Biophysical Assessments of the Zinkwazi & Nonoti Estuaries:

High & Low Flow Surveys 2012/2013

ORI Unpublished Report No. 310

Biophysical Assessments of the Zinkwazi & Nonoti Estuaries: High & Low Flow Surveys

December 2013

OCEANOGRAPHIC RESEARCH INSTITUTE

Compiled For:	Zinkwazi Beach Ratepayers and Residents Association Lower Tugela Biodiversity Protection Project
Funded By:	Critical Ecosystem Partnership Fund & through Wildlands Conservation Trust
Compiled By: Fiona MacKay Jill Sheppard Bronwyn Goble	Oceanographic Research Institute
In Collaboration With: Steven Weerts	Council for Scientific & Industrial Research

ORI Unpublished Report 310

Oceanographic Research Institute
P.O. Box 10712
Marine Parade, 4056
Durban, KwaZulu-Natal, South Africa
Tel: +27 31 3288222
Fax: +27 31 3288188
Web site: www.ori.org.za

Title:	Biophysical Assessments of the Zinkwazi & Nonoti Estuaries: High & Low Flow Surveys
Document Creator/s:	Fiona MacKay, Jill Sheppard, Steven Weerts & Bronwyn Goble
Client/Funding Agencies:	Zinkwazi Beach Ratepayers and Residents Association Lower Tugela Biodiversity Protection Project Critical Ecosystem Partnership Fund & through Wildlands Conservation Trust
Subject and keywords:	Zinkwazi & Nonoti Estuaries, baseline biophysical surveys, macrobenthos, ichthyofauna, information for estuarine management plans and environmental flow assessments
Description:	This study presents data and information gathered during low (winter, July 2012) and high flow (summer, February 2013) surveys conducted in the Zinkwazi and Nonoti Estuaries. An account of the biophysical condition of each system is presented, including additional material on spatial analysis of land use, coastal vulnerability and interpolation of the estuarine physico-chemical habitat as they pertain to input information towards estuarine management plans and estuarine flow assessment studies.
ORI Project Codes:	330 & 335
Document Status:	Final
Year Issued:	2013
Report Type:	Unpublished Report
ORI Report No.:	310
Latest Version	ORI Unpublished Report No. 310.pdf
Language:	English
Coverage:	KwaZulu-Natal, South Africa
Distribution:	ORI Library, authors and clients
Cover Photos:	by F MacKay
Citation:	MacKay F., Sheppard J. Weerts S. & Goble B. 2013. Biophysical Assessments of the Zinkwazi & Nonoti Estuaries: High & Low Flow Surveys. Oceanographic Research Institute, Durban: 160pp & Appendices 126pp. (ORI Unpublished Report 310).

Table of Contents

1. PREAMBLE

The assessment and monitoring of abiotic parameters and biological communities in the evaluation and management of water resources such as estuaries, is now well recognised and commonplace. National (e.g. DWAF 1999) and international directives (e.g. European Union 2000) indicate that there is increasing recognition that such programmes should be based on monitoring of environmental indicators against a baseline condition. In many cases monitoring programmes are only implemented after anthropogenic activities have impacted upon a water resource and the lack of information on the reference state of the system being monitored is often problematic. In such cases, the reference condition could be determined by comparison with a control area (often difficult to locate), hindcasting (requires good previous data), predictive modelling (requires adequate empirical and stochastic models) or expert judgement (subjective and difficult to quantify) (Whitfield & Elliot 2002).

The state of our environment in recent years has used 'change' as a measure of condition. Detecting status and trends has become one of the central themes of modern ecology. Aiding the meaningful assessment of environmental change is the implementation and development of environmental indicators (Bortone 2005). Only through setting a baseline reflecting change as temporal and spatial trends will meaningful data be captured and most importantly, will appropriate management decisions and mitigation measures be put in place.

1.1 Terms of Reference

The Nonoti and Zinkwazi Estuaries have either directly or indirectly suffered some form of ecological degradation and/or habitat destruction. Clearly, both systems are subject to a high degree of anthropogenic impact resulting from various activities arising from communities adjacent to the estuaries. Unchecked, the consequences of all these activities will undermine the ecological services that these systems provide.

To address some of these issues, and to provide a framework within which to commence setting up management plans and protocols for the catchment, the Zinkwazi Blythedale Conservancy (ZBC) approached the Oceanographic Research Unit to conduct baseline biophysical surveys of the Nonoti and Zinkwazi Estuaries. The aim of these surveys was to provide baseline ecological data on the state of these two Temporarily Open/Closed Estuaries (TOCEs) for future reference and as input to various initiatives including, but not limited to, Estuarine Management Plans (EMPs) and the National Estuarine Monitoring Protocol (this study has ensured that the Nonoti and Zinkwazi Estuaries are two of the eight pilot systems in the province) and as potential input to Environmental Flow Requirement (EFR) studies on these water courses.

Abiotic data, including water physico-chemistry (as measured *in situ* in the field) and grain size distribution of sediments, and biotic data, including benthic macroinvertebrates and ichthyofauna, were collected to characterise the ecological condition of these estuarine systems.

1.2 Layout of Document

This study presents data and information gathered during low (winter, July 2012) and high flow (summer, February 2013) surveys conducted in the Nonoti and Zinkwazi Estuaries. An account of the biophysical condition of each system is presented, including additional material on spatial analysis of land use, coastal vulnerability and interpolation of the estuarine physico-chemical habitat as they pertain to input information towards estuarine management plans and estuarine flow assessment studies.

In addition, background information such as the legal landscape around estuaries is presented. This document will form the basis of either, or both, an EMP or an EFR, the collection of data and assessment protocols having being aligned with accepted methods.

2. INTRODUCTION TO ESTUARINE CONCEPTS & LEGAL FRAMEWORKS

2.1 Basic definitions pertaining to estuarine ecology

Biodiversity

Biodiversity is the variety of living organisms within an environment or geographic region, coined from the terms 'biological' and 'diversity'. Biodiversity includes animals and their habitats as well as the complex interconnections between them, and therefore incorporates environmental goods and services that have economic, physical and emotional values (Braus 1999). Such goods and services include life support systems like photosynthesis, insect pollination of plants and soil fertilisation by bacteria (Daily et al. 1997), as well as the provision of resources like wood for building and crops and animals for food. Some uses have not yet been realised, such as the existence of natural compounds that may prove useful in the formation of new pharmaceuticals (Wilson 1992). High rates of loss of biodiversity are attributed to human development, habitat destruction, population growth and pollution among other threats. Preserving biodiversity is only achieved by conserving habitat in a network of protected areas. About 12% of the land's surface is currently protected (Lopoukhine 2008) and less than 1% of the ocean (Laffoley 2008), although human impacts directly impact approximately 83% of the land (Sanderson et al. 2002) and 100% of the ocean (Halpern et al. 2008).

Biomonitoring

The goal for monitoring is to detect significant environmental change from a baseline/reference condition in a manner that is statistically reliable (Clark 1996). Trying to monitor an entire community or ecosystem is expensive both economically and in terms of time. A common approach therefore is to use the response of biological indicators that represent the community as a whole, to assess change. A species is selected as an indicator because it is sensitive to change but also because it is easy to work with. Benthic macroinvertebrates are most commonly used because they stay in place and are sensitive to disturbance, but rooted plants may also be used for similar reasons (Clark 1996). If appropriate, a suite of indicators can be used and factors such as density and percentage cover measured to indicate change from a baseline.

Habitat

The environment that supports the life of an organism or community, supplying everything needed for survival (Braus 1999) is it's habitat. It therefore encompasses biotic as well as abiotic factors, such as the presence of predators, and sediment type or light availability (Odum 1971). Habitat loss/fragmentation is the primary cause of loss of biodiversity (Wilson 1992). Fragmentation occurs when a large habitat is broken up into smaller areas by development or other such causes, and serves to reduce available habitat, creates barriers to dispersal and introduces edge effects such as increased light/wind penetration that change the nature of the habitat. Habitat quality therefore, and not just habitat availability is important.

Geographic boundaries

Coastal zone

The coastal zone of South Africa includes all coastal habitats and resources, as well as land uses up to 100m above the high water mark (HWM) (urban areas), 1000m above the HWM (rural areas) and 100m from the upper boundary of estuarine influence. Land uses are mixed and may include recreation, agriculture, industry, ports and mining. The goal of Integrated Coastal Zone Management (ICZM) is to manage coastal zone vulnerability (e.g. climate change, hazards such as wave action) and impacts on coastal systems and communities while allowing for sustainable development (Clark 1996). It therefore involves joint management of both the land and sea.

Estuary

- High water mark

Integrated Coastal Zone Management makes use of setback lines that serve to exclude certain uses from areas close to the shoreline for the purpose of avoiding damage from flooding or for protection of ecological functions (i.e. create a buffer zone). They may be defined by a set distance, or by natural features such as contour lines (Clark 1996). The high water mark is one such setback line, and is defined by the ICM Act (2008) as being "the highest line reached by coastal waters, but excluding any line reached as a result of an estuary being closed to the sea". The high water mark is not accurately delineated for the entire South African coastline, and so the 5m amsl contour line is used to delineate estuarine functional zone (estuarine ecosystem area). The 5m contour line represents the furthest influence of the ocean on land during storm conditions, and provides a buffer zone that includes the estuarine, floodplain and fringing terrestrial vegetation that contribute to estuarine detritus, allows for flooding when the estuary mouth is closed and water level rise as a result of climate change, among other things (Van Niekerk et al. 2012).

- River-Estuary Interface (REI)

That part of an estuary where estuary and river waters mix, or "the sector where integrated vertical salinity values are generally less than 10 mg.L $^{-1}$", and associated with a distinct and rich community (Bate et al. 2002). The length of seawater intrusion upstream and gradient of salinity change (steep to shallow) are dependent upon freshwater inflow with a strong flow limiting seawater intrusion. High river flow therefore increases REI length and volume. A study of the REI within 13 estuaries in the Eastern Cape encompassing four different estuary types (Bate et al. 2002) revealed that the REI region has a unique community tolerant of low salinities, and is dominated by the filter-feeding benthic component, probably in response to elevated phytoplankton production. The macrobenthic, zooplankton and microalgal communities were found to respond to salinity and be stable over time, but have a spatial range that varies in response to freshwater inflow. Highest abundances for zooplankton were recorded at the most saline stretches of an estuary, while for benthic macrofauna abundances are commonly highest where salinity is brackish.

Biota

Flora

The plant life of a particular region or habitat are the flora. Estuarine flora comprises submerged aquatics (e.g. *Zostera capensis*), emergent macrophytes (e.g. *Phragmites australis*) and terrestrial species that can tolerate occasional flooding (e.g. mangrove species like *Avicennia marina*). Floral biomass varies primarily according to water currents and salinity tolerance (Whitfield & Lubke 1998). Increased plant habitat variation and availability increases estuary species diversity (Whitfield, 1983), and submerged vegetation is associated with increased fish abundance than other bare areas (Branch & Grindley 1979). Submerged vegetation is however affected by water flow and silt loads, as high turbidity reduces light penetration and sediment deposition may smother growing plants (Day et al. 1981). Freshwater inflow also affects phytoplankton size structure and productivity, as river inflow replaces limiting macro-nutrients (Adams & Bate 1999; Froneman 2002; Perissinotto et al. 2002)

Fauna

Fauna are the animals of a particular region or habitat. Estuarine fauna includes invertebrates, fishes and waterbirds like herons and ducks. Mobile aquatic estuarine fauna can select their habitat with respect to salinity (Whitfield & Lubke 1998), and may be classified based on salinity tolerance; oligohaline organisms live in freshwater, true estuarine organisms are mostly found in the central reaches of estuaries but can tolerate marine salinities, euryhaline marine organisms are comfortable in salinities to about 18, stenohaline marine organisms tolerate salinities to 25 and marine migrants spend only a part of their life in an estuary (e.g. reproductive migrants like Anguilid eels) (McLusky 1981). Estuaries characteristically have lower faunal species diversity than the neighbouring marine and freshwater environments but very high abundances due to their exceptional productivity (Whitfield & Lubke 1998).

Macrobenthos

Defined according to size, the macrobenthos are those organisms greater than 1mm (or retained by a 0.5mm sieve) living at the bottom of the water column, either on (epifauna) or within (infauna) the substrate. It is made up of three main groups - crustaceans, molluscs and worms, and includes suspension feeders that feed on particles in the water column (eg. mussels feeding on phytoplankton), and deposit feeders that eat the detritus within the sediment. Macrobenthic species that occur within estuaries can be divided into marine species, oligohaline (freshwater) species and estuarine endemic species which can further be divided into those associated with sand and those with mud. The macrobenthos is therefore affected by salinity and the nature of the sediment, but of these two sediment characteristics (especially mud content) was identified as being the primary environmental variable determining macrobenthic zonation patterns (Teske & Wooldridge 2001, 2003). Indeed, estuarine macrobenthic species can tolerate a salinity range of 5-55 (de Villiers et al. 1999). Macrobenthic characteristics do not appear to vary by season but vary by estuary type, with small Temporarily Open/Closed Estuaries (TOCEs) having highest densities recorded, and river-dominated permanently open systems the lowest richness and diversity (Teske & Wooldridge 2001).

Macrocrustacea

Macrocrustacea are mainly aquatic arthropods of the subphylum Crustacea, of a size class large enough to be retained by a 0.5mm sieve mesh and visible to the naked eye. Crustaceans are characterised by an exoskeleton, biramous (two part) limbs and three body regions; the head with two pairs of antennae and other sensory organs, the thorax and abdomen. This group includes common estuarine invertebrates including amphipods, isopods, crabs and prawns. Some of the decapod species such as mud- and sandprawns support small-scale fisheries within estuaries (Branch et al. 2002; Cockcroft et al. 2002) and penaeid prawns support important commercial fisheries offshore (de Villiers et al. 1999). As with other estuarine biota, these animals show preference for specific estuarine habitat types and are often closely associated with submerged aquatic vegetation (De Freitas 1986; Forbes et al. 1994). Estuary use also varies with life history (de Villiers et al. 1999; Papadopoulos et al. 2002) and ranges from estuarine species with a marine larval phase to marine species with an estuarine larval phase (e.g. penaeid prawns) and typical estuarine species (e.g. Brachyuran crabs). As a result of these varying life histories some species show seasonal increases in abundance linked to breeding cycles (e.g. Weerts et al. 2003).

