a "Rapid level" assessment, specialists were provided with sufficient time to interrogate all available data sets and to capture such data in specialist reports (CSIR, 2008). The information then was used by the specialists to determine the Present Ecological State (PES) of the estuary, as well as the REC as per the method prescribed for estuaries (DWAF, 2008).

The **PES of the Keurbooms Estuary was set at a Category A/B**. The system was rated as **highly important**, forming part of the core set of estuaries in need of formal protection to achieve biodiversity targets (Turpie *et al.*, 2012). According to the DWAF (2008) method guidelines, the systems therefore should be managed in a Category A, or at least in a Best Attainable State (BAS). Based on the present level of urban development around the estuary (and related tourist activities), as well as the collapsed status of certain linefish species (e.g. Steenbras and Dusky cob), specialists at the 2008 workshop concluded that it will be unlikely to rehabilitate the Keurbooms Estuary to a Category A, and therefore set the REC at a Category A/B (i.e. the BAS). This implied that the estuary must be maintained in its present state and that any anthropogenic activities potentially driving a negative trajectory of change had to be mitigated. In setting the recommended ecological flow scenario for the estuary, critical data sets were not available for the 2008 study. The missing data sets included reliable river inflow measurements on both the Keurbooms and Bitou rivers; longitudinal salinity profile datasets taken under various flows from both Bitou and Keurbooms catchments; and mouth state and water level data sets coinciding with river inflow gauging during periods of extended low flow. These data sets had to be collected for different mouth configurations, especially when the mouth is located in the eastern corner along the beach. As a result, a precautionary approach was adopted in setting the recommended ecological flow scenario in 2008, that is, the **present flow (92.7% of MAR) but including a 0.45 m^3/s diversion to Plettenberg Bay, a 0.145 m^3/s to Roodefontein and the recommended EWR for the river.**

While the Gouritz Reserve Determination Study (GRDS) initially did not include a re-assessment of the EWR of the Keurbooms Estuary, concerns raised by various interested and affected parties at stakeholder meetings motivated the estuarine specialist team to gather limited additional data (i.e. water quality, microalgae, macrophytes and invertebrates) on the Keurbooms Estuary and to conduct a Desktop re-evaluation of the 2008 EWR study. This report presents the outcome of a one-day workshop where this Desktop re-evaluation was conducted, as well as recommendations proposed for a way forward. Also included in this report is a summary of the additional data collected during a field survey on 9 December 2013.

2 CONFIRMATION OF ESTUARY BOUNDARIES

The previous EWR study on the Keurbooms Estuary was conducted prior to the delineation of the estuarine functional zone (EFZ) as per the National Biodiversity Assessment in 2011 (NBA 2011) (Van Niekerk and Turpie, 2012). The lateral geographical boundaries of the Keurbooms Estuary, in terms of the EFZ now extend further compared with the delineation used in 2008 (**Figure 2.1**). Based on the NBA 2011 the geographical boundaries for the Keurbooms Estuary therefore are defined as follows (Van Niekerk and Turpie, 2012):

Downstream boundary:	Estuary mouth 34° 2'36.41"S 23°22'54.06"E
Upstream boundary:	Keurbooms 33°57'8.04"S, 23°24'6.51"E Bitou 33°59'58.44"S, 23°20'27.49"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

Figure 2.1 Geographical boundaries of the Keurbooms Estuary

3 PRESENT ECOLOGICAL STATUS

For the re-assessment of the EWR on the Keurbooms Estuary, the following additional data and information were available:

- Geographical boundaries of the Keurbooms Estuary as per the EFZ (NBA 2011) (Van Niekerk and Turpie, 2012);
- River inflow data and water quality data (from 2009 onwards) collected by the DWS at station K6H19 in the Keurbooms River just upstream of the Keurbooms Estuary;
- Additional field data collected on water quality, microalgae and invertebrates in the Keurbooms Estuary on 9 December 2013; and
- Personal observations regarding human disturbance of birds along the estuary (J Turpie, *pers. comm.*).

Based on the additional data and information, the following was evident:

- The flow ranges allocated to various abiotic state in the Keurbooms Estuary during the 2008 study were still considered to be appropriate:

	State	**Flows (m^3/s)**
	State 1: Marine Dominated	< 0.5
	State 2: Saline with full salinity gradient	0.5 - 1.0
	State 3: Fresh with full salinity gradient	1.0 - 10.0
	State 4: Freshwater Dominated	> 10.00

- Data collected from the DWS station K6H19 indicated that modification in inorganic nutrient concentrations (dissolved inorganic nitrogen and dissolved inorganic phosphate) in river inflow from reference to present was over-estimated during the 2008 study. As a result the health score allocated to inorganic nutrients (measured as similarity between Reference Condition and Present State) increased slightly, from 88 to 90.
- With the amended geographical boundaries – the EFZ – the area previously considered for assessing the health of the supra-tidal estuarine vegetation was less. However, the extended area comprises areas that have been modified by development. As a result the health score for macrophytes reduced from 85 to 75.
- The influence of human disturbance on bird populations was mostly likely under-estimated in the helath score allocated to birds in the previous study. Therefore the similarity score for birds reduced from 83 to 77.

Table 3.1 presents the amended PES for the Keurbooms Estuary using the Estuarine Health Index (EHI) (DWAF, 2008).

Table 3.1 Revised Present Ecological Status for the Keurbooms Estuary

Variable	Weight	Score	Confidence
Hydrology	25	98	M
Hydrodynamics and mouth condition	25	99	L/M
Water quality	25	92	M
Physical habitat alteration	25	85	L
Habitat health score		**94**	
Microalgae	20	90	M
Macrophytes	20	75	M
Invertebrates	20	95	L/M
Fish	20	75	L/M
Birds	20	77	M
Biotic health score		**82**	
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		**88**	**Medium**
PRESENT ECOLOGICAL STATUS (PES)		**A/B**	

The revised PES scoring (see **Table 3.1**) revealed a slight decrease in the overall health score compared with the 2008 study (from 91 to 88), but remains in the scoring band allocated to a Category A/B. Thus the PES of the Keurbooms Estuary remains in a **Category A/B** as per the previous study (CSIR, 2008).

4 RECOMMENDATIONS

4.1 RECOMMENDED ECOLOGICAL CATEGORY

Rated as a "**highly important**" estuary, the Keurbooms Estuary should be managed in a Category A, or at least in the BAS. As concluded in the 2008 study, specialists agreed the present level of urban development around the estuary (and related tourist activities) and the collapsed status of certain linefish species makes it unlikely for the system to be rehabilitated to a Category A. They therefore re-confirmed a **REC Category A/B.** However, in order to maintain this category a range of anthropogenic activities currently causing the system to be on a negative trajectory of change must be mitigated for. As recommended in the 2008 study, the following **actions** should be undertaken as soon as possible to stabilise and improve the health state of this estuary (as per the *Keurbooms/Bitou Estuarine Wetland Assessment* – CSIR, 2008) (highest priority mitigation measures are highlighted):

- *Bitou Drift:* The drift through the Bitou River should be removed in total including all foreign rock material.
- *Northern floodplain of the lower Bitou Estuary:* Remove all exotic invasive trees from the flood plain. No further development should be allowed on the floodplain to prevent further loss of floodplain functionality. Remove the old gravel road to the south of the R340.
- *Southern floodplain of the lower Bitou Estuary:* Remove all exotic invasive plant species from the floodplain, remove the infilling, create a buffer zone (~10 m wide separating the wetland from the agricultural activities on the floodplain).
- *Road Bridge across the lower Bitou Estuary:* Remove concrete piers of the old road bridge to facilitate flow and tidal exchange in the Bitou Estuary and investigate **establishing connection with old Bitou channel.**
- *Middle reaches of the Keurbooms Estuary:* Remove all alien trees from the banks and The Island. Establish a buffer adjacent to the estuary and restrict new development on the banks of the estuary.
- *Upper reaches of the Ganse Spruit:* Remove all exotic vegetation from the stream bed.
- *The Ganse Spruit Wetlands*: Install a sufficient number of large culverts in the roads bisecting the wetlands to allow the free flow of surface water through the wetlands and remove all exotic invasive tree species.
- *Earthen barricades across tidal channels in the Bitou Arm:* **Completely remove all earthen barricades to restore connectivity on the supratidal marsh.** Maintain freshwater flow from the northern sections into the supratidal marsh south of the R340.
- *Middle reaches of the Bitou Estuary:* Remove all exotic tree species from this area, allow the artificial canal to naturally silt up, allow salt marsh to naturally re-colonise the extensive *Stenotaphrum* grasslands, insert culverts below the road bisecting the floodplain to link up the old channels.

4.2 RECOMMENDED ECOLOGICAL FLOW

A precautionary approach was adopted in setting the recommended ecological flow scenario in the 2008 study. The scenario represented a flow distribution similar to the **Present State (92.7% of MAR) but including a 0.45 m^3/s diversion to Plettenberg Bay, a 0.145 m^3/s to Roodefontein and the recommended EWR for the river.**

Despite the Keurbooms Estuary being classified as a permanently open estuary, uncertainty around potential closure remains a concern as illustrated in an aerial photograph taken of the mouth area in 1942 **(Figure 4.1**) showing a very constricted mouth. Unfortunately measurements were not available to verify river inflow patterns at the time, but it is assumed that this coincided with a period of extended low flows.

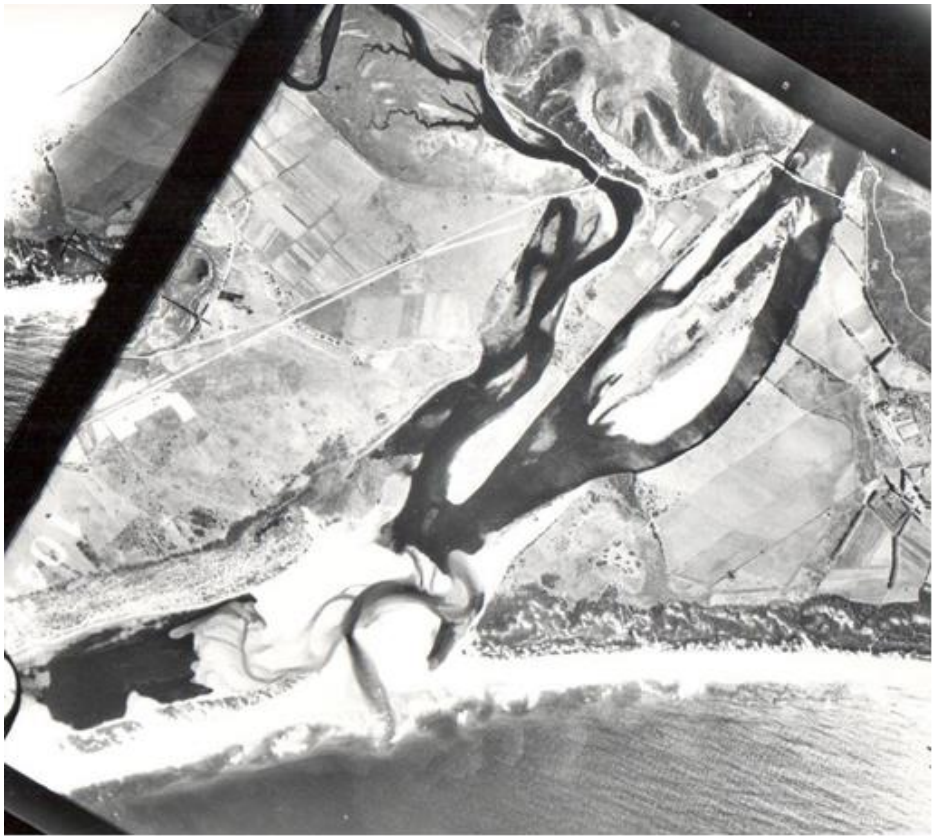

Figure 4.1 Image of the Keurbooms Estuary during 1942 showing a constricted mouth

The implications of mouth closure in a system like the Keurbooms Estuary will have significant ecological and socio-economic consequences including:

- Abundance of the sand prawn, *Callichirus kraussi* and the mudprawn *Upogebia africana* contribute over 50% to total biomass of the benthic macrofauna in the estuary and the mudprawn particularly will be markedly reduced with ripple effects into higher trophic levels such as fish and birds.
- The iconic pansy shell is likely to disappear in the dynamic tidal parts of the lower estuary around the mouth (if present) as they prefer more open marine conditions.
- Extended periods of closure will result in flooding and die-back of supra-tidal salt marsh areas.

- Macrophyte beds (e.g. Zostera) can increase to nuisance levels, and filamentous algal blooms may also start to develop under periods of reduced tidal flushing.
- A closed mouth state will prevent this important fish nursery estuary from contributing to the recovery of overexploited and collapsed stock.
- The endangered Knysna Seahorse only occurs in estuaries that is permanently open to the sea and will likely be lost from this system.
- All of the above will contribute to the loss in bird diversity.
- It increases the risk of flooding to adjacent properties surrounding the estuary.

Without the critical data sets providing understanding of the estuary's response (i.e. mouth state and saline penetration), especially during extended periods of low river inflow, it was considered irresponsible to recommend any scenario that included a significant dam development (when extended periods of low river inflows may become a reality especially during drought periods) for such an ecologically important estuary as the Keurbooms. The specialists therefore concluded that the **precautionary approach** in setting the Recommended Ecological Flow should prevail until such time as suitable data is available for refinement. Therefore the Ecological Flow Scenario recommended for maintaining the Keurbooms Estuary in a Category A/B in the 2008 study remains, that is **Present State (92.7% of MAR) but including a 0.45 m^3/s diversion to Plettenberg Bay, a 0.145 m^3/s to Roodefontein and the recommended EWR for the river** (see **Annexure B** for details) (**Table 4.1**).

Table 4.1 Recommended ecological flow scenario for the Keurbooms Estuary (Category A/B)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99	25.67	27.17	18.66	15.52	16.33	18.03	28.70	45.23	25.72	24.66	38.84	29.62
95	20.58	17.91	14.06	8.27	10.96	11.67	10.32	18.86	16.55	12.03	21.14	18.36
90	15.50	16.00	9.22	7.01	8.59	8.71	8.79	11.18	8.24	10.70	14.36	13.02
80	9.60	10.46	5.38	5.30	5.06	6.03	6.70	6.10	5.60	6.02	9.15	10.16
70	7.58	7.38	4.17	4.18	3.15	4.75	4.86	4.61	4.64	4.51	7.01	8.41
60	7.00	5.47	3.37	2.46	2.52	3.89	3.92	3.70	4.03	3.83	5.87	6.83
50	5.87	3.82	2.38	1.77	2.30	3.12	2.60	2.88	2.86	3.16	4.64	5.35
40	4.79	3.06	2.01	1.35	1.77	2.18	2.01	2.17	2.34	2.76	3.49	4.52
30	3.83	2.58	1.58	0.86	1.35	1.56	1.58	1.70	1.87	2.09	2.76	3.21
20	3.17	2.13	1.04	0.65	0.92	0.92	1.30	0.82	1.18	1.43	2.07	2.62
10	1.94	1.61	0.57	0.53	0.62	0.55	0.70	0.56	0.58	1.03	1.45	1.78
1	0.82	1.04	0.35	0.30	0.33	0.31	0.30	0.34	0.33	0.58	0.55	0.56

In the absence of data (i.e. only one hydrographical station located in the lower part of the Bitou Arm) no recommendations could be made regarding modification of inflow from the Bitou catchment. Therefore the recommended flow scenario assumes that the river flow from the Bitou River remains similar to the Present State for the following reasons:

- Base flow from the Bitou River is already very low and any further modification (abstraction) is likely to lead to periods of zero inflow to the Bitou Arm of the estuary

- The Bitou Arm supports an important, ecologically sensitive wetland, especially the upper part of the tributary where it is very narrow and shallow and potentially very sensitive to changes in flows.

In the interim, it is recommended that water resource development in this area follows an incremental, adaptive approach. This can be achieved by provisionally implementing only the "precautionary" recommended ecological flow scenario (i.e. allowing limited water abstraction, but without any dam development) and implementing the recommended monitoring programme and measuring results against EcoSpecs. This practice will provide decision-makers with the crucial data and information to gradually refine the water delivery from this catchment. In addition, **mitigation actions** – mainly aimed at rehabilitating important estuarine habitat damaged by inappropriate development – will further enhance the system's health, and possibly its resilience to support additional water delivery in future.

4.3 ECOLOGICAL SPECIFICATIONS

The EcoSpecs and associated TPCs representative of a **Category A/B for the Keurbooms Estuary** are presented in **Table 4.2**. These may need to be refined as new data become available on the system.

Table 4.2 EcoSpecs and associated TPCs for the Keurbooms Estuary (Category A/B)

Ecological component	EcoSpecs	Thresholds of Potential Concern
Hydrology	▪ Maintain flow regime	▪ Varies more than 10% of present MAR ▪ Inflow < 1.0 m^3/s for more than 10% of the time over a five-year period.
Hydrodynamics	▪ Maintain mouth state to create the required habitat for birds, fish, macrophytes, microalgae and water quality	▪ Mouth closure occur ▪ Average water level change by more than 20% from present ▪ Mouth entrance channel becomes <1.0 m deep

Ecological component	EcoSpecs	Thresholds of Potential Concern
Water quality	▪ Salinity distribution not to cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae ▪ Turbidity and Dissolved oxygen not to cause exceedance of TPCs for biota ▪ DIN/DIP concentrations not to cause in exceedance of TPCs for macrophytes and microalgae ▪ Toxic substances not to cause exceedance of TPCs for biota	▪ Average salinity > 10 at the top of the estuary in the Keurbooms and/or Bitou Arms. ▪ Average salinity > 20 along the length of the system (to be confirmed by monitoring) ▪ Dissolved oxygen (DO) < 5 mg/ℓ in estuary ▪ Turbidity > 10 NTU in low flow ▪ Secchi: to bottom ▪ DIN > 100 ug/ℓ once-off ▪ DIP > 20 ug/ℓ once-off ▪ Concentrations in water column exceed target values as per SA Water Quality Guidelines for coastal marine waters (DWAF, 1995) ▪ Concentrations in sediment exceed target values as per WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009)
Sediment dynamics	▪ Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota ▪ Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates ▪ Change in average sediment composition and characteristics ▪ Change in average bathymetry	▪ Average sediment composition (% fractions) along estuary change from baseline (to be measured) by 30% (per survey) ▪ Average depth along main channel change from 30% of baseline (to be determine) (system expected to significant fluctuation in bathymetry between flood and extended closed periods)
Microalgae	▪ Maintain median phytoplankton/ benthic microalgae biomass ▪ Prevent formation of phytoplankton blooms	▪ Phytoplankton > 3.5 ug/ℓ (median) ▪ Benthic microalgae > 11 mg/m^2 (median) ▪ Phytoplankton > 20 ug/ℓ and/or cell density >10 000 cells/ml (once-off)

Ecological component	EcoSpecs	Thresholds of Potential Concern
Macrophytes	▪ Maintain the distribution of sensitive macrophyte habitats (e.g. salt marsh, submerged macrophytes, reeds & sedges) (off special importance is the submerged macrophytes in the Bitou Arm as habitat for the endangered seahorses *Hippocampus capensis*) ▪ Rehabilitate the Bitou wetlands by removing weirs, berms, old bridges ▪ Limit the spread of invasive plants ▪ Maintain the integrity of the riparian zone	▪ Greater than 20% change in the area covered by salt marsh, submerged macrophytes and reeds & sedges ▪ No weirs, berms, old bridges in the Bitou wetlands ▪ Invasive plants cover less than 5% of the total estuarine area ▪ Unvegetated cleared areas along the banks caused by human disturbance
Invertebrates	▪ Maintain high biomass and diversity of benthic invertebrates in the lagoon area in the lower estuary. ▪ Maintain rich invertebrate communities associated with the REI zone in the upper estuary (zooplankton and benthos).	▪ Invertebrate densities of each of the three numerically dominant benthic species should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 30% in each season. ▪ The dominant species in the zone (zooplankton and benthos) should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 30% in each season.