Ichthyofauna

All fishes inhabiting a particular water body or region are the ichthyofauna. Fishes found within South Africa's estuaries can be divided into four groups based on breeding and degree of estuarine dependence (Whitfield 1994a). They are truly estuarine species that breed in estuaries (e.g. *Atherina breviceps*), euryhaline freshwater species (e.g. *Oreochromis mossambicus*), marine migrants that stray into estuaries but are not dependent upon them (e.g. *Lithognathus mormyrus*) and marine species that breed at sea but whose juveniles are to some degree dependent upon estuaries as a nursery area (e.g. *Liza* spp.). The marine ichthyofauna that can use estuaries are those that are adapted to the fluctuating physical and chemical conditions that exist within the estuarine environment, these are only about 80 of the over 2000 southern African coastal water species (Whitfield & Bok 1998). Fish species richness varies with estuary type and size, with permanently open systems having the highest richness and small closed estuaries the lowest, this being directly related to recruitment opportunity as well as habitat availability (Vorwerk et al. 2003; Harrison & Whitfield 2006). Ichthyofaunal characteristics also vary by bioregion, with migratory species (estuarine and marine) dominating cool-temperate systems and warm-temperate and subtropical systems dominated by estuarine dependent species (estuarine residents and estuarine-dependent marine migrants) (Harrison & Whitfield 2008).

Estuarine environmental conditions

Water

- Physico-chemistry

The physics and chemistry of a water body, including factors such as salinity, temperature, dissolved oxygen and turbidity is the physic-chemistry. Since physical conditions within the majority of South African estuaries are unstable and fluctuate, it is the physical and chemical conditions rather than biological factors that are the primary determinants affecting the distribution and abundance of estuarine fauna and flora (Blaber 1997; Whitfield & Bok 1998; Whitfield 1999). Salinity is one of the primary factors structuring estuarine faunal assemblages (Teske & Wooldridge 2004; Harrison & Whitfield 2006; Gordon et al. 2008; Cyrus et al. 2011), and low salinity conditions are common in South African estuaries, especially during periods of freshwater flooding (Whitfield, 1999). Temperatures are regulated by seawater or river water if either of those inputs are strong, or fluctuate according to season when the estuary is shallow. Estuarine systems with a large surface area to volume ratio can undergo sudden changes in water temperature which are lethal to the fauna (Kyle 1989; Forbes & Cyrus 1993; Whitfield 1999). Temperature also affects oxygen availability. Oxygen is introduced in river water flowing in as well as by photosynthesis, but activities such as decomposition and high animal abundances rapidly deplete available oxygen and results in sediments that are anoxic (McLusky 1981). Few estuaries in South Africa are clear (<10 NTU) with the majority being semi-turbid or turbid (10 - >50 NTU) (Cyrus 1988a), and it is argued that turbid waters add to the nursery function of an estuary as they offer protection from visual predators as well as increased feeding success (Cyrus & Blaber 1987c; Whitfield 1999). As most of South Africa's estuaries have periods where they are shut off from the sea, estuary mouth phase directly affects fish and invertebrate assemblages with overtopping or open mouth conditions representing recruitment opportunities (Bell et al. 2001; Kemp & Froneman 2004).

Sediment

- Sediment granulometry

The size distribution of sediment grains making up the substrate type is the granulometry. Sediment is transported into an estuary from rivers, the sea or from the surrounding landscape, and deposition is controlled by current speed (fast-flowing rivers or tidal action) and particle size (McLusky 1981). High silt and clay content in the water increases turbidity as these particles settle out slowly. Sediment characteristics affect the zonation of estuarine macrobenthos in particular (Teske & Wooldridge 2003), with estuarine endemic species showing a clear affinity for either sand or mud (Teske & Wooldridge 2001).

- Sediment organic content

The percentage of sediment that is carbon material (plant or animal in origin) is termed 'total organic content' (TOC). Organic sources include estuarine plants and animals, *in situ* bacteria, or anthropogenic sources in the catchment (e.g. sewage and effluent). TOC is correlated with sediment mud content as the organic material adsorbs to finer grains (CSIRO 2000). The material is degraded by microbial action during burial, but this decomposition process uses oxygen so when decomposition rates are high anoxic conditions may develop.

2.2 The legal landscape pertaining to South African estuaries

National Environmental Management Act (No. 107 of 1998)

Under the Constitution of South Africa everyone has the right to an environment that is not harmful to health and wellbeing (Clause 32 of Bill of Rights). The National Environmental Management Act (NEMA) serves as the overlying template of environmental policy in South Africa, guiding environmental legislation and lays out environmental principles that must be adhered to as well as the environmental rights of individuals. It therefore promotes among other things the prioritisation of people and their needs, a cooperative approach to environmental governance, sustainable development (environmentally, socially and economically) and the principle of Integrated Environmental Management (IEM). Integrated Environmental Management itself has its roots in Agenda 21 of the United Nations Conference on Environment and Development (Rio de Janiero 1992), which recognised the need for sustainable development and management of environmental resources in a more integrated manner. The National Environmental Management Act is a framework that encourages consideration of the environment and of environmental impacts at every stage of the development process, with the aim of promoting environmentally sustainable development. It sets up procedures that govern actions by organs of state and private individuals wherever they may significantly affect the environment, and creates an institutional obligation to use appropriate environmental management tools such as environmental impact assessments (EIA). The NEMA EIA regulations for example identify the estuarine functional zone (estuary water body together with physical and biological processes and habitats that support estuarine function and health) as being a sensitive area requiring environmental authorisation before development may proceed (Van Niekerk & Turpie 2012). It also gives the public the right to question whether these procedures have been/are being followed as well as the ability to defend their environmental rights. The Department of Water Affairs (DWA) IEM imperatives as they pertain to NEMA principles (DWA 2011) include

- Promoting social and economic development in an ecologically sustainable manner that limits ecosystem disturbance and biodiversity loss
- Promoting human rights and protecting human health and safety
- Practicing cooperative governance and integrated management of resources through regular monitoring and public participation
- Addressing climate change, managing transboundary impacts and practicing proactive disaster planning and management

National Water Act (No. 36 of 1998)

Demands on freshwater resources (rivers, estuaries, wetlands and groundwater) are varied, and include meeting basic human need as well as allowing economic growth, access to and distribution of goods and services from aquatic ecosystems as well as conservation requirements. These uses are potentially conflicting as they include the use and development of water resources as well as their protection and conservation. The National Water Act (1998) is South Africa's principal legal instrument relating to the management of the country's water resources, including those on the surface as well as below-ground. Together with the National Water Policy for South Africa (1997), the Act was developed according to the principles of equity, sustainability and efficiency of water use. Two provisions of the Bill of Rights laid out in the Constitution of South Africa (1996) deal specifically with the management of the country's resources and are the basis for development of the Policy and Act. They are:

- Section 24: Everyone has the right to an environment that is not harmful to their health or wellbeing, and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation, promote conservation, and secure sustainable development and use of natural resources while promoting justifiable economic and social development.
- Section 27: Everyone has the right to have access to, among other rights, sufficient food and water, and the State must take reasonable legislative and other measures, within its available resources, to achieve the progressive realisation of these rights.

The Act's principal objectives therefore are equity of access to water, and sustainable and efficient use of water primarily by protecting the water resources of the country to ensure the security of future use. This approach is termed "integrated water resources management", where South Africa's water resources are provided comprehensive protection that balances use and development of the resources with the need to protect and conserve them.

In order to manage the country's water resources two types of control have been put in place; those directed at maintaining the condition of a resource which is directly linked to resource ecological status (Resource Directed Measures, RDM) and those measures to limit impacts arising from water use by regulating its use at the source of impact (Source-Directed Controls). Under the RDM water resources are classified according to the National Water Resource Classification System (NWRCS) (Dollar et al. 2006) gazetted in 2008, which is a participatory process that uses ecological, social and economic criteria for Reserve determination. The Reserve is the quantity and quality of freshwater set aside in order to maintain desired condition of a water resource as well as meet resource quality objectives. The Reserve provided by the NWA is thus made up of two parts; the Basic Human Needs reserve, and the Ecological Reserve which is the water required to protect the aquatic ecosystems of the resource and therefore ensure sustained health and functioning. Importantly, the Reserve is constituted not only by the *quality* and *quantity* of freshwater inflows but also by their *timing*.

Methodology for Ecological Reserve determination is laid out in detail in DWA (2010) and further discussed in Section 3 of this report, but basic steps include a baseline study used to determine Present Ecological State (PES) of the resource which indicates degree of change from a reference (pristine) condition. The Estuary Health Index (Turpie 2012) is central to this step. A Recommended Ecological Category is then assigned for the resource within which it will be managed. This could be a higher ecological class than present status and is set as a target for management, according to a pre-determined level of resource protection based on ecological, social and economic criteria. Resource Quality Objectives and a monitoring programme help to manage the resource within this boundary. The Ecological reserve is then quantified based on the category assigned, and tested under different flow scenarios. DWAF sets the final category, and the final Reserve is specified and implemented.

Any human water demand above the Basic Human Needs reserve (approximately 25 L per person per day) requires authorisation in the form of licences administered by the Minister of the Department of Water Affairs, or Catchment Management Authorities. The Act gives highest priority to water for the Reserve however before addressing international obligations in the case of shared rivers (e.g. the Limpopo, shared by South Africa with Botswana, Zimbabwe and Mozambique), or allocation of water licences and other uses.

Integrated Coastal Management Act (No. 24 of 2008)

Estuaries fall within the Coastal Zone of South Africa, the terrestrial boundary of which stretches 100m above the high water mark (HWM) (urban areas), 1000m above the HWM (rural areas) and 100m from the upper boundary of estuarine influence. As such, estuarine management as well as the discharge of effluent into estuaries are governed by the Integrated Coastal Management Act (ICM) of 2008 (Ch4, Sections 33 and 34 and Ch8, Section 69 respectively).

The ICM Act creates a protocol for integrating and improving management of estuaries within South Africa. This is achieved through the establishment of the National Estuarine Management Protocol (NEMP), which guides the development and implementation of individual estuarine management plans (EMP). As outlined in Chapter 4 of the Act, the purpose of the NEMP is to provide a framework that ensures effective integrated estuarine management through the setting of objectives and guidelines for management, defining management roles and responsibilities as well as establishing minimum requirements of and a process for preparation of estuarine management plans. The Act further specifies that provincial government must put strategies for development of estuarine management plans into place for all estuaries in the province, and that these management plans must be consistent with relevant legislation at all levels of government. As well as management actions to be instituted at the resource level, one of the objectives of the NEMP is to protect a sample of the country's estuaries to achieve the estuarine biodiversity targets determined by the 2011 National Biodiversity Assessment (Van Niekerk & Turpie 2012).

Responsibility for the development and implementation of EMPs within government structures varies according to location of the estuary in relation to jurisdictive boundaries, and is outlined in Government Gazette No. 36432 (10 May 2013). Responsibility lies with:

- The local municipality if the estuary falls completely within its boundary
- District municipality where an estuary falls within the boundaries of two municipalities
- Provincial Environmental Department where an estuary falls within the boundaries of more than one district municipality
- The Department where an estuary crosses the boundary between provinces or the state, or is in a harbour
- The protected area management authority where an estuary is in a protected area (current or according to future expansion)

Prior to the publishing of the NEMP a generic EMP was developed by the Cape Action for People and the Environment (CAPE) Estuaries Programme in accordance with the protocol outlined in the ICM Act. It integrates the management mandates of various government departments to ensure conservation and sustainable development of Cape estuaries, by incorporating strategic decision making into estuarine management. This generic EMP has been tested on a number of Cape estuaries including the Breede, Olifants and Klein, with plans to identify pilot estuaries in KZN in partnership with DWA (Matoti et al. 2008). The NEMP has however recently been published (Government Gazette No. 36432, May 2013) and management plans will be in line with this protocol.

Chapter 4 of the ICM Act addresses effluent discharge into estuaries. According to the Act, no person may be permitted to discharge effluent into coastal waters. Special authorisation with regards to discharge into estuaries may however be granted by the Minister responsible for environment affairs in consultation with the Minister responsible for water affairs after consideration to the relevant estuarine management plan.

3. ESTUARIES

3.1 Importance and value

The importance of estuaries is vast and can be measured in terms of direct use values, indirect uses including environmental services and intrinsic values or attributes. Estuaries are productive environments that support important fish and invertebrate resources that sustain commercial and recreational fisheries. Estuarine and estuary-dependent fisheries in South Africa were for example estimated to be worth a total of R1 251 billion in 2002 (Lamberth & Turpie 2003), and approximately 2 000 tonnes of fish comprising 80 species are caught directly from South Africa's estuaries every year (Van Niekerk & Turpie 2012). Moreover, estuaries support the livelihoods of rural communities through subsistence fishing (bait organisms and fishes), and the harvesting of estuarine plants such as reeds and sedges for crafts and handiwork and mangroves for building (Branch et al. 2002; Traynor 2008). Estuaries perform many important ecological functions including providing nursery areas (Whitfield 1994a; Lamberth & Turpie 2003; Harrison & Whitfield 2008) and refugia for coastal organisms and migratory birds as well as environmental services such as nutrient cycling and the export of production, nutrients and sediment as well as freshwater flow to the marine environment (van Ballegooyen et al. 2007; Lamberth et al. 2009; Van Niekerk & Turpie 2012). Estuarine environments also increase local biodiversity by hosting a mix of marine and freshwater species but also estuarine specific species; animals that are only found in the estuarine environment. Estuaries further have aesthetic value as well as cultural, spiritual and recreational functions.

3.2 Classification

The widely accepted definition of an estuary for the South African context is that provided by Day (1980), being "a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is measurable variation of salinity due to the mixture of seawater with fresh water derived from land drainage". The classification of an estuary as laid out in the ICM Act (24 of 2008) very closely follows this, and is "a body of water that is permanently or periodically open to the sea, in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the water course is open to the sea, or in respect of which the salinity is measurably higher as a result of the influence of the sea".