Ecological component	EcoSpecs	Thresholds of Potential Concern
Fish	Fish assemblage should comprise the five estuarine association categories in similar proportions (diversity and abundance) to that under the reference (see 2008 EWR report). Numerically assemblage should comprise: ▪ Ia estuarine residents (50-80% of total abundance) ▪ Ib marine and estuarine breeders (10-20%) ▪ IIa obligate estuarine-dependent (10-20%) ▪ IIb estuarine associated species (5-15%), ▪ IIc marine opportunists (20-80%) ▪ III marine vagrants (not more than 5%) ▪ IV indigenous fish (1-5%) ▪ V catadromous species (1-5%) Category Ia species should contain viable populations of at least four species (*G.aestuaria, Hyporamphus capensis, Omobranchus woodii*). Category IIa obligate dependents should be well represented by large exploited species (*A. japonicus, L. lithognathus, P. commersonii, Lichia amia*). REI species dominated by both *Myxus capensis* and *G. aestuaria*.	▪ Ia estuarine residents < 50% ▪ Ib marine and estuarine breeders < 10% ▪ IIa obligate estuarine-dependent < 10% ▪ IIb estuarine associated species < 5% ▪ IIc marine opportunists < 20% ▪ III marine vagrants > 5% ▪ IV indigenous fish < 1% ▪ V catadromous species < 1% Abundance of *Hippocampus capensis* deviate by more than 10 % from baseline (Project Seahorse studies, e.g. Lockyear *et al.* 2006; Bell *et al.* 2003).
Birds	▪ Maintain population of original groups of birds present on the estuary	▪ Number of birds in any group, other than species that are increasing regionally such as the Egyptian Goose, drops below the baseline median (determined by past data and or initial surveys) number of species and/or birds counted for three consecutive summer or winter counts.

4.4 RECOMMENDED MONITORING PROGRAMME

The recommended monitoring programme to improve the confidence of the EWR study, as well as to monitoring implementation in terms of meeting ecological ROQs is presented in **Table 4.3**. Specifically the following crucial monitoring should continue/commence as soon as possible:

- Continuous water level recordings at the mouth and at the N2 Bridges in the Keurbooms Estuary to monitoring mouth state and tidal variation;
- Proper gauging of the river flow and water quality from the Keurbooms and Bitou rivers for at least a **3-5 year period that includes both extreme low flow periods and high flow event;**
- Monitoring of salinity structure and water quality (e.g. nutrients and dissolved oxygen) under various river flow conditions **for at least a 3-5 year period, especially covering extreme low flow periods in both the Keurbooms and Bitou arms;**
- Bathymetric survey of the Keurbooms Estuary between the N2 bridges and the mouth, as well as the Bitou flood plain
- Invertebrates and fish surveys including both the Bitou and Keurbooms arms.

Table 4.3 Recommended monitoring programme for the Keurbooms Estuary (priorities are highlighted)

Ecological component	Monitoring action	Temporal scale	Spatial scale
Hydrology	For larger systems record river inflow at head of estuary (smaller systems hydrology to be simulated every 10 years)	Continuous	Head of estuary in Bitou arm (to be confirmed) and Keurbooms arm [K6H19]
Hydrodynamics	Record water levels (to record mouth state and tidal variation)	Continuous	Near mouth (K6T018)
	Aerial photography (or using high resolution satellite imagery i.e. 5x5 m pixel size, e.g. Google Pro or BirdEye) (e.g. to map mouth position over time)	Annual	Entire estuary
Sediment dynamics	Monitoring Berm height using appropriate technologies	Quarterly	Mouth
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed (e.g. 300-500 m intervals) but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Every three years (and after large resetting event)	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (and ideally origin, i.e. microscopic observations)	Every three years	Entire estuary
Water quality	Electrical conductivity, pH, inorganic nutrients and organic content (e.g. TP and Kjeldahl N) in river inflow *(preferably also suspended solids and temperature)*	Monthly continuous (as in DWS monitoring programme)	Head of estuary in Bitou River (to be confirmed) and Keurbooms River [station K6H19]

Ecological component	Monitoring action	Temporal scale	Spatial scale
	Salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity)	Ideally monthly for the first year and then quarterly	12-15 stations along length of estuary (e.g. see **Figure A.1**, but include additional station into the Bitou arm towards head of estuary)
	Inorganic nutrient concentrations (together with above)	Every three years (high and low flows) or when significant change in water quality expected	12-15 stations along length of estuary (e.g. see **Figure A.1**, but include additional station into the Bitou arm towards head of estuary)
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Watling and Newman, 2007).	Once-off, then every three – six years, if results show contamination	Entire estuary, including depositional areas (i.e. muddy areas)
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. Chlorophyll-*a* measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe. Intertidal and subtidal benthic chlorophyll-*a* measurements (four replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe.	Quarterly, for first two years and then low flow surveys every three years	Along length of estuary minimum five stations

Ecological component	Monitoring action	Temporal scale	Spatial scale
Macrophytes	Map area covered by different macrophyte habitats using recent imagery. Conduct field survey to record total number of macrophytes habitats, identification and total number of macrophytes species, number of rare or endangered species, or those with limited populations. Assess extent of invasive species in EFZ. Where there are salt marsh areas greater than 1 ha measure % plant cover along elevation gradient. Sediment samples collected along the transect and analysed in the laboratory for sediment moisture, organic content, EC, pH and redox potential. In the field measure depth to water table and ground water salinity.	Every three years in summer	Entire estuary (mapping) Where there is salt marsh (minimum three transect sites)

Ecological component	Monitoring action	Temporal scale	Spatial scale
Invertebrates	Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) along estuary. Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um). Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um). Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site). Establish the species concerned *(Callichirus kraussi* or *Upogebia Africana*) using a prawn pump. Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton) (*preferably link with sediment dynamics*)	Quarterly, for first two years and then every two years mid-summer	Minimum of three sites along length of entire estuary including the Keurbooms and Bitou arms For hole counts –three sites in each of muddy or sandy areas

Ecological component	Monitoring action	Temporal scale	Spatial scale
Fish	• Record species and abundance of fish, based on seine net and gill net sampling. Sampling with a small beam trawl for channel fish should also be considered • Seine net specifications: 30 m x 2 m, 15 mm bar mesh seine with a 5 mm bar mesh with a 5mm bar mesh 5 m either side and including the cod-end • Gill nets specifications: Set of gill nets each panel 30 m long by 2 m deep with mesh sizes of 44 mm, 48 mm, 51 mm, 54mm, 75 mm, 100 mm and 145 mm • Gill net sampling can be replaced by a large mesh seine (44 mm stretch mesh, 100 m x 2 m) • Trawl specification: 2 m wide by 3 m long, 10 mm bar nylon mesh in the main net body and a 5 mm bar in the cod-end	Quarterly, over at least one year to account for the seasons, then twice annually spring/ summer and autumn/ winter	12-15 stations along length of estuary (e.g. see **Figure A.1**, but include additional station into the Bitou arm towards head of estuary)
Birds	Undertake counts of all non-passerine waterbirds, identified to species level.	Quarterly, over at least one year to account for the seasons, then twice annually summer and winter	Entire estuary (approximately seven sections)

The implementation of the monitoring programme should be undertaken in collaboration of various responsible departments in Department of Water and Sanitaiton (DWS), as well as other national and provincial departments and institutions responsible for estuarine resource management such as Department of Agriculture, Forestry and Fisheries (DAFF), Department of Environmental Affairs (DEA: Oceans and Coasts), South African National biodiversity Institute (SANBI), CapeNature, as well as relevant municipal authorities. It is recommended that the estuarine management planning process and the associated institutional structures (as required under the Integrated Coastal Management Act, 2008) be used as a mechanisms to coordinate and execute this long-term monitoring programme.

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APPENDIX A: SUMMARY OF ADDITIONAL DATA COLLECTED ON 9 DECEMBER 2013

A.1 WATER QUALITY

Sampling locations in the Keurbooms Estuary (**Figure A.1**) on 9 December 2013 is provided in **Figure A.1**. Raw data is presented in **Table A.1**.

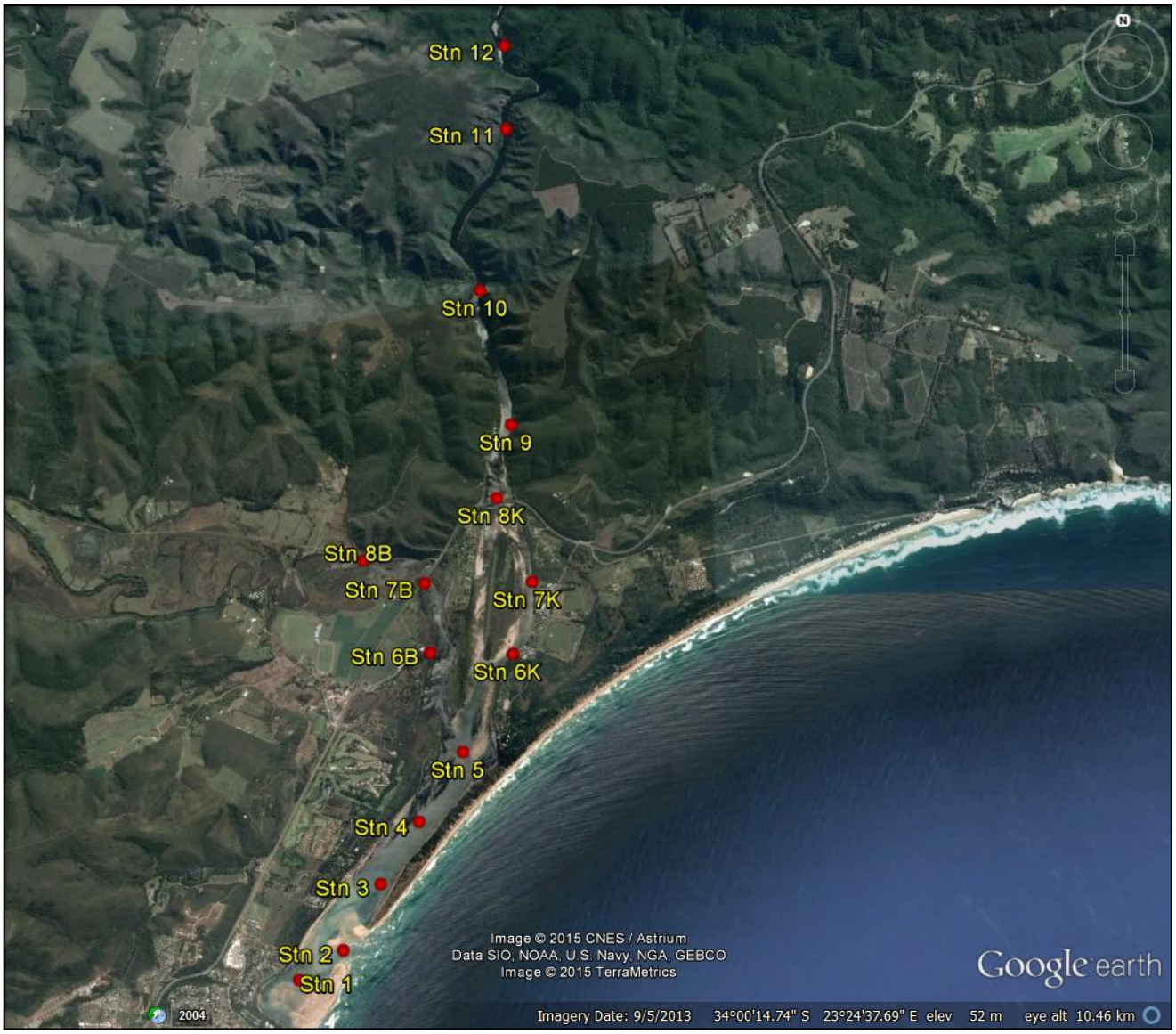

Figure A.1 Water quality sampling station in Keurbooms Estuary on 9 December 2013

During the December 2013 survey, sampling in the Bitou arm only went up to Station 8B. However, waters at this location were still brackish, but due to time constraints this arm could not be sampled further upstream. In future, sampling stations in the Bitou arms should be extended up stream up to the head of the estuary (see **Figure 2.1** in the main report for the proposed upper boundary of this arm).

The salinity profiles recorded in the estuary on 9 December 2013 is presented in **Figure A.2a**, while a summary of other water quality data are presented in **Figure A.2b**.

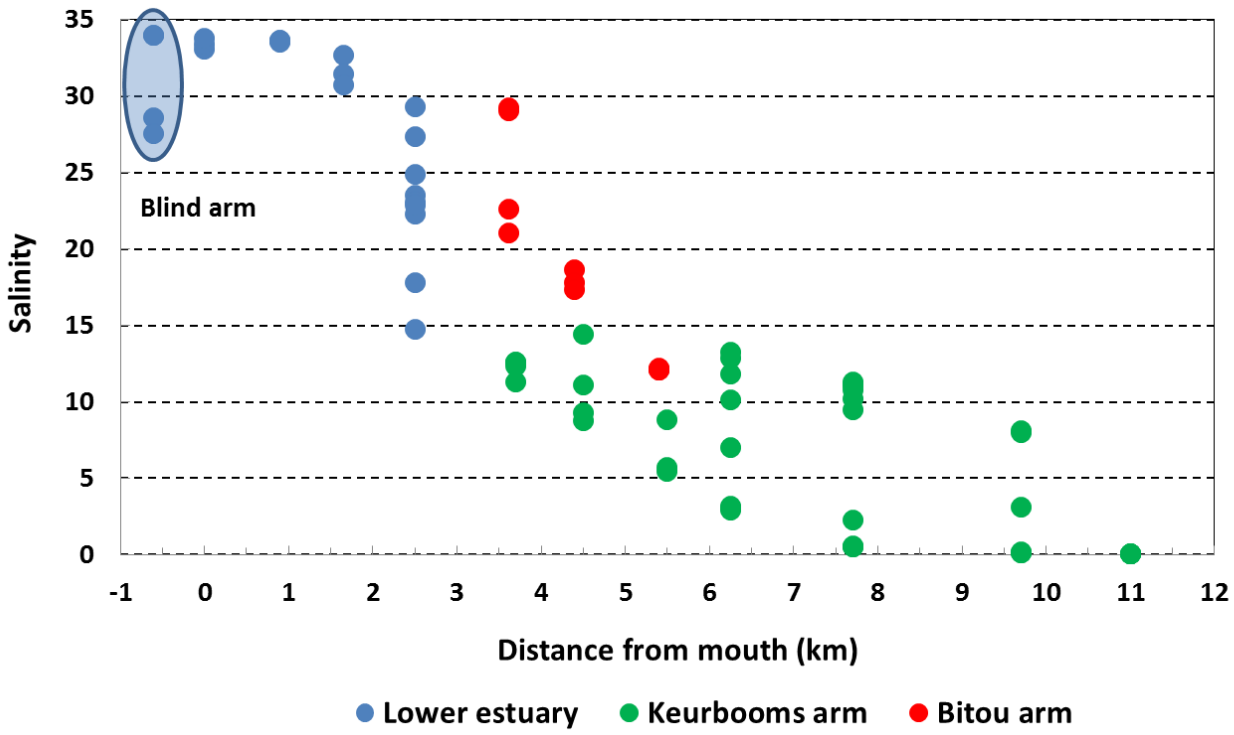

Figure A.2a Salinity profile in the Keurbooms/Bitou Estuary on 9 December 2013

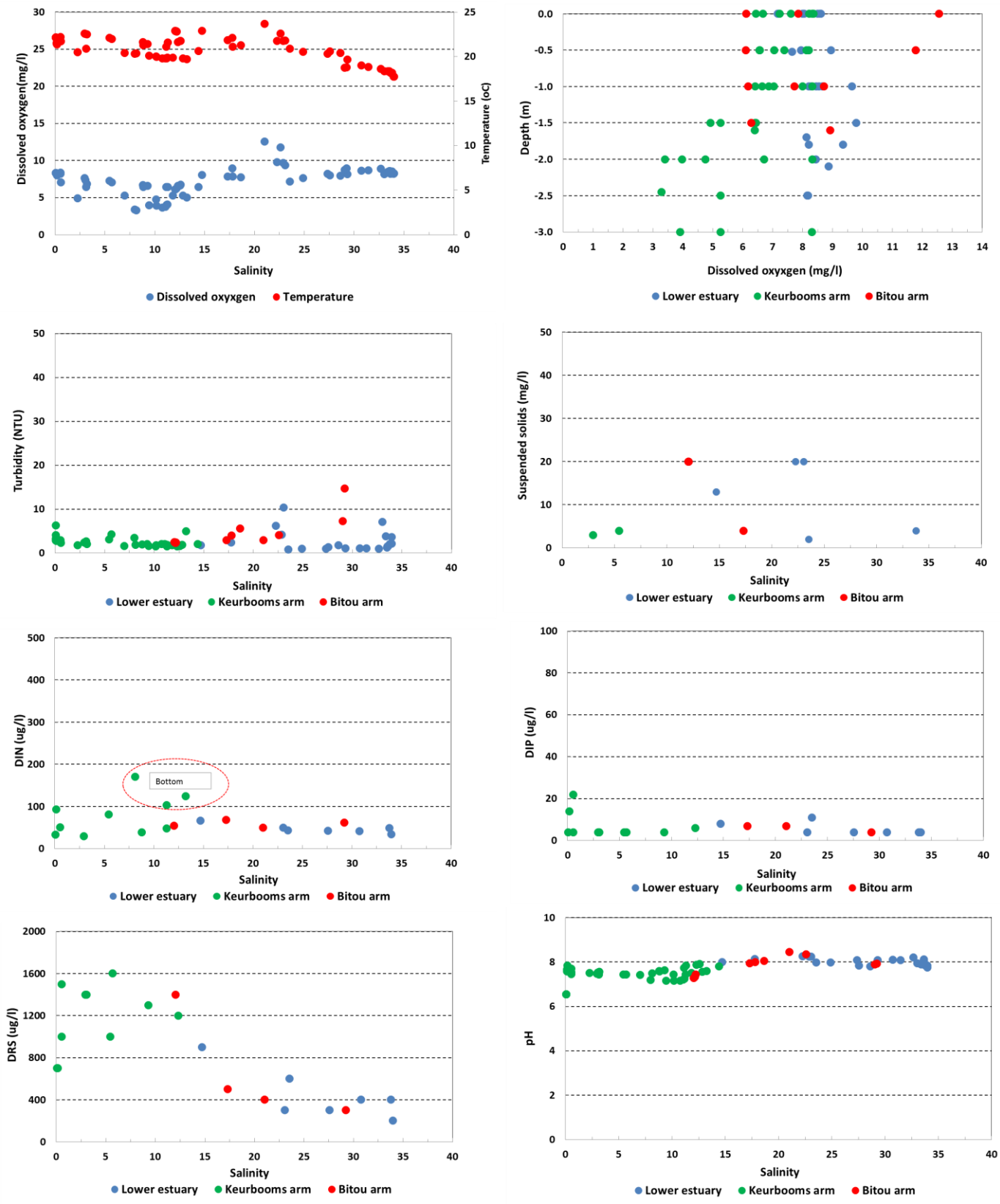

Figure A.2b Summary of water quality data collected in the Keurbooms Estuary on 9 December 2013

Table A.1 Summary of water quality data collected in the Keurbooms Estuary on 9 December 2013