The physical characteristics of an estuary are determined by the profile of the coast, climate and river catchment area (Whitfield & Lubke 1998). Within South Africa, Whitfield (1992) recognises five estuary types based on their dominant physiographic, hydrographic and salinity conditions. These are permanently open estuaries, temporarily open/closed estuaries (TOCEs), estuarine lakes, estuarine bays and river mouths (Table 3.1). Classifying estuaries into categories such as these facilitates management as we understand how different groups behave and what their drivers are, and therefore what consequences are likely to arise from a pressure and how best they can be managed.

TABLE 3.1. PHYSICAL CHARACTERISTICS OF THE FIVE ESTUARINE TYPES CHARACTERISTIC OF SOUTHERN AFRICA. ADAPTED FROM WHITFIELD (1992).

System	Tidal prism	Mixing process	Average salinity	Catchment size km^2	KZN Example
River mouth	Small[a]	Riverine	< 10	> 10 000	Mfolozi
Permanently open	Moderate[b]	Tidal/riverine	10 - > 35	> 500	Mlalazi; Mzimkulu
Temporarily closed	Absent	Wind	1 - > 35	< 500	Zinkwazi; Nonoti
Estuarine bay	Large[c]	Tidal	20 - 35		Durban Bay
Estuarine lake	Negligible[d]	Wind	1 - > 35		Kosi; St Lucia
[a]<1 x 10^6 m^3 per spring tidal cycle			[c]>10 x 10^6 m^3 per spring tidal cycle		
[b]1 - 10 x 10^6 m^3 per spring tidal cycle			[d]<0.1 x 10^6 m^3 per spring tidal cycle		

South Africa has approximately 300 recognised estuaries (Van Niekerk & Turpie 2012). The most common estuary type is a temporarily closed system, making up 77% of all estuaries in the country (Figure 3.1). Because these estuaries are commonly relatively small however, they only account for 7% of the country's total estuarine area. In contrast 4% of SA's estuaries are classified as estuarine lakes and bays but these groups contribute 68% to total estuarine area due to the large size of these systems.

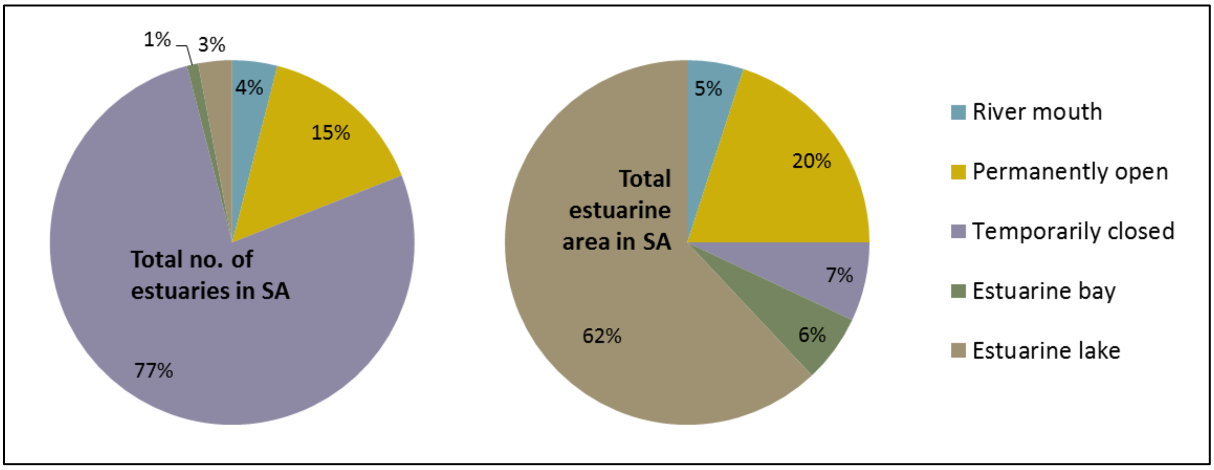


FIGURE 3.1. WHITFIELD'S DIFFERENT ESTUARY TYPES AS THEY ARE REPRESENTED WITHIN SOUTH AFRICA (DATA FROM TURPIE ET AL. 2012)

Of the 77 recognized estuaries in KZN, there are 65 TOCEs, five permanently open estuaries, three estuarine bays, two estuarine lakes and two river mouths. The Nonoti and Zinkwazi Estuaries are classified as TOCEs, and in general take on the characteristics of this estuarine classification.

The mouths of temporarily open/closed estuaries (TOCEs) are closed by a sandbar at the mouth during periods of low river flow. During these periods water back floods away from the mouth and estuarine area is increased. Breaching of the mouth causes sediment to be scoured from the estuary and mouth area, although it is quickly built up again by marine (longshore drift) or fluvial sediment. Generally these systems have small river catchments (<500 km^2), limited marine exchange when open (small tidal prisms <1 x 106 m3), and normally low river flow often resulting in the formation of a terminal basin in the lower reaches during the prolonged closed phase (Begg 1978, Whitfield 1992). Similar estuaries are also found in Australia, India, Sri Lanka and on the southeastern coasts of Uruguay and Brazil, along the west and south coasts of the USA, and in parts of New Zealand and the Mediterranean (Perissinotto et al. 2010).

Temporarily Open/Closed Estuaries are always in one of five hydrodynamic conditions: the *outflow*, *tidal*, *semi-closed* and *closed* phases with the *marine overwash* phase occuring during the closed mouth state (Whitfield et al. 2008). During the *outflow* and the *tidal* phases the estuary is open and connected to the sea. *Outflow* is dominated by freshwater conditions and strong river outflow while during the *tidal* phase a tidal regime is established within the estuary (Whitfield et al. 2008). In the *semi-closed* condition, river inflow is low while marine input is limited to near peak high tide levels, and the ebb flow is prevented by the development of the sandbar at the mouth (Whitfield et al. 2008). While the estuary is *closed* there is no connection to the sea as the sandbar prevents both marine ingress and the outflow of estuary water resulting in the accumulation of water within the system (Whitfield et al. 2008). This is the most common phase in South African TOCEs.

The natural opening of TOCEs is seasonal and in KwaZulu-Natal they are generally open during the wet summer months (October-March) but are closed or close more frequently, for longer periods during dry winter months (Perissinotto et al. 2010). Floods are important for breaching of closed estuaries causing erosion of the mouth sandbar, whilst purging and scouring sediment from the lower reaches to deepen these systems (Perissinotto et al. 2010).

3.3 Distribution

South Africa's 300 estuaries have an area of approximately 700km^2 (Whitfield 1995). Over 65% percent of this area is distributed in KZN. Topography and climate of South Africa means that the majority of estuaries are found along the country's east coast. South Africa's estuaries can be grouped according to the geographical region within which they fall, according to latitude and climate (Brown & Jarman 1978). The three regions are subtropical (estuaries north of the Mbashe in the Transkei), warm temperate (Mbashe to Cape Point) and cool temperate (Cape Point to north of Walvis Bay in Namibia). The KwaZulu Natal province has the highest mean annual precipitation (MAP) of the country (Lynch 2004), and estuaries in the subtropical region therefore receive a higher runoff and in the case of TOCEs, open more frequently to the sea than those in other regions. Peak rainfall season, runoff and therefore marine-estuarine connectivity also vary between regions, with the subtropical estuaries experiencing summer rainfall, the west (cool temperate) winter rainfall and the south (temperate) all-year rainfall (Schulze & Lynch 2007).

As with estuary type, biogeographic classification allows for the emergence of general patterns concerning estuaries in the different groups (e.g. Harrison 2002). The highest number of species for example is found in subtropical and warm temperate estuaries, while cool temperate estuaries on the west coast characteristically have higher production (Turpie 1999). Biogeographical zonation further assists in estuary management by indicating estuary "uniqueness"; an estuary of a type that is poorly represented in a region will have a higher conservation importance than other estuaries of types that are common in that bioregion.

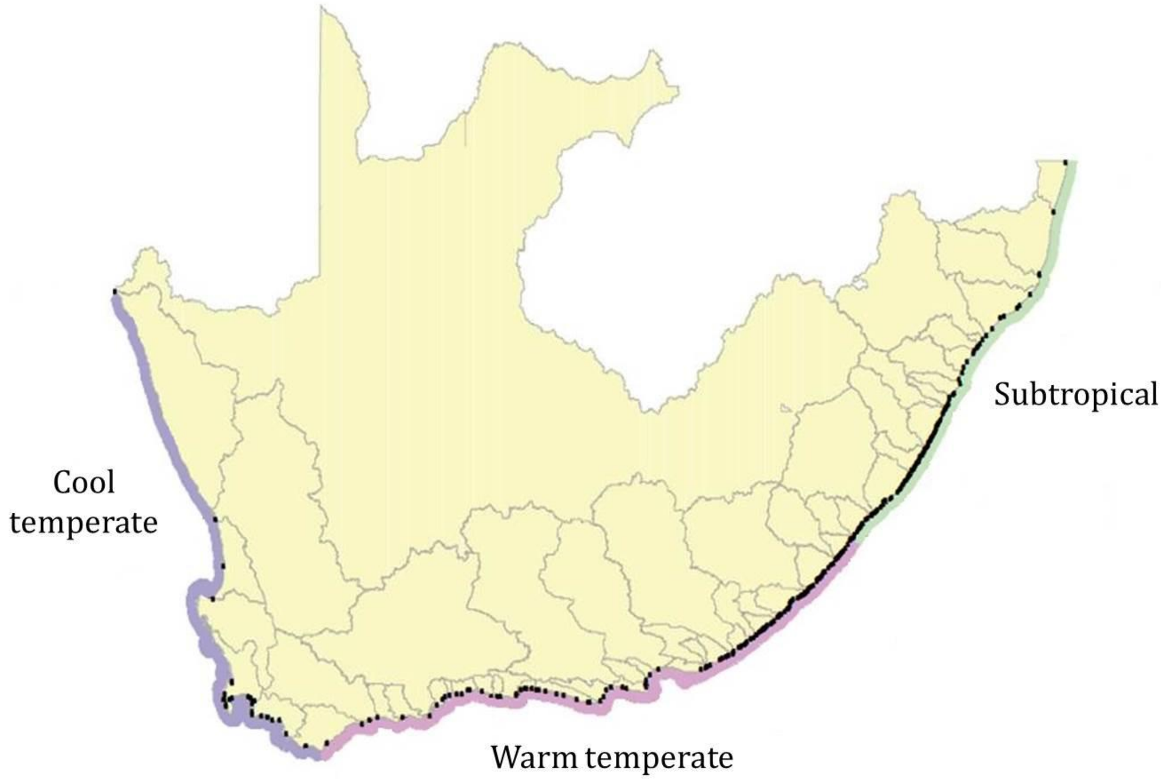


Figure 3.2. The distribution of South Africa's estuaries according to biogeography (Modified from Turpie et al. 2012)

3.4 Estuarine habitats

Estuarine habitats reflect the transition from freshwater to marine conditions. Nine habitat types are recognised for South Africa's estuaries (DWA 2010), although the prevalence of each type varies by system according to climate and other physical conditions. The habitat types are open water surface area, intertidal mud and sand flats, submerged macrophyte beds, macroalgae, salt marsh (inter- and supratidal), reeds and sedges, mangroves and swamp forest.

Emergent habitats

Emergent habitats are those that occur along or above the high water level. As well as vegetated habitats, intertidal sand and mudflats host burrowing animals and associated benthic microalgae. Plants living along the water's edge are limited by their tolerance to inundation, soil salinity, oxygen and nutrient availability. In temperate (Cape) estuaries extensive intertidal and supratidal saltmarshes form in areas of low water flow, however mangrove stands are more common in sub-tropical estuaries (Kwa-Zulu Natal). The upper margins of estuaries in KZN are characterised by reeds and sedges (e.g. *Phragmites australis*, *Schoenoplectus littoralis*) in their natural undisturbed states. In KZN *Juncus kraussi* is harvested for use in the production of various crafts and therefore provides a direct source of income for people who are typically poorly educated and have little other employment opportunities (Traynor 2008).

Mangroves grow in soil that is anoxic and oxygen is absorbed through the pneumatophores or prop-roots, which must therefore be exposed to the air periodically. *Avicennia marina* is a common pioneer species and is tolerant of a wide range of temperatures and salinities, while *Barringtonia racemosa* and *Hibiscus tiliaceus* are typically freshwater species and form luxuriant swamp forest. *Rhizophora mucronata* is tolerant to shade and often outgrows *Avicennia marina* where the two are found together. Mangroves of marine (in systems where they occur) and freshwater reaches of estuaries provide shelter and a habitat not only for animals that live in the water but also those living within the canopy, as well as food in the form of detritus (Nagelkerken et al. 2008). Their roots slow the flow of water and create a sheltered, muddy environment that is an important habitat for numerous commercial prawn species including juvenile *Penaeus monodon* and *P. indicus* (de Freitas 1986). Threats to mangroves in South African estuaries include wood harvesting and changes in freshwater inflow from upstream catchments.

Submerged habitats

Submerged habitat types include open water, macrophyte and macroalgae beds, as well as mud and sand beds. Soft sediment areas are the most common habitat type in estuaries, and support a rich variety of organisms. They are therefore important feeding areas for many higher consumers. Substrate type (sand or mud) was identified as being an important determinant in the distribution of macrobenthic fauna (Teske & Wooldridge 2003).

Submerged vegetation provides a food source for estuarine consumers and also creates a complex habitat that provides shelter from predators (Franco et al. 2006), and therefore adds to the nursery function of estuarine systems. They are associated with increased invertebrate species abundance, biomass and diversity (Wyda et al. 2002), and elevated fish density and biomass (Humphries et al. 1992). Algae may be attached or free-floating (Adams et al. 1999), and can form dense mats in response to elevated nutrient availability, and macrophytes are rooted plants with leaves and stems fully (e.g. *Ruppia*) or partially submerged (Adams et al. 2012). Macrophyte beds slow water flow, allowing sediment to settle, and therefore promote water clarity. As well as salinity tolerance, submerged vascular plants in estuaries are limited by light and sediment abrasion, and therefore favour systems where water is clear and silt loads are low.