Date	Time	Stn	X Cordinates	Y Coordinates	Depth (m)	Temp	Salinity	pH	NTU	SS (mg/l)	DO (mg/l)	DO (%)	Secchi (m)	NH4-N (µg/l)	NOX-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
09-Dec-13	11:50	1	34 2.717S	23 22.6E	1.80	17.7	34.0	7.8	2.2		8.2	106		29	5	4	200	
09-Dec-13	11:50	1	34 2.717S	23 22.6E	1.00	17.7	34.0	7.8	3.7		8.3	106						
09-Dec-13	11:50	1	34 2.717S	23 22.6E	0.50	20.4	28.6	7.8	1.8		8.0	105						
09-Dec-13	11:50	1	34 2.717S	23 22.6E	0.00	20.6	27.6	7.8	1.4		8.0	104	>1.8	37	5	4	300	
09-Dec-13	12:20	2	34 2.566S	23 22 895E	2.50	18.4	33.0	8.0	7.1		8.2	106						
09-Dec-13	12:20	2	34 2.566S	23 22 895E	1.00	18.4	33.4	7.9	3.8		8.5	109						
09-Dec-13	12:20	2	34 2.566S	23 22 895E	0.00	18.2	33.8	7.8	2.1	4	8.5	110		34	15	4	400	<50
09-Dec-13	12:35	3	34 2.216S	23 23.156E	2.50	18.2	33.6	8.1	1.6		8.2	107						
09-Dec-13	12:35	3	34 2.216S	23 23.156E	2.00	18.2	33.6	8.0	1.6		8.4	109						
09-Dec-13	12:35	3	34 2.216S	23 23.156E	1.00	18.2	33.6	8.0	1.5		8.5	111						
09-Dec-13	12:35	3	34 2.216S	23 23.156E	0.00	18.4	33.5	8.0	1.3		8.6	112	>2.5					
09-Dec-13	12:42	4	34 1.886S	23 23.424E	2.10	18.6	32.7	8.2	1.0		8.9	115						
09-Dec-13	12:42	4	34 1.886S	23 23.424E	1.00	18.9	31.4	8.1	1.1		8.7	111						
09-Dec-13	12:42	4	34 1.886S	23 23.424E	0.00	19.0	30.7	8.1	1.1		8.6	113	>2.1	34	7	4	400	
09-Dec-13	12:52	5	34 1.514S	23 23.732E	1.70	19.7	29.3	8.1	1.1		8.1	106						
09-Dec-13	12:52	5	34 1.514S	23 23.732E	1.00	20.3	27.4	8.1	1.0		8.2	107						
09-Dec-13	12:52	5	34 1.514S	23 23.732E	0.52	20.5	24.9	8.0	1.0		7.6	97						
09-Dec-13	12:52	5	34 1.514S	23 23.732E	0.00	20.9	23.5	8.0	0.8	2	7.2	92	>1.7	37	6	11	600	<50
09-Dec-13	14:30	5	34 1.514S	23 23.732E	1.80	21.8	23.1	8.3	10.4	20	9.4	121		22	28	4	300	
09-Dec-13	14:30	5	34 1.514S	23 23.732E	1.50	21.7	22.3	8.3	6.2	20	9.8	127						
09-Dec-13	14:30	5	34 1.514S	23 23.732E	1.00	21.8	22.9	8.3	4.2		9.7	124						
09-Dec-13	14:30	5	34 1.514S	23 23.732E	0.50	22.1	17.8	8.1	2.4		9.0	114						
09-Dec-13	14:30	5	34 1.514S	23 23.732E	0.00	22.9	14.7	8.0	1.8	13	8.1	98		37	29	8	900	<50
09-Dec-13	13:32	6 (BITOU)	34 0.963S	23 23.533E	1.60	18.8	29.2	7.9	14.7		8.9	114		41	21	4	300	
09-Dec-13	13:32	6 (BITOU)	34 0.963S	23 23.533E	1.00	18.8	29.0	7.9	7.3		8.7	111						
09-Dec-13	13:32	6 (BITOU)	34 0.963S	23 23.533E	0.50	22.6	22.6	8.4	4.1		11.8	153						
09-Dec-13	13:32	6 (BITOU)	34 0.963S	23 23.533E	0.00	23.7	21.0	8.5	3.0		12.6	170	>1.6	38	12	7	400	
09-Dec-13	13:45	7 (BITOU)	34 0.579S	23 23.511E	1.00	21.3	18.7	8.1	5.6		7.7	97						
09-Dec-13	13:45	7 (BITOU)	34 0.579S	23 23.511E	0.50	21.1	17.8	8.0	4.0		7.8	99						
09-Dec-13	13:45	7 (BITOU)	34 0.579S	23 23.511E	0.00	21.8	17.3	7.9	3.0	4	7.9	99	>1	43	25	7	500	<50
09-Dec-13	14:10	8 (BITOU)	34 0.44S	23 23.11E	1.50	22.8	12.2	7.4	2.4		6.3	78						
09-Dec-13	14:10	8 (BITOU)	34 0.44S	23 23.11E	1.00	22.8	12.2	7.3	2.3		6.2	77						
09-Dec-13	14:10	8 (BITOU)	34 0.44S	23 23.11E	0.50	22.9	12.1	7.3	2.4	20	6.1	76						
09-Dec-13	14:10	8 (BITOU)	34 0.44S	23 23.11E	0.00	22.9	12.1	7.3	2.5	20	6.1	77	>1.5	44	10		1400	

Date	Time	Stn	X Cordinates	Y Coordinates	Depth (m)	Temp	Salinity	pH	NTU	SS (mg/l)	DO (mg/l)	DO (%)	Secchi (m)	NH4-N (µg/l)	NOX-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
09-Dec-13	15:08	6 (KEURB)	34 0.987S	23 24.086E	2.00	21.7	12.6	7.9	1.6		6.7	82						
09-Dec-13	15:08	6 (KEURB)	34 0.987S	23 24.086E	1.00	21.8	12.6	7.9	1.6		6.6	81						
09-Dec-13	15:08	6 (KEURB)	34 0.987S	23 24.086E	0.50	21.6	12.3	7.9	1.5		6.6	79						
09-Dec-13	15:08	6 (KEURB)	34 0.987S	23 24.086E	0.00	21.6	11.3	7.8	1.5		6.4	78	>2	21	27	6	1200	
09-Dec-13	15:20	7 (KEURB)	34 0593S	23 24232E	1.60	20.6	14.4	7.8	2.1		6.4	78						
09-Dec-13	15:20	7 (KEURB)	34 0593S	23 24232E	1.00	21.1	11.1	7.7	2.0		6.4	77						
09-Dec-13	15:20	7 (KEURB)	34 0593S	23 24232E	0.50	21.4	9.3	7.6	2.1		6.6	79						
09-Dec-13	15:20	7 (KEURB)	34 0593S	23 24232E	0.00	21.6	8.8	7.6	2.0		6.7	80	>1.6	19	20	4	1300	
09-Dec-13	15:37	8 (KEURB)	34 0.12S	23 24.014E	1.50	21.3	8.8	7.6			6.4	75						
09-Dec-13	15:37	8 (KEURB)	34 0.12S	23 24.014E	0.50	22.0	5.7	7.4	4.3		7.1	84						
09-Dec-13	15:37	8 (KEURB)	34 0.12S	23 24.014E	0.00	22.1	5.5	7.4	3.1	4	7.2	86		48	33	4	1600	<50
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	3.70	19.7	13.2	7.6	5.0		5.0	58		63	61	4	1000	
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	3.00	19.8	12.8	7.6	1.9		5.3	62						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	2.50	19.9	11.8	7.5	1.8		5.3	61						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	2.00	20.0	10.2	7.4	1.5		4.8	56						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	1.50	20.4	7.0	7.4	1.6		5.3	62						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	1.00	22.5	3.2	7.6	2.1		6.9	82						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	0.50	22.5	3.0	7.5	2.3		7.4	87						
09-Dec-13	15:50	9 (KEURB)	33 59.718S	23 24131E	0.00	22.6	2.9	7.5	2.4	3	7.6	82	1.9	18	11	4	1400	<50
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	7.00	19.9	11.3	7.4	1.9		4.0	47		63	40	4	1400	
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	6.00	19.8	11.2	7.3	1.9		4.0	47						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	5.00	19.8	11.1	7.2	2.1		3.8	44						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	4.00	19.8	10.8	7.2	2.1		3.7	43						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	3.00	20.0	10.2	7.2	1.8		3.9	46						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	2.00	20.1	9.5	7.2	1.6		4.0	46						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	1.50	20.5	2.3	7.5	1.8		4.9	58						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	1.00	21.7	0.6	7.7	2.3		7.0	56						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	0.50	22.2	0.5	7.5	2.8		8.2	95						
09-Dec-13	16:32	10 (KEURB)	33 58.960S	23 23.954E	0.00	22.2	0.5	7.5	3.0		8.4	96		46	5	4	1000	
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	2.45	20.3	8.1	7.5	1.9		3.3	23		114	56	22	1500	
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	2.00	20.3	8.0	7.2	3.5		3.4	40						
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	1.50	20.9	3.1	7.4	2.7		6.4	75						
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	1.00	21.4	0.2	7.8	2.8		8.0	91						
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	0.50	21.4	0.2	7.7	2.8		8.1	93						
09-Dec-13	16:57	11 (KEURB)	33 58.046S	23 24.167E	0.00	21.5	0.2	7.6	2.8		8.2	93	1.4	86	7	14	700	
09-Dec-13	17:10	12 (KEURB)	33.57.569S	23 24177E	3.50	22.2	0.1	6.6	6.3		8.3	95						
09-Dec-13	17:10	12 (KEURB)	33.57.569S	23 24177E	3.00	22.1	0.1	6.6	4.1		8.3	95						
09-Dec-13	17:10	12 (KEURB)	33.57.569S	23 24177E	2.00	22.2	0.1	6.6	3.3		8.3	96						
09-Dec-13	17:10	12 (KEURB)	33.57.569S	23 24177E	1.00	22.1	0.1	6.6	3.1		8.3	96						
09-Dec-13	17:10	12 (KEURB)	33.57.569S	23 24177E	0.00	22.1	0.1	6.6	2.9		8.3	96		28	5	4	700	

A.2 MICROALGAE

A summary of the microalgae data collected in the Keurbooms Estuary on 9 December 2013 is presented in **Tables A.2** to **A.4** (see **Figure A.1** for station positions).

Table A.2 Phytoplankton chlorophyll *a* measured in the Keurbooms Estuary on 9 December 2013

Stn	Distance from mouth (km)	Water depth (m)	Phyto plankton chl *a* (ug/ℓ)
1	0.3	0.0	1.51
1	0.3	0.5	1.86
1	0.3	1.0	1.84
5	2.4	0.0	0.44
5	2.4	0.5	0.80
5	2.4	1.0	0.83
8B	5.2	0.0	0.92
8B	5.2	0.5	1.04
8B	5.2	1.0	1.18
9	5.9	0.0	1.10
9	5.9	0.5	1.39
9	5.9	1.0	0.95
9	5.9	2.0	0.41
9	5.9	3.0	0.50
12	10.7	0.0	0.21
12	10.7	2.5	0.09

Table A.3 Phytoplankton community structure in the Keurbooms Estuary on 9 December 2013

Phytoplankton community composition (%)					
Stn	**Flagellates**	**Diatoms**	**Dinoflagellates**	**Blue-green**	**Coccolithophorids**
1	29.1	67.5	2.8	0.0	0.6
5	65.4	32.4	2.1	0.0	0.0
8B	85.5	14.1	0.4	0.0	0.0
9	96.8	1.5	1.7	0.0	0.0
12	64.9	35.1	0.0	0.0	0.0

Table A.4 Benthic microalgal chlorophyll *a* and community structure measured in the Keurbooms Estuary on 9 December 2013

Stn	Benthic chl a (mg/m^2)	Benthic microalgal composition (relative abundance of dominant benthic diatoms >10%)
1 intertidal	35.84	*Nitzschia linkei* = 21%; *Opephora horstiana* = 18% *Plagiotropis tayrecta* = 11%; *Nitzschia frutulum* = 10%
1 sub-tidal	56.53	Very few frustules; *Fallacia cassubiae* = 43%
5 intertidal	42.96	Sample empty, no frustules present
5 sub-tidal	136.25	*Gyrosigma faciola* var. arcuatum = 16%; *Opephora horstiana* = 11%
8B intertidal	109.46	*Nitzschia clausii* = 16%
8B sub-tidal	56.78	*Nitzschia filiformis* v. filiformis = 31%; *Achnanthes delicatula* = 25%
9 intertidal	59.80	Sample empty, no frustules present
9 sub-tidal	58.71	Sample empty, no frustules present
12 intertidal	5.00	Sample empty, no frustules present
12 sub-tidal	13.57	Sample empty, no frustules present

A.3 MACROPHYTES

Vegetation and sediment characteristics were analysed along five transects located in the lower reaches of the Keurbooms Estuary below the N2 Bridge (Veldkornet unpublished data) across the terrestrial – salt marsh habitats (**Table A.5**). Constrained Correspondence Analysis (CCA) of species and environmental factors separated the vegetation into three distinct communities: salt marsh, fringe and terrestrial (**Table A.6**).