3.5 Status of KZN estuaries

Estuaries are sensitive environments, and are subject to changes in both upstream freshwater and downstream marine factors. An estimated 25% of South Africa's population is found within 60km of the coastline and of this, 70% is considered poor (ASCLME 2010), and estuaries are therefore also vulnerable to anthropogenic influence. Key pressures facing South Africa's estuaries include changes to freshwater quantity, quality and timing of inflow, artificial breaching of temporarily open/closed systems, habitat modification and exploitation of living resources (Van Niekerk et al. 2013). Indeed, of the entire estuarine area of South Africa only 1% is considered to be in excellent condition, with 14% in good condition, 31% ranked as fair and 54% in a poor condition (Van Niekerk & Turpie 2012). Estuaries are however generally resilient environments, and with many of the pressures affecting estuaries happening at catchment level estuaries will benefit from integrated catchment management practices (Clark 1996).

KwaZulu-Natal estuaries are considered to be in fair to poor health. Approximately 20 of the provincial estuaries are degraded. Nine of KZN's estuaries are partially protected but with no specific measures to protect or manage their catchments. The most recent National Estuarine Spatial Biodiversity Assessment sets out that although KZN supports 68% of the total estuarine area in the country, none of the 77 estuaries are in an 'excellent state' (Van Niekerk & Turpie 2012). Umkhanyakude and eThekwini with 4 and 16 estuaries, respectively show that 85% and 72% of these systems per district are in a poor state (Table 3.2).iLembe has a negligible portion of the total estuarine area in South Africa, but just over half of the systems are only in fair condition, the rest being good.

TABLE 3.2. SUMMARY OF ESTUARINE HEALTH AS A PERCENTAGE OF TOTAL ESTUARINE HABITAT IN THE COASTAL DISTRICT/METROPOLITAN MUNICIPALITIES OF KWAZULU-NATAL (NUMBER OF ESTUARIES IN BRACKETS). AFTER VAN NIEKERK AND TURPIE (2012).

District Municipality	% of SA estuarine area	Health Condition (%)			
		Excellent	Good	Fair	Poor
eThekwini (16)	2	0	6	22	72
iLembe (9)	0	0	45	55	0
Ugu (41)	1	0	26	72	2
Umkhanyakude (4)	61	0	8	7	85
Uthungulu (5)	4	0	6	94	0
% of total SA estuarine habitat	68				

Freshwater quantity, quality and timing

Fresh water is a limited resource that must be shared between a number of different user groups. Access to fresh water, specifically in terms of quantity and quality is one of the biggest threats to estuaries in South Africa (Schlacher & Wooldridge 1996; Turpie et al. 2002), and in many cases very little of the mean runoff reaches the sea, if indeed at all (Whitfield & Wooldridge 1994). Recent surveys show that total freshwater inflow from the 20 largest catchments in South Africa has been reduced by approximately 40% from pristine levels, and 22% of the country's estuaries are experiencing either moderate or significant modification to flow (Van Niekerk & Turpie 2012) (Figure 3.3). Significantly fewer estuaries in the warm temperate or subtropical regions are under flow pressure than those in the cool temperate region, however many of these estuaries have very small catchments with little or no development (Van Niekerk et al. 2012).

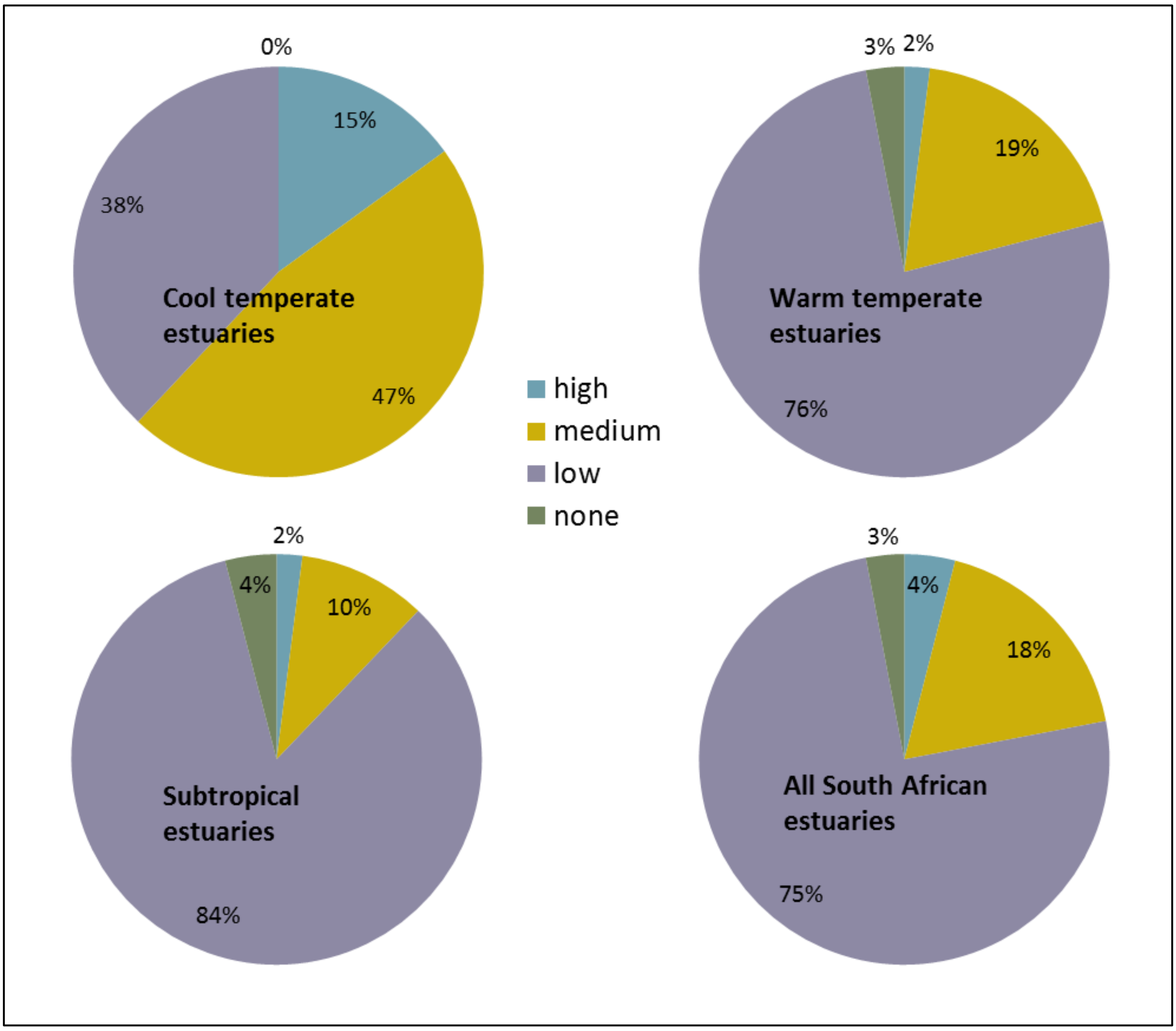


FIGURE 3.3. QUANTIFIED FLOW MODIFICATION PRESSURES FOR SOUTH AFRICAN ESTUARIES BY BIOGEOGRAPHICAL REGION, MODIFIED FROM VAN NIEKERK ET AL. 2012

Fresh water inflow is a critical driver in terms of maintaining physical habitat by flushing an estuary and eroding accumulated sediment, restoring channel dimensions and providing recruitment opportunities for marine organisms (Whitfield 1994a; Wooldridge 1994) as well as maintaining the axial salinity gradient and input of nutrients (Whitfield 1992). Freshwater availability therefore affects habitat diversity and availability (Adams et al. 1992), promotes production by phytoplankton and zooplankton and pulses of freshwater can act as cues for fish and invertebrate reproduction and migration (Whitfield 1994c). The marine environment also relies on freshwater flow from estuaries, with freshwater affecting habitat characteristics (e.g. changes in temperature and salinity) and processes including productivity, and cues for reproduction (van Ballegooyen et al. 2007; Lamberth et al. 2009). Catchment practices including upstream agriculture, industry and waste water treatment works have affected the quality of freshwater inflow by increasing sediment and pollution loads (Begg 1978), and upstream impoundments and water transfer schemes reduce the baseflow volume of water entering a system and affect flood regime (frequency and size).

Habitat modification

Estuarine habitat includes the immediate channel and banks, as well as the estuarine functional ecological area defined by the 5m amsl contour. Increasing urbanisation leads to inappropriate development and practices including the construction of bridges, weirs and causeways that disrupt water flow, stabilisation of banks and the mouth, and dredging of the channel. Land within the floodplain and estuarine functional area is commonly cleared for both infrastructure and agriculture. Practices such as these lead to increased sedimentation and runoff as well as loss of biodiversity and critical habitat. Further, inappropriate low-level development can lead to mouth manipulation and artificial breaching to prevent inundation of the flood plain. Harvesting pressure can also alter habitat, or in extreme cases lead to the complete loss of mangrove stands, for example (Van Niekerk & Turpie 2012). Not only are such changes detrimental to immediate functioning and system health, but they decrease the estuary's resilience to withstand future stress caused by factors such as global climate change.

Management

In general, estuarine research in South Africa has been focussed on few systems with the result that many lack even basic information. Although the legal framework exists for good management of our estuaries, the lack of available information (e.g. only 12% of South Africa's estuaries have had ecological water requirement studies performed for them, Van Niekerk & Turpie 2012) translates into poor classification and a low level of protection being afforded. To illustrate this, Turpie et al. (2002) performed an analysis based on existing data for all of South Africa's estuaries and identified a minimum total of 32 estuaries representative of all South African estuarine biodiversity which should be formally protected. At present only ten of these identified by the study have protected status. Indeed, 83% of the country's estuarine area is unprotected (Van Niekerk & Turpie 2012). Other consequences of a lack of information include over-subscription of upstream water resources and exploitation of natural resources including fish, invertebrates and estuarine vegetation.

Management actions can affect estuary pressures including flow reduction, habitat modification, resource harvesting and pollution (Van Niekerk & Turpie 2012). Invasive species are also a growing threat to South Africa's estuaries that relate to poor management. The mollusc *Tarebia granifera*, originally from south-eastern Asia, was first reported in northern KZN in the late 1990s and since then has spread to at least 30% of KZN's estuaries (Van Niekerk & Turpie 2012). It is highly fecund and can tolerate a wide range of environmental conditions, and thus attains very high densities (over 1000 ind.m^{-2} in some northern KZN estuarine systems, Miranda et al. 2011). It out-competes native snail and benthic organisms (Appleton et al. 2009) and will affect ecosystem functioning and reduce local biodiversity (See Section 9).

3.6 Study systems

The Nonoti (S 31.407080 E 29.318857) and Zinkwazi (S 31.443478 E 29.281590) Estuaries are two TOCEs located just south of the Thukela River on the north-eastern coastline of South Africa, in the KwaZulu-Natal province (Figure 3.4).

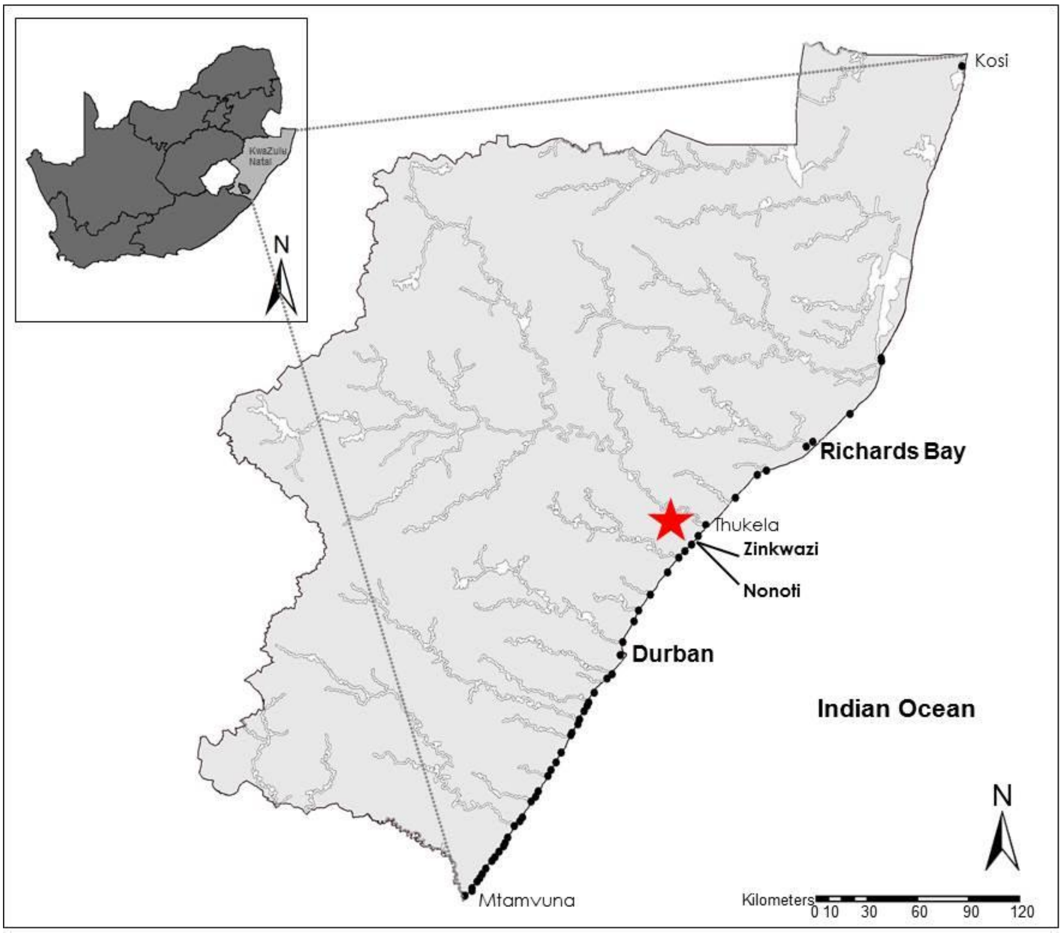


FIGURE 3.4. MAP OF THE KWAZULU-NATAL PROVINCE SHOWING THE LOCATION OF THE ZINKWAZI AND NONOTI ESTUARIES RELATIVE TO OTHER ESTUARIES (REPRESENTED BY DOTS) IN THE PROVINCE.

Nonoti Estuary

The Nonoti Estuary is a small TOCE within the iLembe coastal zone of the KwaDukuza Municipality (for photographs see Appendix 3), and is classified as one of five barrier lagoon types characterised by large catchments with mixed sediment inputs, wide floodplains and long barriers (in excess of 900m) (Cooper et al. 1993). The mouth parallels the coast for a long section, mouth condition is usually closed and mouth area is shallow with an average depth along its length of ~2m. Back flooding occurs during winter or periods of low flow and significantly expands estuarine area (to approx. 139ha). Catchment estimates vary but average 251km^2 (Begg 1978), and major tributaries are the Little Novoti, Gungqu and Mfenge Rivers.

Sugar cane is extensively farmed throughout its catchment and there are two mills (Doorn/Doringkop near the river source and Darnall 8km above the estuary) on the river. The estuary suffers from a number of problems related to sugar farming, including pollution from the mills, siltation and artificial breaching of the mouth. Moreover, there is a growing rural community on the south bank and activities linked to this human presence include gillnetting and subsistence farming. There are also currently plans underway to develop a 20 ha resort incorporating a 4 star hotel and self-catering units on community-owned land on the south bank (Edwards 2012).

In the upper reaches, the channel is overgrown by macrophyte invasives such as water hyacinth (*Eichhornia crassipes*), Buffalo/Hippo/Antelope grass closing available openwater areas (species still unverified) and duckweed (*Lemna minor*) as well as water lilies (*Nymphaea* spp.). Although reports up to twenty years ago indicated that the estuary's water quality recovered from a severely polluted state (Begg 1984a; Cooper et al. 1993), the biology of this system has been labelled as being below average (Cooper et al. 1993 and references therein) and was still considered to be in a 'poor' state of health at the beginning of 2000 (Whitfield 2000) (Table 3.3).

TABLE 3.3. CHARACTERISTICS OF THE NONOTI ESTUARY, FROM THE NBA 2011 (VAN NIEKERK & TURPIE 2012). MAR IS MEAN ANNUAL RUNOFF.

Estuary classification	Subtropical TOCE		
Location	S 31.407080 E 29.318857		
Estuary length km	1.941	**Openwater (ha)**	12
MAR Mil.m^3	14.3	**Floodplain (ha)**	138
Health (Whitfield 2000)	Poor	**Protection level**	Poor

Existing measures of health for the Nonoti system include an estimate of importance score combining measures of estuarine fauna associated with the estuary and more general biodiversity factors (Turpie & Clark 2007; Table 3.4a) and an estimate of health condition based on a desktop survey for the South African National Biodiversity Assessment (NBA) (Van Niekerk & Turpie 2012; Table 3.4b). Of the 256 estuaries surveyed nationally, the Nonoti Estuary was ranked 96th overall in terms of importance, and was identified as being of particular importance for estuarine-associated birds (Turpie & Clark 2007). The estuary was assigned a "good" status for habitat state, and "fair" for biological state leading to a mean estuary health state assessment of "good" status, and the assignment of an estuary ecological category of "B" (Van Niekerk & Turpie 2012). This category indicates that the system is largely natural with few modifications, and has a 75-90% similarity to the reference condition (DWA 2010). However, it is important to remember however that the NBA was a desktop survey and that no actual current data was collected from the estuary to perform the assessments and these are therefore guidelines only. This recent study will show that Whitfield's assessment (2000) is likely to be more correct, in that the Nonoti Estuary is in a poor state of health.

TABLE 3.4. EXISTING MEASURES OF HEALTH.

3.4A. OVERALL IMPORTANCE SCORE (CONSISTING OF THE IMPORTANCE SCORE AND BIODIVERSITY SCORE) AND RANK (WITHIN SA) OF THE NONOTI ESTUARY. ZTR = ZONAL TYPE RARITY. NOTE THAT FUNCTIONAL IMPORTANCE IS NOT INCLUDED IN THIS SCORE. (TURPIE & CLARK 2007)

Importance Score				Biodiversity Score				Importance Score /100	Rank /256
Plant	20	**Fish**	30	**Biodiversity**	74.5	**Habitat**	60		
Invert	40	**Bird**	100	**Size**	60	**ZTR**	10	58.6	96

3.4B. HEALTH CONDITION OF THE NONOTI ESTUARY, BASED ON A NATIONAL DESKTOP SURVEY. E=EXCELLENT, G=GOOD, F=FAIR, P=POOR (SOURCE: VAN NIEKERK & TURPIE 2012).

Hydrology	E	Microalgae	G
Hydrodynamics	G	Macrophytes	F
Water quality	F	Invertebrates	F
Physical habitat	F	Fish	F
		Birds	F
Habitat state	G	**Biological state**	F

Mean estuary health state	G
Estuary ecological category	**B**

Zinkwazi Estuary

The Zinkwazi Estuary is a temporarily open/closed estuary (TOCE) (for photographs see Appendix 3), and is one of three barrier lagoon types classified by their mud-yielding catchments, wide floodplains and short barrier lengths (shorter than floodplain width) (Cooper et al. 1993). It is one of the longest estuaries in the province, extending at least 7.5km inland (Begg 1984a) (Table 3.5), and its water is highly mineralised with a small catchment of approximately 73km^2 (Begg, 1978) characterised by deeply weathered Pleistocene soil (McCormick et al. 1992). Twenty years ago, it was considered to be one of the province's healthiest systems (Cooper et al. 1993). Now, with its entire catchment under sugar cane cultivation the estuary suffers from a number of associated problems including artificial breaching, siltation (estimated sediment yield 29 200 tonnes yr^{-1}, Rooseboom 1975) and reed encroachment, loss of natural vegetation and bank erosion due to cultivation extending to the water in some areas as well as organic pollution from runoff. Both the invasive gastropod *Tarebia granifera* and the invasive floating duckweed *Lemna minor* have been observed within this system, although densities at this stage are unknown. The estuary is however considered to be an area of conservation significance within the KwaDukuza Municipality (KwaDukuza Strategic Environmental Assessment, KwaDukuza Municipality 2012- 2017 Integrated Development Plan, May 2012).

Breaching of the mouth occurs when the back-barrier water levels elevate to the point of spilling over the barrier, linked to season (Bond et al. 2013). An extreme storm surge event in 2007 shifted the landward shoreline of the mouth to a deeper position which has been maintained since then and allows greater emptying when the mouth is open (Bond et al. 2013).

Holiday and residential accommodation has developed near the mouth. Estuary uses are therefore largely recreational and include boating and swimming. Faecal contamination has been found to occur following peak holiday periods (Begg 1978). The settlement of Zinkwazi is one of a small number within the KwaDukuza Municipality that have been identified as presenting a growth opportunity for urban expansion (Collins et al. 2012) and it is possible therefore that population density and pressure on the estuary may increase in the future.

TABLE 3.5. CHARACTERISTICS OF THE ZINKWAZI ESTUARY, FROM THE NBA 2011 (VAN NIEKERK & TURPIE 2012). MAR IS MEAN ANNUAL RUNOFF.

Estuary classification	Subtropical TOCE		
Location	S 31.443478 E 29.281590		
Estuary length km	7.481	**Openwater (ha)**	32
MAR Mil.m³	3753.6	**Floodplain (ha)**	205
Health (Whitfield 2000)	Fair	**Protection level**	Poor

Existing measures of health for the Zinkwazi Estuary include an estimate of importance score combining measures of estuarine fauna associated with the estuary and more general biodiversity factors (Turpie & Clark 2007; Table 3.6a), an estimate of health condition based on a desktop survey for the South African National Biodiversity Assessment (NBA) (Van Niekerk & Turpie 2012; Table 3.6b) and following on from this the identification of the Zinkwazi Estuary as a national priority for protection (Turpie et al. 2012; Table 3.6c).

Of the 256 estuaries surveyed nationally, the Zinkwazi Estuary was ranked 48th overall in terms of importance (Turpie & Clark 2007). In the NBA desktop survey the estuary was assigned a “good” status for habitat state, and “fair” for biological state leading to a mean estuary health state assessment of “fair” status, and the assignment of an estuary ecological category of “C” (Van Niekerk & Turpie 2012). This category indicates that the system is moderately modified, and has a 61-75% similarity to the reference condition (DWA 2010). Because of its importance Turpie et al. (2012) recommend that the estuary be partially protected and measures such as a no-take zone included in its protection plan. They also recommend that 50% of the estuary’s margin remain undeveloped (Table 3.6c).

TABLE 3.6. EXISTING MEASURES OF HEALTH.

3.6A. OVERALL IMPORTANCE SCORE (CONSISTING OF THE IMPORTANCE SCORE AND BIODIVERSITY SCORE) AND RANK (WITHIN SA) OF THE ZINKWAZI ESTUARY. ZTR = ZONAL TYPE RARITY. NOTE THAT FUNCTIONAL IMPORTANCE IS NOT INCLUDED IN THIS SCORE. (TURPIE & CLARK 2007).

Importance Score				Biodiversity Score				Importance Score /100	Rank /256
Plant	50	**Fish**	90	**Biodiversity**	80	**Habitat**	90		
Invert	70	**Bird**	70	**Size**	80	**ZTR**	10	75.5	48

3.6B. HEALTH CONDITION OF THE ZINKWAZI ESTUARY, BASED ON A NATIONAL DESKTOP SURVEY. E=EXCELLENT, G=GOOD, F=FAIR, P=POOR (SOURCE: VAN NIEKERK & TURPIE 2012).

Hydrology	G	Microalgae	F
Hydrodynamics	G	Macrophytes	P
Water quality	F	Invertebrates	F
Physical habitat	F	Fish	F
		Birds	F
Habitat state	G	**Biological state**	F

Mean estuary health state	F
Estuary ecological category	C

3.6C. THE ZINKWAZI ESTUARY IDENTIFIED IN A DESKTOP ASSESSMENT AS A NATIONAL PRIORITY FOR PROTECTION (TURPIE ET AL. 2012).

Current health category	Recommended extent of protection	Recommended degree of undeveloped margin	Desktop estimate of Ecological Reserve Category
C	Partial (incl. no-take zone)	50%	B

4. FRAMEWORK FOR MANAGING BIOPHYSICAL FUNCTION OF THE NONOTI & ZINKWAZI ESTUARIES

4.1 RDM Methodologies

Methods for determination of the Ecological Reserve for water resources as specified in Chapter 3 of the NWA of 1998 have been laid out in the Resource Directed Measures (RDM) of DWA, 2010 (Version 3). As it pertains to estuaries, the Reserve determines the quality, quantity and timing of freshwater inflows required by an estuary to maintain ecological functioning and health. The Preliminary Reserve has an ecological endpoint, and methodology for setting this reserve is in line with this. The allocated Reserve varies, and is determined by balancing the estuary's health and development with socio-economic demands to determine management class (Turpie et al. 2002). This class or category may range from a near-pristine state to satisfactorily-functioning but altered (Adams et al. 1999).

Prior to gazetting of a comprehensive Classification and Reserve Determination, a Preliminary Reserve was instituted to prevent irreversible degradation and against which licences may be issued in the interim. The National Water Resource Classification System (NWRCS) was gazetted in 2008. Although similar in their methods leading up to definition of class, the WRCS and Preliminary Reserve Determination differ in that WRCS is applied at the catchment rather than reach level, and takes social and economic as well as ecological impacts into consideration when determining class. Methodology for the Preliminary Reserve has since been aligned to meet the requirements of the WRCS such that the Preliminary Reserve may be converted to a comprehensive Classification Process.

Methodology

The methodology for Reserve Determination can be broken down into a number of steps (DWA 2010), defined and described as follows (Figure 4.1):

1) Initiate study and define resource units

Baseline description to describe the present state of the estuary:

This basic methodology is used for EIA, EMP and Reserve determination, and covers all aspects of estuary functioning (biotic and abiotic components and processes), as well as pressures and impacts on the system. The level of detail in the baseline assessment may vary depending on budgetary and time constraints which in turn will affect assessment confidence, or may be realigned to focus on the more critical ecosystem components (minimum requirements for a high-confidence baseline assessment are laid out in (See Appendix 4). Fieldwork must be undertaken for any Reserve determination studies, and for high-quality results this fieldwork should ideally take place over a one year period with components sampled on a quarterly basis or biannually during high- and low-flow seasons.

Describe and characterise estuary geographic boundaries, and catchment (desktop survey). Catchment description (size, tributaries, land-use, water abstraction) will identify upstream drivers and impacts affecting the estuary. A hydrologist will also simulate monthly or daily flows from catchment rainfall data, as estuary health is indicated by degree of change from the reference state and modification to river inflow is one such aspect of change.

Describe anthropogenic activities affecting the biotic and abiotic components and processes of the estuary, again important as an indicator of change from a reference state. Such influences can include land-use and development (e.g. weir construction, artificial breaching of mouth) and those influencing water quantity and quality (e.g. waste water treatment works) and biota (e.g. fishing).

Describe estuary abiotic components (bathymetry, hydrodynamics, sediment patterns and processes, water quality/biogeochemistry), define abiotic states. The physical nature of an estuary determines the biota and nature of the processes, and is often where anthropogenic influences (e.g. changes to flow, water quality) manifest first. Understanding of these variables is therefore crucial. For small estuaries (<5km long) a minimum of five water quality stations should be distributed geographically along the estuary length and for big estuaries (>5km long) stations should be distributed geographically at recommended intervals of approximately 1/10 estuary total length as well as along cross-sections where cross-sectional area is large. Abiotic states can be derived from river inflow and are descriptions of the state of a suite of factors (e.g. mouth state and salinity distribution) under identified typical inflow regimes (Taljaard et al. 2009).