Table A.5 GPS location of the transects in the Keurbooms Estuary

Transect 1	34.008002° S; 23.394644° E
Transect 2	34.008112° S; 23.394620° E
Transect 3	34.022526° S; 23.389666° E
Transect 4	34.023115° S; 23.389340° E
Transect 5	34.023709° S; 23.388847° E

Table A.6 Species composition of the salt marsh, fringe and terrestrial habitats in the Keurbooms Estuary

	Salt marsh	Fringe	Terrestrial
1	*Disphyma crassifolia*	*Carpobrotus edulis*	*Acacia cyclops*
2	*Plantago crassifolia*	*Disphyma crassifolia*	*Acacia saligna*
3	*Cotula coronopifolia*	*Juncus kraussii*	*Asparagus racemosus*
4	*Gazania regins*	*Lycium* sp.	*Brachyleana discolour*
5	*Juncus kraussii*	*Passerina vulgaris*	*Carpobrotus edulis*
6	*Limonium linifolium*	*Pennisetum clandestimum*	*Chrysanthemoides monilifera*
7	*Sarcocornia pillansii*	*Samolus porosus*	*Ekebergia capensis*
8	*Sarcocornia* sp	*Searsia schintz*	*Grewia occidentalis*
9	*Spartina maritima*	*Senecio* sp.	*Helichrysum cymosum*
10	*Sarcocornia tegetaria*	*Sideroxylon inerme*	*Lauridia tetragonia*
11	*Aster sqamatus*	*Stenotaphrum secundatum*	*Lycium* sp.
12	*Bassia diffusa*	*Tetragonia fruticosa*	*Passerina vulgaris*
13	*Spergularia media*	*Themeda triandra*	*Rhoicisus tridentate*
14	*Sporobolus virginicus*		*Searsia pterota*
15	*Stenotaphrum secundatum*		*Searsia lucida*
16	*Triglochin buchenaui*		*Sideroxylon inerme*
17	*Triglochin striata*		*Solanum sp.*
18	*Zostera capensis*		*Tetragonia decumbens*
19			*Themeda triandra*

Past (1936) and recent (2007) vegetation maps of the Keurbooms Estuary is presented in **Figure A.4.**

Figure A.4 Past (1936) and recent (2007) vegetation maps of the Keurbooms Estuary. Floodplain agriculture (471 ha) and invasive plants (20 ha) have resulted in a loss of estuarine habitat

A.4 INVERTEBRATES

Quantitative data on the zooplankton of the Keurbooms estuary are not available, although Grindley (unpublished data) described the estuarine zooplanton as 'rich and abundant' (36 cm net used). Thirty-nine taxa were recorded during his survey in 1969. The copepod, *Pseudodiaptomus hessei* was the numerically dominant species, being particularly abundant towards the upper reaches of the estuary. Other important taxa in the zooplankton included the copepod *Acartia natalensis* and the mysid shrimp *Gastrosaccus brevifissura*.

Forty-two macroinvertebrate species are recorded from the Keurbooms estuary (earlier surveys). The benthic fauna is best developed (species richness) between the tidal inlet and bridges across the respective estuaries. Although the diversity is relatively high, seven of these species make up 95% of the biomass of the benthic community. Mudprawns reached a maximum density of 480 holes m^{-2} (average of about 335 holes m^{-2}, or 170 prawns m^{-2}, Duvenage and Morant, 1984). The mudprawn *Upogebia qfricana* and the sandprawn *Callichirus kraussi* are particularly common (Zoutendyk and Bickerton 1996, unpublished data).

Integrating data provided by Duvenage and Morant (1984) (**Table A.7**) average number of prawns m^{-2} for each grid square (250 x 250 m)) enables rough calculations to be made. The total estuarine mudprawn population is about 65 million prawns. Similarly, the *Callichirus kraussi* (maximum density is about 360 sandprawn m^{-2} with an average of 175 prawns m-2) population is estimated to be about 70 million prawns. Currently, recreational fishermen are permitted to collect 50 of each prawn species per day. In sandy areas on the northern side of the lagoon, Solen reached a maximum of 40 holes m^{-2} while the maximum for *Arenicola* was 1 hole m^{-2}.

Table A.7 Species contribution to standing stock (tons of carbon) of the seven dominant macrobenthic species in different regions of the Keurboos-Bitou estuary. BA = Blind arm, MR = Middle reaches, UR = Upper reaches, B = Bitou. Bold = Peak distribution

Species	BA	MR	UR	B	Total	%
Upogebia africana	0.5	-	**3.9**	**7.5**	11.9	24.9
Callichirus kraussi	0.5	0.9	**8.1**	-	9.5	19.6
Upogebia/Callichirus	1.8	-	**2.9**	-	4.7	9.8
Loripes clausus	**2.8**	**1.4**	**2.6**	-	6.8	14.1
Sesarma catenata	0.3	0.1	**4.9**	0.5	5.8	12.0
Nassarius kraussianus	1.4	0.5	**2.4**	0.8	5.1	10.6
Dasybranchus caducus	**0.8**	**0.7**	-	-	1.5	3.0

The location of sampling stations in the December 2013 survey is presented in **Figure A.1** (Stations 1, 5, 8B, 9).

Physico-chemical information was collected at four sites, focusing on water temperature, salinity, oxygen content of the water. Unfortunately, strong winds developed during the field study and

prevented additional sites being covered. Dater were collected at the surface and at 0.5 m depth intervals

Physico-chemical data were collected on a strong out-going tide when sampling commenced at Station 1 (**Figure A.1**). A strong south-easterly wind was also blowing, particularly at the mouth. Results are shown in **Table A.8** for all parameters measured and in **Figure A.5** for water temperature and salinity collected at two levels in the water column (near the surface and just above the substrate). Near-surface and bottom water salinity below the N2 bridge suggested a highly stratified estuary. Upstream of the bridge the water was well mixed in shallow water areas. However, lack of data precludes any comment along the main channel of the estuary. At the time, very strong winds impacted sampling efficiency and it was not possible to complete further study.

Table A.8 Physico-chemical data collected on the 9 December 2013 in the Keurbooms Estuary, coinciding with the invertebrate sampling survey

Station	Depth (m)	Temperature	Salinity	DO %	DO (mg/ℓ)	pH
1	0	25.18	17.73	97.4	7.26	7.93
	0.5	21.22	28.32	97.4	7.33	7.92
	0.75	19.56	32.26	110.9	8.38	8
5	0	24.55	15.3	116.5	8.94	8.22
	0.5	23.41	22.77	84.2	6.23	7.96
	1	23.01	28.96	66.1	4.75	7.89
	2	22.12	31.74	12.1	5.22	7.89
8B	0	22.86	7.4	93.8	7.73	7.04
	0.5	22.52	7.98	95.2	7.87	7.11
	1	23.86	25.48	76.9	5.5	7.15
	2	22.93	30.42	53.7	3.85	7.44
	3	22.83	30.61	55.1	2.94	7.61
	4	2207	30.64	45	3.3	7.64
	5	22.65	30.65	41	2.85	7.65
9	0	19.7	0.12	99	9.6	7.81
	0.5	19.59	0.12	99	9.7	7.67

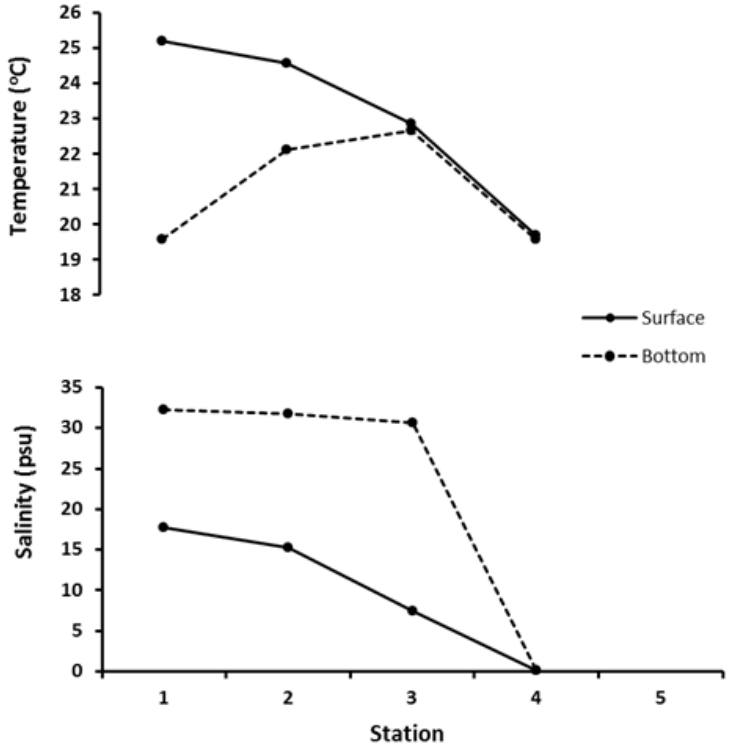

Figure A.5 Temperature and salinity distribution measured on 9 Dec 2013 in the Keurbooms Estuary (coinciding with the invertebrate survey, corresponding stations in Figure A.1: 1=1; 2=5, 3=8B; 4 = 9)

Analysis of biological samples was completed in the laboratory. Final abundance was expressed as the average number of each species per m^2 of substratum at each site, determined from the six replicates respectively. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.6 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

Hyperbenthos

Hyperbenthic animals were sampled at all sites in the two estuaries using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm. Attached to this frame was a 500 µm mesh net. A calibrated flowmeter mounted in the entrance quantified water volume passing through the net. Animals collected were then stored in 500 ml plastic bottles and preserved in 10% formaldehyde solution. In the laboratory animals were identified to species level under a microscope and final abundance expressed as average numbers per m^3 of water calculated from the two samples collected at each site. Animals captured in sled samples are usually fairly large, measuring up to 1-2 cm. Most of the smaller organisms such as copepods escape through the mesh and were therefore not enumerated or identified in sled samples, although their presence was noted **Table A.9 and Figure A.5**).