Describe the estuary biotic components (microalgae including benthic microalgae and phytoplankton, macrophytes, invertebrates including zooplankton, subtidal benthic invertebrates and intertidal benthic invertebrates, fish, birds) in a detailed specialist report (Table 4.1). Descriptions should include the present state of the biota as well as defining features of it. For all biotic components measurements of species richness, rarity, abundance, community composition, biomass, productivity (primary producers) and seasonal variability must be made, where applicable. Also, an overview of the effect of other biotic and abiotic components and processes should be given, key links and critical periods of the year identified, and an indication of the extent of anthropogenic influences must be given for all biotic components. Such descriptions create a baseline against which future change can be measured, as well as feeding into the development of models and management strategies. As biotic components are closely linked to the abiotic environment, measurements of water quality parameters (salinity, inorganic nutrients, turbidity, sediment particle size distribution and organic content) at the time of sampling should also be made. For this reason it is expedient to align biotic sampling sites with abiotic sites. For example, estuarine invertebrates are strongly influenced by water and sediment characteristics as well as submerged vegetation, and so these components should all be measured at the same site to match the habitat characteristics with the fauna. Sites that are selected should be representative of the salinity range and habitat types. As with the abiotic characteristics and as a guideline for the biotic sampling a minimum of five sites distributed geographically along the estuary length would be adequate for small estuaries (<5km long). For large estuaries (>5km long) sites should be distributed geographically at recommended intervals of approximately 1/10 estuary total length as well as along cross-sections where cross-sectional area is large. In general, 10-15 sites should be adequate.

Perform an estuary health assessment (following Turpie 2012, Appendix 4). This is achieved by first estimating the Reference (pristine) condition of the estuary prior to any disturbance for both biotic and abiotic components (hydrology, hydrodynamics, physical habitats, water quality, biota), used then in comparison with current condition to calculate the estuary health score (/100) according to the Estuary Health Index (Turpie 2012). This is followed by an estimation of Present Ecological Status (A-F) (See Table 4.2). In essence therefore this step assesses the degree to which current state of the estuary reflects pristine conditions. A statement of confidence in the assessment should be made as the assessment is subjective and influenced by available data as well as specialist experience.

TABLE 4.1. BIOTIC COMPONENTS FOR INCLUSION IN RDM METHODOLOGY, AND DETAILS PERTINENT TO THEIR SAMPLING (DWA 2010)

	Microalgae	Macrophytes	Invertebrates	Fish	Birds
Rationale	Indicators of water quality. Important producers and helps with understanding higher consumers esp. invertebrates	Habitat and food for estuarine consumers. Indicators of water level and salinity	Zooplankton, nekton and benthic invertebrates are important as food and bait. Good indicators of estuarine condition	Important food source for other estuarine consumers as well as man. Helps with interpretation of bird data	Nutrient input and predation. Indicators of habitat and fish abundance
Sampling methods	1) Phytoplankton: collect duplicate samples at the surface and 0.5m depth intervals at each site. 2) Benthic microalgae: collect triplicate benthic intertidal and subtidal samples at each site	Historical aerial photos to determine habitat types and area, groundtruthed by fieldwork. Quadrats (1m^2) taken in duplicate along a minimum of four permanent transects (sites) for on-going monitoring	1) Zooplankton: Dusk and daytime mid-water trawls, and daytime hyperbenthic trawls with a net and flow meter. 2) Benthic invertebrates: Van Veen or Zabalocki-type Eckman grab sampler with 5-9 replicates per site filtered through 500µm sieve. 3)Intertidal benthic invertebrates: Sample with a pump or count hole density within quadrats (minimum 0.25m^2, five replicates) 4) Macrocrustaceans: Benthic sled with flow meter, two prawn/crab traps set overnight	Seine nets (30m long x 2m deep with 5mm mesh size in the cod end) and monofilament gill nets with at least four panels of different mesh sizes between 40-150mm. Where historic data are available gear specifications should match those used.	Seasonal bird counts within the estuary, divided into areas based on habitat type. Identify breeding aggregations and key habitat for feeding/roosting etc.
Key focus interests	Biomass, distribution, composition and relative abundance of different groups	Available habitat types and characteristics (dominant species, percentage cover)	Dominant species within each group, abundance (individuals.m^{-2} or .m^{-3})	Species and size distribution, link to estuarine dependence categories and trophic guilds	Species distribution and abundance
Related to	Water quality and sediment characteristics	Water quality and sediment characteristics	Water quality, sediment grain size and organic content	Invertebrates	Invertebrates and fish

TABLE 4.2. THE ECOLOGICAL CATEGORIES USED TO SET PES AS WELL AS ASSIGN REC (MODIFIED FROM DWA 2010)

Ecological Category	Present Ecological Status	Recommended Ecological Category
A	Unmodified, or approximates natural condition (> 90% similarity to reference condition)	The natural abiotic template should not be modified. The characteristics of this resource should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
B	Largely natural with few modifications (75-90% similarity to reference condition)	Only a small risk of modifying the natural abiotic template and exceeding the resource base should be allowed. Although the risk to the well-being and survival of intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.
C	Moderately modified (61-75% similarity to reference condition)	A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
D	Largely modified (41-60% similarity to reference condition)	Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
E	Seriously modified (21-40% similarity to reference condition)	Undesirable category
F	Critically modified (< 20% similarity to reference condition)	Undesirable category

2) Determine Recommended Ecological Category

The Recommended Ecological Category is a target for the resource protection and management. This is assigned based on the estuary's health, importance and protection status. The Estuary Importance Index (Turpie 2012) is used to calculate estuary importance. It takes into account the factors of estuary size, rarity of type with regards to geographical position, habitat diversity, biodiversity importance and functional importance in terms of the link between freshwater and marine environments, each of which are scored and the scores weighted to create an overall importance rating (/100). The Recommended Ecological Category uses the same ecological categories as those to determine PES with the exclusion of categories E and F, as it is undesirable to manage an estuary at anything below 40% of its natural condition. A description of management actions according to Recommended Ecological Category is provided in Table 4.2.

3) Determine ecological consequences of Operational and Ecological Reserve scenarios

A range of flow scenarios is required to test the relationship between flow and estuary health, and therefore identify the thresholds between different Ecological Categories (A to E). Operational scenarios, received from DWAF, usually represent real hydrology planning options, while Ecological Reserve scenarios are hypothetical and used to augment the Operational scenarios to provide a full range of hydrological scenarios. The scenarios are used to describe expected changes in all other estuary components, and a health score and ecological category (A-F) are calculated for each scenario as for the calculation of PES. These simulations form the basis for quantification of the Reserve, with the scenario that yields an ecological category equal to (high-confidence studies) or higher than (low-confidence studies) that of the REC used to define the Reserve. As with the baseline assessments and for this reason therefore a statement of confidence in the accuracy of the flow simulations must be provided by the hydrologist.

4) Reserve and Resource Quality Objectives specification

Set parameters for Reserve quality and quantity, as well as Resource Quality Objectives (RQO) (specific goals for the quality of the resource, based on the ecological category). Thresholds of potential concern (TPC) are early warning indicators for changes in water quantity, quality, habitat and biota that are set up to prompt management action when reached, and are measurable targets for RQOs. RQOs for the abiotic components must be set in conjunction with those for the biota due to the direct influence of habitat requirements on the characteristics of the biota.

5) Implementation

This step includes the establishment of operating rules for dams, mitigation measures and monitoring programme design. Long-term monitoring programmes are used to identify change from a baseline and to indicate whether RQOs are being complied with, and may be used to adapt and refine the RQOs as well as improve the baseline assessment. Of particular importance as variables to be monitored due to their influence on other components are water quality and quantity (flow), and salinity distribution. A monitoring programme must outline appropriate indicators, the temporal and spatial scales at which monitoring actions are to be executed as well as an estimation of the human resource requirements for execution of the monitoring actions (DWA 2010).

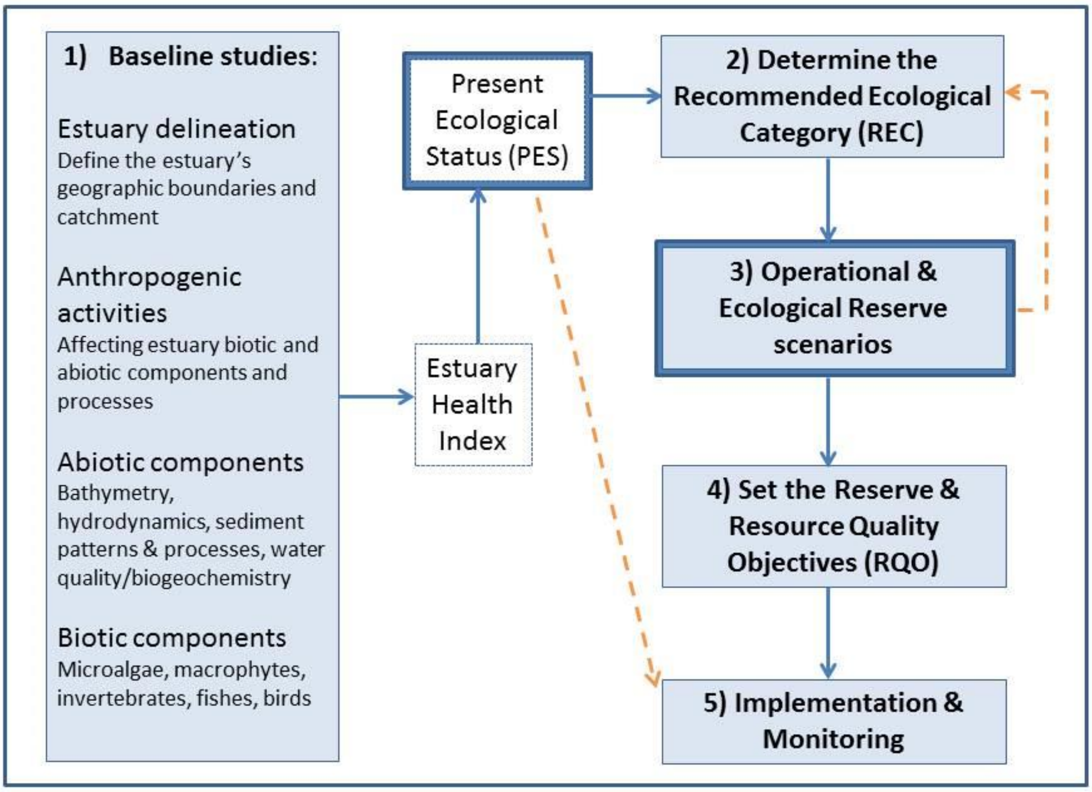


Figure 4.1. Framework for the RDM methodology (adapted from DWA 2010). Orange lines show feedback connections, and the thickened dark blue frame indicates steps where a statement of confidence must be given by the service provider.

4.2 Estuarine Management Plans

Under the ICM Act the National Estuarine Management Protocol (NEMP) (published in Government Gazette No. 36432, 10 May 2013) provides a framework for integrated estuarine management. The development of Estuarine Management Plans for all of South Africa's estuaries is critical to this. The purpose of an Estuarine Management Plan (EMP) is to provide actionable management steps that facilitate an established vision for the state of an estuary by managing the environmental, economic and social aspects of the system.

According to the NEMP an EMP must be in line with existing governmental coastal management programmes (at national, provincial and municipal levels) and has the following minimum requirements:

- Situation Assessment Report, containing information that would inform/influence management decisions
- Geographical description and map of the estuary based on Estuarine Functional Zone
- Vision and objectives for the resource as a whole

- Management objectives and activities in line with the vision (including management of living and non-living resources, social issues, land-use and development, water quality and quantity, climate change, education, compliance and enforcement)
- Spatial zonation of estuary
- An indication of which organs of state will be involved in consultation and implementation
- Monitoring plan that identifies suitable indicators
- Details of the institutional capacity and arrangements required for managing different EMP elements

The EMP can be broken down into three phases (as illustrated in Figure 4.2):

i) Scoping phase

Create a Situation Assessment Report (SAR) by collating and evaluating all available information on estuary status (health and functioning including an estimate of PES where possible), legislation pertaining to it (e.g. catchment management strategies), socio-economic state of the local communities and their dependence and impacts on the estuary's resources and the current goods and services offered by it.

ii) Objective-setting phase

Set a realistic vision for the environmental state of the estuary taking into account factors such as estuary goods and services, threats and socio-ecological opportunities and constraints. A list of objectives in line with the vision must also be provided and pertain among other things to the conservation and use of estuary resources, management of water quality and quantity, land-use and development. The vision and objectives must be aligned with those of the NEMP, and it should be stated how local objectives will give effect to those of the NEMP.

iii) Implementation phase

Management actions for the government department responsible for estuary management must be outlined. Appropriate management strategies are put in place to achieve these objectives including setting an estuarine zonation plan that limits activities to suitable areas of the estuary. These plans must directly link to the vision and objectives and be able to be implemented. As such they should include a work schedule as well as an indication of parties responsible for action, a resource plan and monitoring plan with key indicators identified. This monitoring will be both resource- (to monitor estuary health) and compliance-oriented (to monitor impacts). An on-going system of monitoring and evaluation is used to assess the adequacy of the management strategies put in place, and these are revised when necessary (adaptive management). The effectiveness of the EMP in meeting its vision and objectives will be assessed every five years, as well as identifying any environmental or legislative changes that will affect the estuary and the EMP.

Development of an EMP must include public participation and engage with all relevant stakeholders for its development and implementation. After consideration of the public participation process the EMP must be submitted to a relevant approval authority which has a period of 90 days from acknowledgement of receipt to assess whether it meets the requirements of the NEMP before it can be adopted by the responsible management authority. An Estuarine Management Authority, e.g. Ezemvelo KZN Wildlife, is responsible for the implementation of the EMP operational objectives, but critical to its success is the formation of an Estuary Advisory Forum who will ensure co-operative governance is employed, as well as secure long-term funding for management (Taljaard & Van Niekerk 2007).

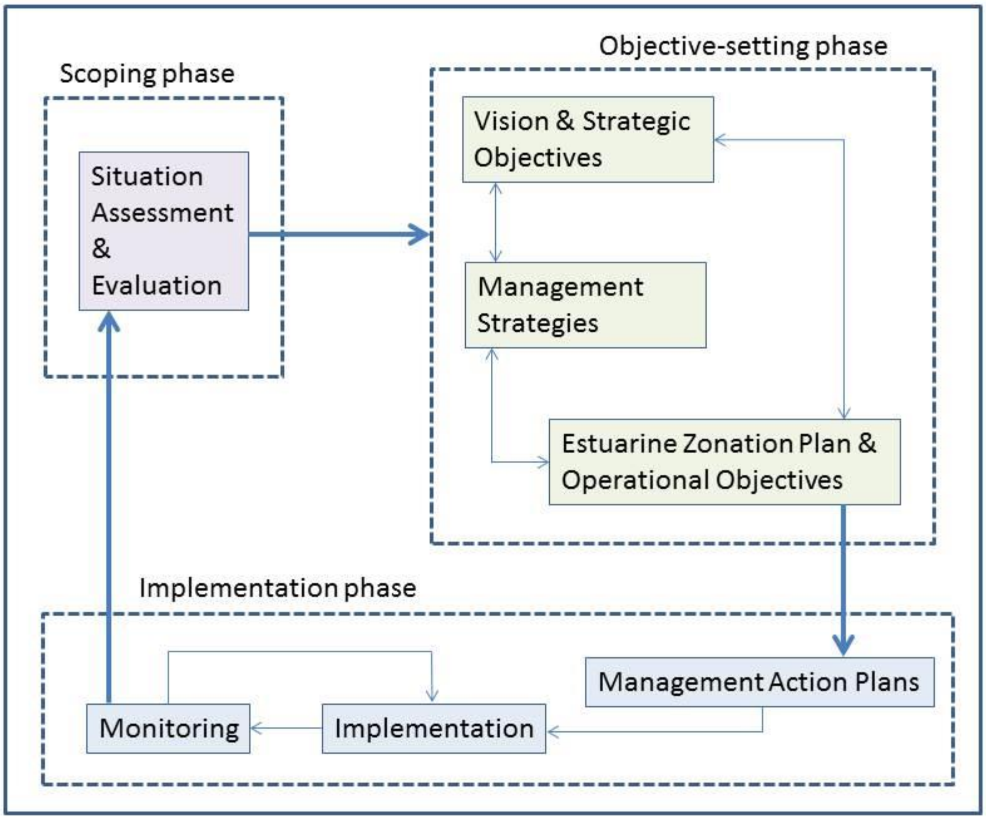


FIGURE 4.2. GENERIC ESTUARINE MANAGEMENT PLAN FRAMEWORK, MODIFIED FROM TALJAARD & VAN NIEKERK (2007).

5. SPATIAL ANALYSIS

Land use and resultant land cover are continually changing in response to human demands, needs and wants (Houghton 1994). Broad changes in land cover often result in significant economic and environmental impacts, which have long-term implications for a range of policy issues including preservation of public open space, maintenance of naturally functioning areas and indirect resource benefits such as water quantity and quality (Lubowski et al. 2003). Changes in land cover can be regarded as the single most important variable affecting ecosystems (Vitousek 1994). However, little is known about the dynamics and the significance of changes in land cover, which in turn can result in degradation of the natural environment (Gangai & Ramachandran 2010).

While data and information are often limited to assess the impact of historical and current changes, it is broadly recognised that the magnitude of change is significant and that a better understanding of the cause and effect relationships of land cover change is required (Lambin et al. 2001). In South Africa, Biggs and Scholes (2002) undertook an assessment of changes in agriculture and cultivation land for the period 1911 to 1993. Results showed that patterns of agricultural change are partly linked to population growth, culture, political and economic conditions. An increase in population results in, amongst other things, increased demand for food products which in turn leads to an expansion of cultivated areas with land under cultivation more than tripling during the twentieth century (Biggs and Scholes, 2002). 'Man made' areas have expanded at the expense of natural vegetation (Goldewijk 2001), with estimates showing that 18% of South Africa's natural landscape has been transformed due to cultivation (10.46%), degradation (4.47%) urban land use (1.51%) and forestry (1.41%) (DEAT 2006).

Coastal and estuarine areas are of particular concern; these areas are highlighted as undergoing rapid land cover change as a result of coastal development pressure, driven by their attractiveness for residence, leisure, recreation and tourism (Martínez et al. 2006). KwaZulu-Natal (KZN) is no exception to this trend, with the impact of development becoming increasingly visible along the coast (Preston-Whyte & Oelofse 2007).

Both the Nonoti and Zinkwazi Estuaries fall within the KwaDukuza Local Municipality and the iLembe District Municipality. KwaDukuza supports a population of approximately 250 000 people, which increases seasonally to about 300 000 people (KwaDukuza Municipality 2012). The Zinkwazi Estuary is identified as the most significantly modified estuary within the KwaDukuza Municipality, with a number of threats being identified including loss of habitat, poor water quality, land transformation in the catchment area and artificial breaching of the mouth (KwaDukuza Municipality, 2012).

In order to assess changes in land cover around the Nonoti and Zinkwazi Estuaries, all available historical aerial photographs and orthophotographs were sourced and rectified in order to extract information pertaining to land cover and thus land cover change. These changes highlight social and economic drivers of change and demand for alternative land uses along the coast over time.

5.1 Methods

Land cover mapping

Land cover change around the two study estuaries was considered for the period 1937 to 2009. Land cover was captured up to the 20 metre contour from remotely sensed data from aerial and ortho-photographs. This is a useful way of assessing land cover change over time, as it allows for retrospective assessment of change. These changes can then be related to environmental and social drivers and effects on the ground.

For this study monochromatic aerial photographs for years pre-2000 and orthophotos for years post-2000 were used. Aerial photographs (pre-2000) were geo-referenced to the 2008 orthophotos in order to allow for use in a Geographical information System (GIS). Geo-referencing is the process whereby images are located spatially by 'referencing' images to data of a known coordinate system. Time intervals of the historic assessment were largely based on the availability of early aerial photographs, resulting in time intervals as shown in Table 5.1. Land cover data for this research was generated through a process of heads-up digitising, using ArcGIS 10.1 software. Digitising was conducted at a scale of between 1: 5 000 and 1: 8 000 which allows for the identification of features given the varied resolution (pixel size) of the aerial photographs (Table 5.1).

TABLE 5.1. YEARS OF AERIAL AND ORTHOPHOTOGRAPHS FOR THE STUDY

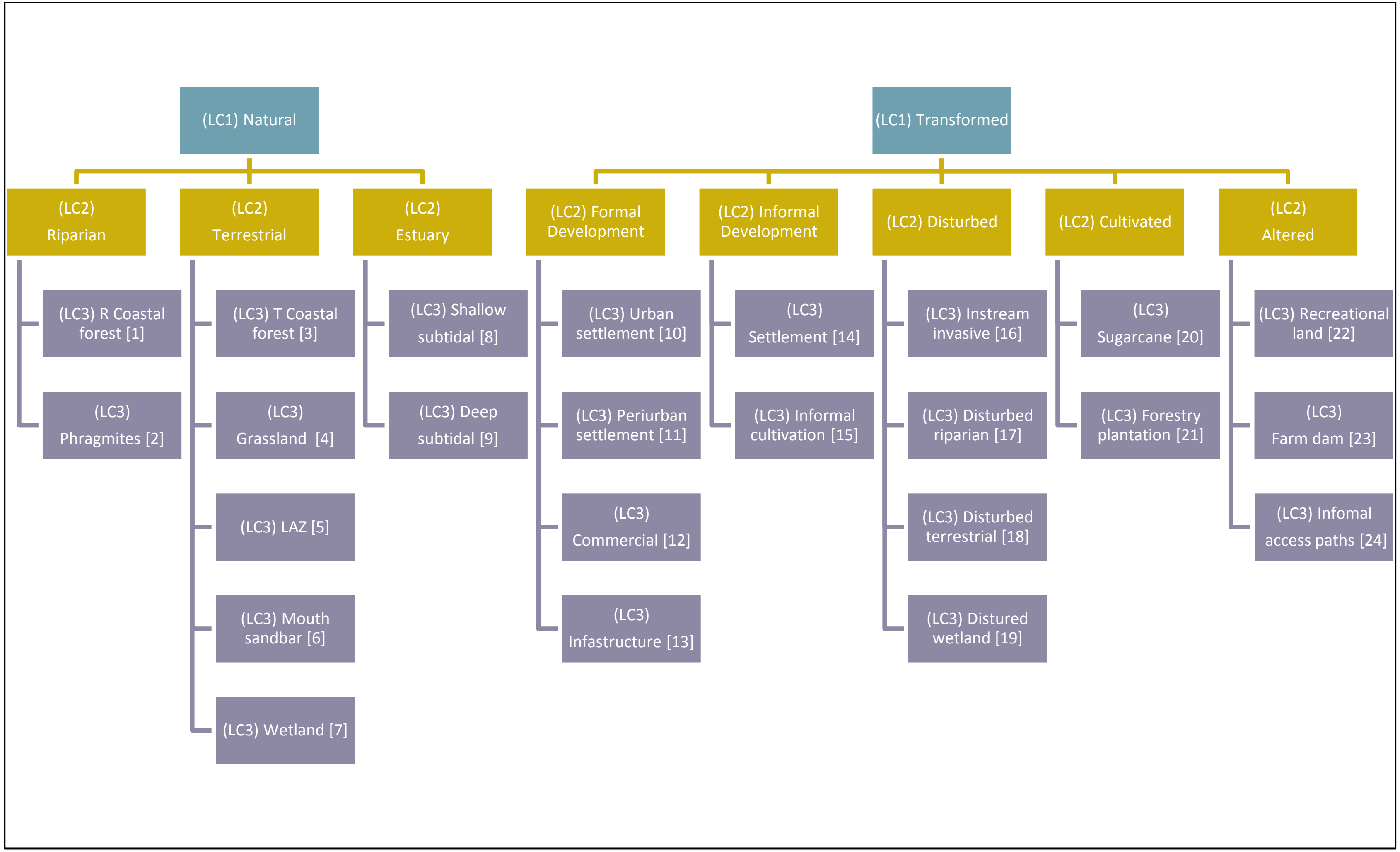
Year	Resolution (pixel size)	
	Nonoti	Zinkwazi
1937	2.12	2.12
1953	3.05	3.05
1964	3.05	3.05
1972		4.23
1973	4.23	
1983	5.54	
1989		4.23
1997	2.71	
2000		2.54
2002	2.71	
2007	2.54	2.54
2009	2.54	2.54

It is important to note that there is inherent error associated with this methodology as a result of both the geo-referencing and digitising processes. The geo-referencing process introduces error in that images cannot be precisely located, introducing a *locational shift*. Digitising of land cover is based on human interpretation of what is visible, thus introducing *human error*. Ability to capture features is further influenced by the *resolution* of the base photography, which is the product of the scale at which the images where captured (Romine et al. 2009). In order to minimise the introduced error, only one analyst geo-referenced images and captured land cover data, thus ensuring consistency of capture (Romine et al. 2009). Given that land cover boundaries are inherently dynamic and variable, the introduced error is considered to be negligible for the purposes of this land cover change assessment.

Land Cover Classification

The distinction between land cover and land use is an important one. Land cover is confined to the description of vegetation and man-made features visible on the land surface, while land use refers to the arrangements, activities and inputs people undertake on land cover for desired outcomes (Di Gregorio 2005). Both are clearly interrelated as a single land use, for example grazing, can be associated with a number of land cover types, e.g. grassland or forest. Furthermore specific land cover, e.g. grassland, can be associated with several land uses, e.g. grazing or recreation (Giri 2012). As a result, land cover is often used as a proxy for land use (Giri 2012). With this in mind this study focused on land cover and land cover change as these are the features that are recognisable and identifiable from the aerial and orthophotos.

Land cover classification for this assessment was based on the National Land Cover (NLC) 2000 data (Thompson et al. 2001) and expert local knowledge, particularly pertaining to estuarine land cover, in order to assess the dynamic changes occurring in this zone. Land cover was divided into 24 land cover classes, falling into eight categories as depicted in Figure 5.1 and explained in Table 5.2. For the analysis, Land Cover (LC) 3 was considered as this allows for the most detailed assessment of changes based on the data available.



**LC- Land Cover*

FIGURE 5.1. SCHEMATIC REPRESENTATION OF LAND COVER CLASSES USED FOR ASSESSMENT OF NONOTI AND ZINKWAZI ESTUARIES.

TABLE 5.2. LAND COVER CLASSES AND DESCRIPTION OF EACH CLASS USED IN THIS ASSESSMENT.

LC1	LC2	LC3	Description
Natural	Riparian	[1] Riparian Coastal forest	Wooded areas, found along estuarine water courses, with greater than 70% tree canopy cover, where the canopy is comprised of mainly self-supporting, single stemmed, woody plants.
		[2] *Phragmites*	Large perennial grass found in estuarine floodplains and wetlands.
	Terrestrial	[3] Terrestrial Coastal forest	Wooded areas with greater than 70% tree canopy cover, where the canopy is comprised of mainly self-supporting, single stemmed, woody plants
		[4] Grassland	All areas of grassland with < 10% tree and/or shrub canopy cover, dominated by grass-like, non-woody, rooted herbaceous plants. The better the condition of the grassland the darker and more even in tone it will appear.
		[5] Littoral Active Zone (LAZ)	Any land forming part of, or adjacent to the seashore that is unstable and dynamic as a result of natural processes. It is characterised by dunes, beaches, sand bars and other landforms comprised of unconsolidated sand, pebbles or such material which is either un-vegetated or only partially vegetated.
		[6] Mouth sandbar	Submerged or partly exposed ridge of sand built by wave action of the sea and estuary.
		[7] Wetland	Natural areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered in either herbaceous or woody vegetation cover. The category includes fresh, brackish and salt water conditions.
	Estuary	[8] Shallow sub tidal	*Shallow, less than 2 metres deep*, naturally occurring body of surface water that is part of a water course that is permanently or periodically open to the sea. Usually found in the lower reaches of estuaries.
		[9] Deep sub tidal	*Deep, greater than 2 metres deep*, naturally occurring body of surface water that is part of a water course that is permanently or periodically open to the sea. Usually found in the middle and upper reaches of estuaries.
Transformed	Formal Development	[10] Urban settlements	Formal built-up areas consisting of permanent structures in which people reside. Identifiable by the *high density* buildings and associated infrastructure (predominantly roads).
		[11] Peri-urban Settlement	Formal built-up areas consisting of permanent structures in which people reside. Identifiable by *low density* building and associated infrastructure (predominantly roads).
		[12] Commercial	Non-residential areas primarily used for the conduct of commerce, industrial and other mercantile business. It includes sites associated with educational (i.e. schools, universities), business development centres such as industrial 'techno-parks', and/or social services (i.e. hospitals).