Table A.9 Abundance of hyperbenthic organisms (ind. m^{-3}) in the Keurbooms Estuary (data represent mean values of two replicates collected on 9 Dec 2013 at four stations – see Figure A.1 for location)

Station	1	5	8B	9
Copepoda				
Acartia longipatella	0.0	5.0	0.0	0.0
Copepod spp	162.0	73.0	20.0	0.0
Oithona spp	0.0	0.0	18.0	0.0
Pseudodiaptomus hessei	0.0	208.0	164.0	163.0
Mysidacea				
Gastrosaccus brevifissura	0.0	0.0	2.0	8.0
Mesopodopsis wooldridgei	0.0	17.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	2.0	0.0	0.0
Cumacea				
Iphinoe truncata	0.0	0.0	6.0	15.0
Isopoda				
Munna sp.	0.0	0.0	0.0	3.0
Sphaeromid juvs	0.0	0.0	1.0	0.0
Amphipoda				
Amphipod sp.	10.0	0.0	0.0	0.0
Corophium triaenonyx	0.0	0.0	0.0	12.0
Grandidierella lignorum	0.0	0.0	0.0	20.0
Caridea				
Carid juvs.	0.0	1.0	0.0	1.0
Penaeidea				
Penaeid juvs	5.0	0.0	0.0	0.0
Brachyura				
Hymenosoma orbiculare larvae	0.0	0.0	10.0	15.0
Hymenosoma orbiculare juvs	1.0	1.0	0.0	3.0
Crab megalopa	1.0	0.0	0.0	0.0
Zoea larvae	39.0	4.0	1.0	0.0

Abundance levels shown in **Table A.9** must be considered low and well below expected levels usually found in south coast temperate estuaries. This was likely due to river flooding a few weeks previously and the community sampled was still in a recovery phase (Refer to **Figure A.5** for salinity recorded).

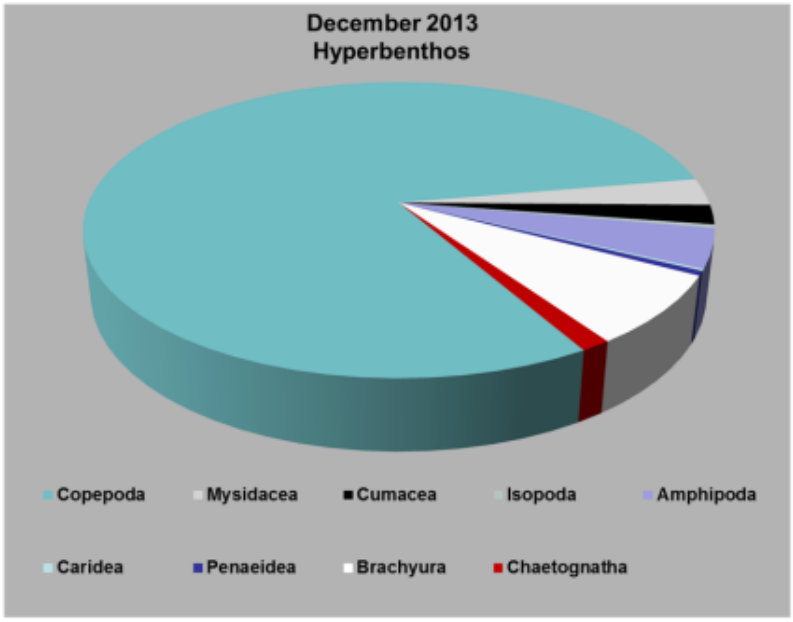

Figure A.4 Pie diagram of the most abundant hyperbenthic taxa in the Keurbooms Estuary. Values represent their total abundance at all sites in the estuary (see Table A.8) and expressed as percentage contribution of each group.

Benthos

A sediment sample collected at each station provided information on particle size distribution and percent organic content. Dry samples (dried at 60^{o}C for 48 h and then weighed) were incinerated at 550^{o}C for 12 h to burn off the organic matter. The difference in weight of the sample after incineration provided information on organic content, expressed as a percentage. Three replicates from each sediment sample were used to obtain a final value. Samples were then soaked in distilled water for 24 h to remove salts. Excess water was carefully siphoned off and the sample again dried at 60^{o}C for 72 h. Dried sediment was then vibrated through a series of metal test sieves (2 mm, 1 mm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, 90 µm, 63 µm and < 63 µm) (**Table A.10**).

Table A.10 Particle size distribution and % organic content in sediments of the Keurbooms Estuary on 9 December 2013 (for location of stations see Figure A.1)

Station	Particle size distribution				Organic matter (%)
	➢ 0.500µm	< 0.500 - 0.125 µm	< 0.125 - 0.065 µm	< 0.065 µm	
1	0	5.29	93.69	1.02	0.71
5	0	2.73	96.48	1.25	1.1
8B	0	26.97	71.78	1.11	0.74
9	22.17	74.94	2.59	1.17	1.01
12	0.43	95.88	65.33	2.10	1.00

Subtidal benthic invertebrates were collected during daylight from the deck of the flat-bottomed boat using a Van Veen type grab. Five sites were sampled in each estuary. Six replicates were collected at each site and the contents of each sieved through a 500 µm mesh screen bag. The grab sampler had a 564 cm^2 bite that penetrated the sediment down to about 10 cm depth. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution for further analysis in the laboratory (**Table A.11 and Figure A.6**). Similar comments apply to the benthic community sampled as for hyperbenthos, with density of species well below expected levels. Species richness was also low.

Table A.11 Abundance of macrozoobenthic organisms (ind. m^{-2}) in the Keurbooms Estuary (data represent mean values of six replicates collected in December 2013 at four stations – see Figure A.1 for location)

Station	1	5	8b	9
Polychaeta				
Ceratonereis keiskama	0	139	0	3
Juvenile polychaeta	92	257	6	0
Nephys sp.	18	0	0	0
Orbinia angrapenguensis	0	30	0	0
Prionospio sp.	393	428	0	0
Mysidacea				
Gastrosaccus brevifissura	0	3	0	3
Cumacea				
Iphinoe truncata	0	0	3	0
Isopoda				
Cyathura estuaria	0	0	6	12
Amphipoda				
Corophium triaenonyx	0	0	0	160
Grandidierella lignorum	0	0	92	257
Brachyura				
Paradylodiplax algoense	0	3	0	0
Mollusca				
Nassa kraussianus	9	33	0	0
Bivalve spat	0	56	0	0
Modiolus capensis	0	0	9	0
Sanguinolaria capensis	15	0	6	0
Solen capensis	18	11	0	0
Tellina sp.	74	160	0	0

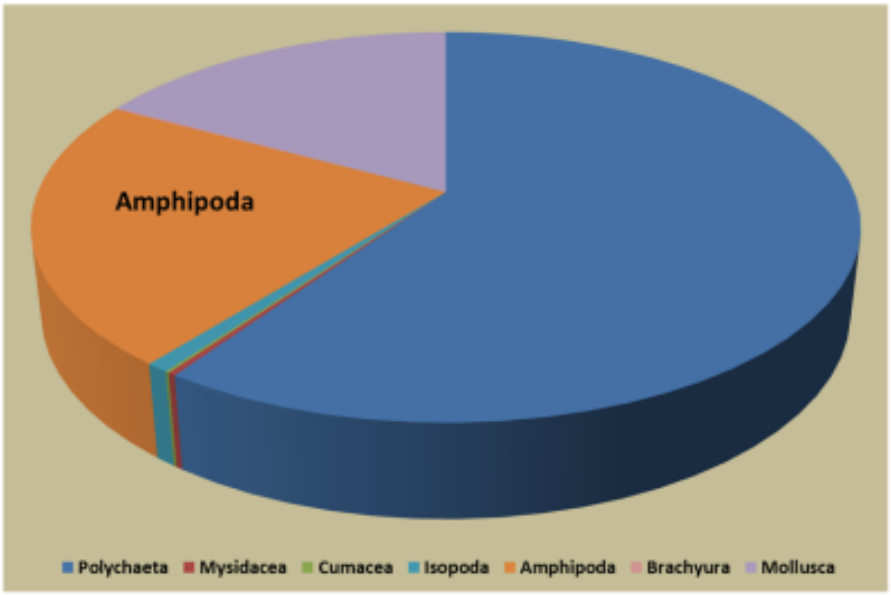

Figure A.6 **Pie diagram of the most abundant hyperbenthic taxa in the Keurbooms Estuary. Values represent their total abundance at all sites in the estuary (see Table A.11) and expressed as percentage contribution of each group**

APPENDIX B: DETAILED SIMULATION FOR RECOMMENDED FLOW SCENARIO

Monthly simulated runoff (72-year period) for the recommended ecological flow scenario to maintain the Keurbooms Estuary in Category A/B:

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
1934	21.43	10.10	0.88	0.33	1.15	0.75	2.00	56.52	24.72	6.04	7.85	9.27	11.834
1935	7.74	7.47	4.18	1.32	0.98	2.85	1.73	5.11	2.96	5.11	3.03	5.28	3.998
1936	5.78	10.46	6.44	2.03	1.40	3.31	1.08	0.36	1.16	5.49	3.83	8.11	4.129
1937	5.28	3.07	4.86	4.65	0.94	0.39	1.11	0.60	0.79	0.66	1.22	3.92	2.301
1938	3.97	7.97	5.21	0.84	9.94	9.09	3.14	0.59	0.34	4.03	19.19	13.06	6.423
1939	4.53	3.29	1.84	3.37	12.87	5.70	1.90	1.54	1.18	2.80	1.63	1.87	3.490
1940	1.32	1.28	0.38	1.10	2.54	1.91	9.24	3.94	5.11	3.72	1.97	3.00	2.944
1941	9.47	5.85	6.09	6.65	2.21	2.12	1.12	7.82	5.79	3.39	2.78	2.42	4.670
1942	4.76	3.37	2.24	6.36	2.33	3.73	2.11	0.78	0.97	1.19	3.85	14.86	3.874
1943	8.23	15.97	10.72	1.56	1.13	1.39	0.69	30.79	15.44	11.88	6.79	11.49	9.724
1944	7.39	2.46	0.63	0.31	0.34	0.31	0.29	16.27	19.61	7.76	3.44	1.86	5.082
1945	3.13	1.38	0.81	0.85	1.48	9.20	3.66	0.50	0.38	1.05	2.48	2.78	2.318
1946	5.72	2.45	0.41	0.47	0.61	5.13	4.40	4.27	4.02	12.15	5.68	4.60	4.190
1947	4.09	3.60	1.45	0.85	0.84	0.73	4.60	1.86	0.77	0.80	1.11	3.71	2.029
1948	7.94	5.08	3.05	2.25	2.31	0.45	1.46	3.02	1.66	0.69	0.75	2.04	2.559
1949	1.34	16.68	5.40	0.39	0.51	0.38	0.40	0.47	0.35	8.13	9.64	7.14	4.243
1950	6.55	24.86	12.99	17.44	7.39	1.03	0.33	1.62	3.28	22.75	14.20	11.61	10.363
1951	4.32	0.57	0.35	4.17	4.91	1.09	1.41	3.53	4.17	3.21	12.22	23.42	5.260
1952	9.42	2.62	1.25	0.82	2.93	0.99	0.74	0.47	6.82	11.53	20.09	12.43	5.866
1953	29.85	13.93	2.68	0.54	0.33	2.38	2.87	8.61	5.98	10.73	44.06	18.38	11.796
1954	2.57	7.56	2.04	4.15	24.31	8.40	2.07	1.28	2.19	2.63	3.88	3.50	5.257
1955	4.93	16.22	4.54	0.78	1.65	3.45	1.70	14.16	6.97	1.46	1.22	8.45	5.459
1956	15.60	7.89	3.81	3.52	3.10	3.72	1.79	3.50	6.69	4.12	5.79	8.48	5.680
1957	6.21	1.54	0.41	0.35	0.34	3.60	4.29	7.56	5.24	1.87	7.77	4.99	3.702
1958	5.15	1.87	2.01	8.34	3.74	4.01	10.75	7.28	2.73	3.71	14.37	8.01	6.018
1959	7.97	3.54	1.85	7.60	2.72	5.15	5.05	3.95	4.04	4.41	2.81	7.56	4.733
1960	3.51	2.95	3.82	4.00	2.10	9.80	5.29	5.02	3.00	2.68	4.60	3.01	4.169
1961	4.16	2.24	1.09	3.37	2.06	7.13	5.17	1.78	0.80	1.09	36.70	15.23	6.781
1962	14.34	10.05	1.87	1.62	0.78	16.96	9.44	3.51	2.23	7.52	6.46	3.11	6.536
1963	2.31	1.12	4.08	6.39	2.21	2.61	4.38	1.77	6.56	4.17	8.74	28.34	6.041
1964	10.38	6.05	1.81	0.57	0.35	6.92	7.53	4.88	4.05	3.38	1.78	1.60	4.130
1965	19.03	19.12	5.60	4.97	3.94	0.74	1.29	2.84	1.84	1.30	6.75	5.89	6.116
1966	2.29	1.81	1.45	0.80	2.26	6.91	27.66	21.68	8.25	6.82	4.62	6.32	7.575
1967	3.50	2.30	1.34	0.41	0.72	4.08	3.09	2.41	27.10	10.80	5.98	8.68	5.860
1968	6.19	5.88	2.00	1.45	2.19	3.68	1.88	0.58	4.85	3.50	2.73	2.61	3.128
1969	5.78	2.30	0.36	0.30	6.09	1.88	0.52	0.41	0.38	0.59	10.72	6.16	2.941
1970	3.22	0.95	13.14	4.36	5.84	5.57	9.16	8.82	4.63	23.21	29.76	10.26	9.981
1971	1.96	6.51	2.94	0.84	11.14	4.84	1.22	2.05	3.89	5.15	7.04	3.63	4.219
1972	1.74	1.02	0.44	0.98	1.96	2.83	4.05	2.42	2.17	1.66	2.19	4.42	2.150
1973	3.02	5.78	1.96	7.40	8.26	8.43	3.14	7.66	4.82	1.65	9.23	7.16	5.694
1974	3.05	3.77	1.09	3.96	6.09	3.61	1.28	0.50	1.75	4.25	4.79	12.62	3.870
1975	4.61	2.20	5.13	2.26	1.62	5.65	2.02	2.02	2.11	5.90	4.09	2.93	3.404
1976	20.27	12.22	3.61	0.62	11.81	7.14	1.61	16.02	8.57	2.31	4.58	6.88	7.948
1977	7.27	7.70	2.61	0.56	0.33	0.35	0.61	0.75	2.07	2.08	7.90	5.14	3.126
1978	4.47	3.98	4.38	3.63	1.61	0.38	1.16	2.14	2.24	8.13	17.72	10.98	5.100
1979	3.44	1.18	0.54	1.63	0.60	0.30	1.78	1.23	4.36	2.52	2.79	4.97	2.113
1980	7.20	5.62	4.96	14.49	7.86	19.56	14.53	40.45	17.90	4.09	22.42	10.05	14.165
1981	11.65	4.93	2.25	0.75	0.53	1.19	30.52	11.35	2.64	2.63	1.91	9.98	6.682
1982	8.00	2.31	0.83	0.30	1.32	0.73	0.42	1.52	9.45	28.05	11.81	6.95	6.023
1983	7.01	3.56	2.21	0.70	1.12	2.03	0.80	0.43	0.43	0.86	0.87	0.96	1.756
1984	1.37	1.85	1.43	5.01	10.08	4.57	3.80	1.56	2.05	3.09	1.86	0.96	3.094
1985	12.80	9.32	7.27	5.64	1.20	0.37	0.31	0.31	0.39	0.71	8.32	5.20	4.350
1986	11.04	4.77	1.60	1.46	2.19	1.77	8.41	3.13	1.86	1.18	3.12	18.34	4.888
1987	7.31	0.99	0.79	0.62	0.35	0.51	7.40	5.02	3.77	2.70	4.27	3.77	3.137
1988	3.89	1.89	1.00	0.60	0.38	0.52	3.98	1.93	1.00	2.34	1.81	1.57	1.747
1989	20.89	19.44	3.75	0.68	8.31	2.90	5.18	3.99	5.07	2.87	2.42	2.69	6.485
1990	5.67	5.34	1.60	1.58	2.93	1.39	0.35	0.47	0.76	1.21	1.59	1.15	1.996
1991	6.67	2.60	3.97	1.33	3.48	1.68	1.02	2.62	2.34	4.68	10.02	5.17	3.813
1992	23.94	15.40	2.35	0.82	0.53	0.54	3.47	3.66	3.67	2.51	2.60	32.75	7.672
1993	12.37	2.73	3.44	2.60	3.16	2.00	6.36	4.14	2.26	3.11	6.70	5.22	4.522
1994	7.39	2.72	14.69	6.73	4.54	7.43	8.21	5.49	3.51	2.20	2.27	1.87	5.611
1995	1.22	16.77	15.43	5.11	0.55	0.43	0.34	0.36	0.33	0.51	1.49	2.23	3.742
1996	19.74	32.55	14.51	1.70	1.75	4.55	8.35	6.10	5.08	3.55	5.60	4.22	8.990
1997	4.83	1.76	0.76	2.28	1.15	4.08	1.72	1.30	1.05	1.95	3.57	2.56	2.266
1998	1.73	2.42	0.93	1.59	1.55	4.06	2.56	0.80	0.40	1.20	1.23	1.59	1.672
1999	6.14	1.99	0.35	5.19	6.59	13.23	5.09	0.58	0.33	0.24	0.24	0.45	3.360
2000	1.06	11.68	9.18	5.82	2.27	1.77	7.20	2.59	0.54	1.00	6.28	4.35	4.478
2001	2.90	3.40	3.29	7.38	2.84	1.34	0.58	0.42	1.02	3.69	7.94	8.27	3.599
2002	2.84	4.75	1.97	0.51	1.58	13.36	7.58	5.94	4.38	1.89	1.28	0.85	3.924
2003	0.78	1.64	0.46	1.00	0.46	0.68	1.30	1.07	1.58	1.81	2.13	9.26	1.841
2004	6.83	1.95	25.73	10.77	1.56	2.88	6.23	2.69	1.10	0.71	0.50	0.45	5.174
2005	0.43	10.60	3.37	1.60	2.80	2.92	3.60	3.09	3.63	4.42	4.86	4.83	3.835

APPENDIX C: COMMENTS AND RESPONSE REGISTER

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Comments: Andrew Gordon (DWS) dated 12 May 2015				
8.2	EcoSpecs	No EWRs and EcoSpecs have been proposed for alternate Ecological Category scenarios	No	In terms of the Estuary methods (DWA, 2008) and ToR for this preliminary Reserve study, EcoSpecs will only be provided for REC
8.2	EcoSpecs	Phrase “Resource Quality Objective” is used to describe what I think are actually EcoSpecs	Yes	RQOs changed to EcoSpecs throughout report
8.3	Monitoring programme	Recommended monitoring programmes for the estuaries are beyond the current capabilities of the DWS/CMA. Is it possible to suggest a monitoring plan that is phased in over a number of years so that the managing agency has a chance to build capacity	Yes, mostly	Priority components in the monitoring programme has been identified. Also the monitoring was split between baseline surveys and long-term monitoring.
8.2	EcoSpecs: Fish	EcoSpecs for fish need to be more explicit	Yes	Uncertainly in EcoSpecs for fish was addressed
Comments: Dr Angus Paterson (external reviewer, SAIAB) dated May 2015				
No specific comments for amendments to Report				
Comments: Esther Lekalake (Classification, DWS) dated 17 Jun 2015				
Entire report	Edits	Some corrections required	Yes	Corrected
List of Acronyms	List of Acronyms	Include list of acronyms	Yes	Included
4	Recommendations	Include ecological flow scenario as Table	Yes	Table included