LC1	LC2	LC3	Description
		[13] Infrastructure	Permanently transformed areas associated with the provision of services, such as roads, pipelines and railways.
	Informal development	[14] Settlement	Non-permanent shack type dwellings (i.e. tin, cardboard, wood etc) typically established on an informal, ad hoc basis, on non-serviced sites. Either high or low building densities.
		[15] Informal cultivation	Small scale cultivation / garden plots, often are located amongst the residential structures, for the raising crops for subsistence utilisation.
	Cultivated	[16] Sugarcane	Areas of land that are ploughed and/or prepared for crops, includes areas currently under crop, fallow land, and land being prepared for planting. Characterised by uniform, well managed field units.
		[17] Forestry plantation	Areas of systematically planted, man-managed areas. Primarily comprised of exotic species.
	Altered	[18] Recreational land	Areas of open space, predominantly grassland, used for recreational activities. This includes areas such as school and public sports fields and golf courses, as well as supporting infrastructure.
		[19] Farm dams	Man-made body of water for the purpose of water supply.
		[20] Informal access paths	Removal of vegetation as a result of persistent use of areas to gain access to the coast or estuarine environment.
	Disturbed	[21] Disturbed riparian	Permanent or near-permanent, man-induced areas along estuarine water courses of degraded or very low vegetation cover.
		[22] Disturbed terrestrial	Permanent or near-permanent, man-induced areas of very low, degraded vegetation cover (i.e. removal of tree, bush, or herbaceous cover) in comparison to the surrounding natural vegetation cover.
		[23] Disturbed wetland	Disturbed wetland area where the water level are naturally at (or very near) the land surface, covered invasive vegetation cover.
		[24] Instream invasive	Invasive or exotic species found within the estuarine water course. These are species that would not naturally occur in the habitat.

Change detection

For this assessment land cover change detection was done by means of *post-classification change detection*, which allows for the determination of differences between independently classified images from each of the dates in question (Fichera et al. 2012). This method removes any limitations associated with the 'normalisation' of multi-date imagery, as is the case for this research (Thompson et al. 2001).

It was anticipated that there would be two primary areas of change, namely *inter-class conversions* and *intra-class transformations* (Thompson et al. 2001). Inter-class conversions are from one primary classification to another, namely natural to transformed (for example riparian coastal forest to urban settlement). Intra-class transformations are transformations within a primary classification such as disturbed riparian to sugarcane, whereby the primary classification remains the same (in this case, transformed). It is important to note that some changes are considered not to be possible, such as a change from urban settlement to riparian, thus highlighting erroneous data capture. In addition, some changes are considered possible but unlikely or highly unlikely as outlined in the change matrix in Figure 5.2. This matrix was used to verify data capture and determine if any unlikely changes have been shown and therefore erroneously captured, allowing for validation of historical data in the absence of ground truthing.

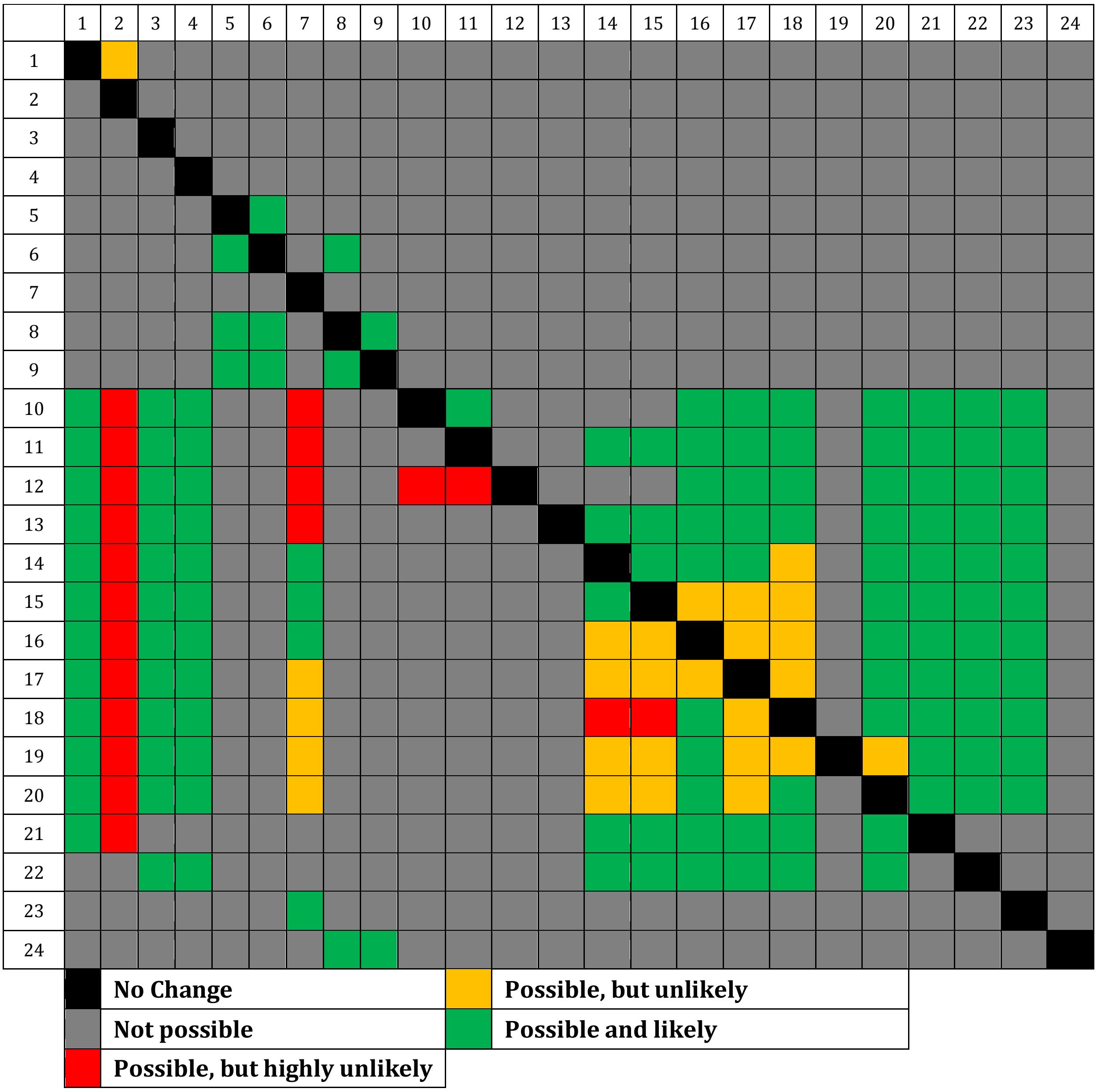


FIGURE 5.2. CHANGE MATRIX FOR LAND COVER CHANGE OVER TIME.

5.2 Nonoti Estuary

The use of GIS to create land cover at different time periods allows for a spatial and temporal assessment of where and when inter-class conversions and intra-class transformations occur. Significant changes in land cover around the Nonoti Estuary for the period 1937 to 2009 are evident (Figure 5.3). Figure 5.4 shows the actual percentage change per land cover class over the period (1937-2009). Significant changes include the increase in the presence of instream invasive plants from 3% in 1937 to 9% by 2009, and an increase in sugarcane from 1937 to 1983, after which point there is a decrease.

Land cover per year for available data (1937-2009) is presented in Appendix 5. A notable change is the development of the N2 freeway (between 1983 and 2000), built in the early 1990s. As is evident from Figure 5.4, there have been a number of changes in land cover around the Nonoti Estuary for the period 1937 to 2009. However, land cover is dominated by *transformed* land cover (Figure 5.3), where the majority of land cover falls within formal development, disturbed, cultivated and altered land cover classes. This suggests that the estuary has been under pressure for a number of years as a result of human coastal activities such as sugarcane cultivation and residential developments. The ratio of transformed to natural classes change from approximately 80%:20% to about 90%:10% from 1937 to 1953, after which point it remained relatively stable (Figure 5.3). While inter-class conversions are evident, in order to gain a better understanding as to the actual changes on the ground, consideration needs to be given to the intra-class transformations.

One of the key changes evident is the increase in sugarcane cultivation, which increased by 49% over the 72 year period (Figure 5.4). An increase in cultivation is driven by a combination of increased demand for sugarcane production and efficiency in farming techniques making in feasible to have more land under cultivation. The 'boom' in agriculture is highlighted between 1937 and 1983, where sugarcane cover increased to 64%. This increase is mainly accounted for by a decrease in disturbed riparian land from 20% to 15% and disturbed terrestrial from 26% to 5% for this period (Figure 5.3). Increased sugarcane cultivation introduces a range of indirect impacts on the estuary including soil erosion, wetland sedimentation, possible introduction of alien species and loss of critical biodiversity and other ecosystem services (Conservation International, 2013) through the introduction of agricultural pesticides, draining of wetlands and cultivation of the estuarine floodplain (South African Sugarcane Research Institute, unknown) (Figure 5.5). In addition, sugarcane production is one of the largest water consumers placing significant pressure on natural water resources in the area (Conservation International 2013), also affecting alternative land uses that require water, such as residential development.

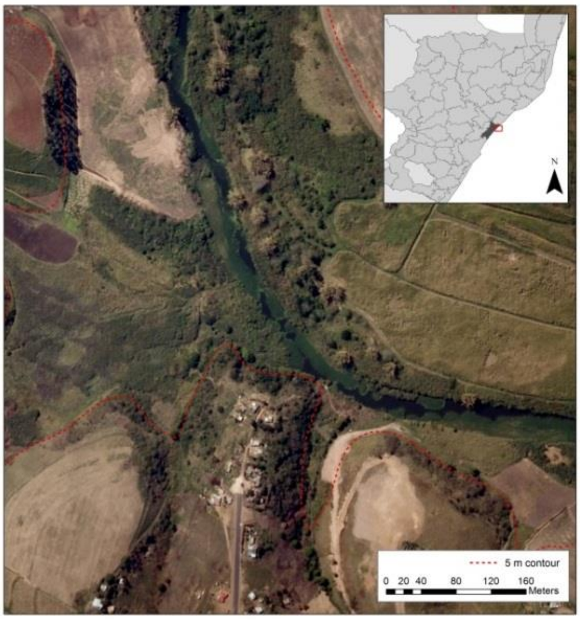


FIGURE 5.5. CULTIVATION WITHIN THE ESTUARINE FLOODPLAIN OF THE NONOTI ESTUARY, WHICH HAS LED TO THE INTRODUCTION OF INVASIVE SPECIES

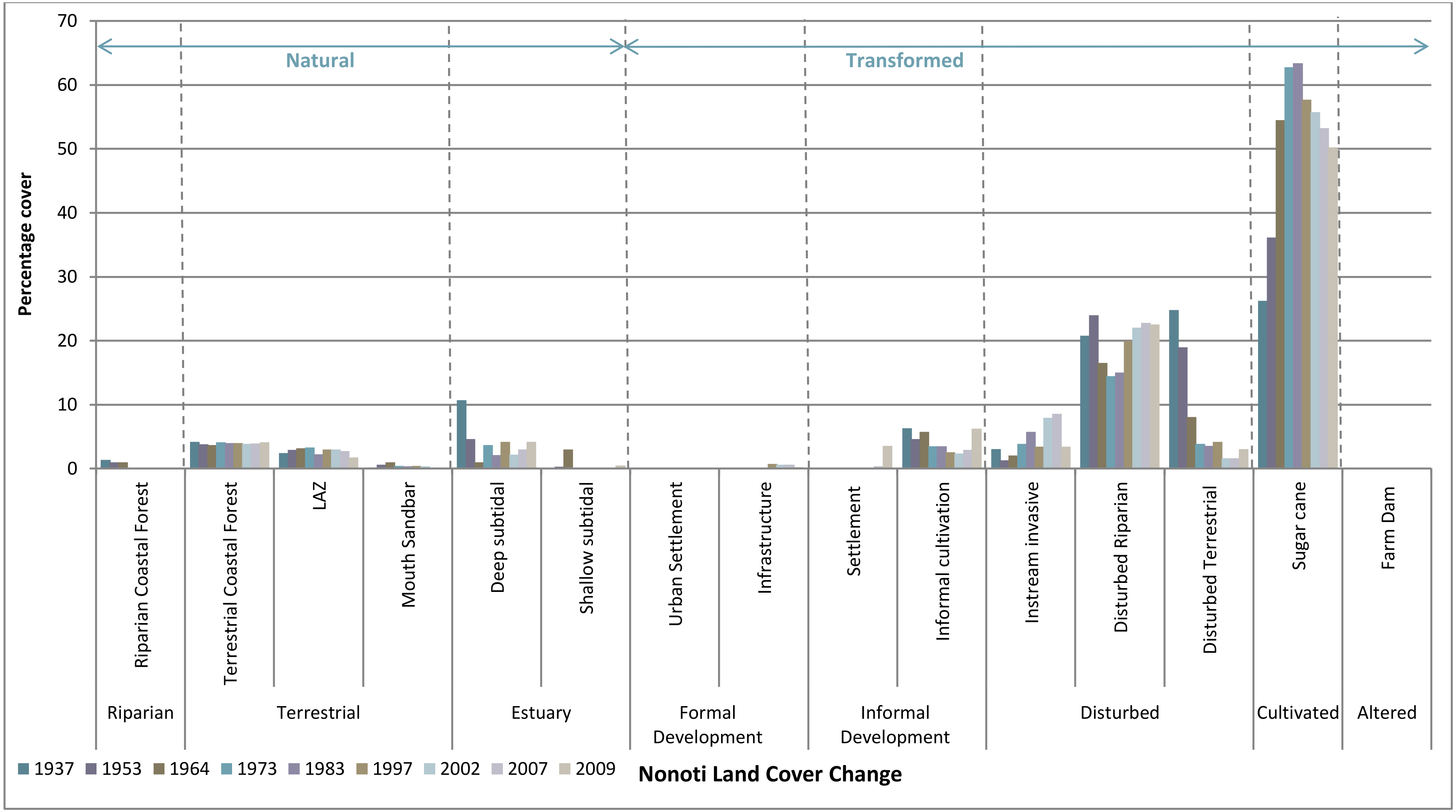


FIGURE 5.3. PERCENTAGE LAND COVER CONTRIBUTION AND CHANGE OVER TIME IN AND AROUND THE NONOTI ESTUARY.

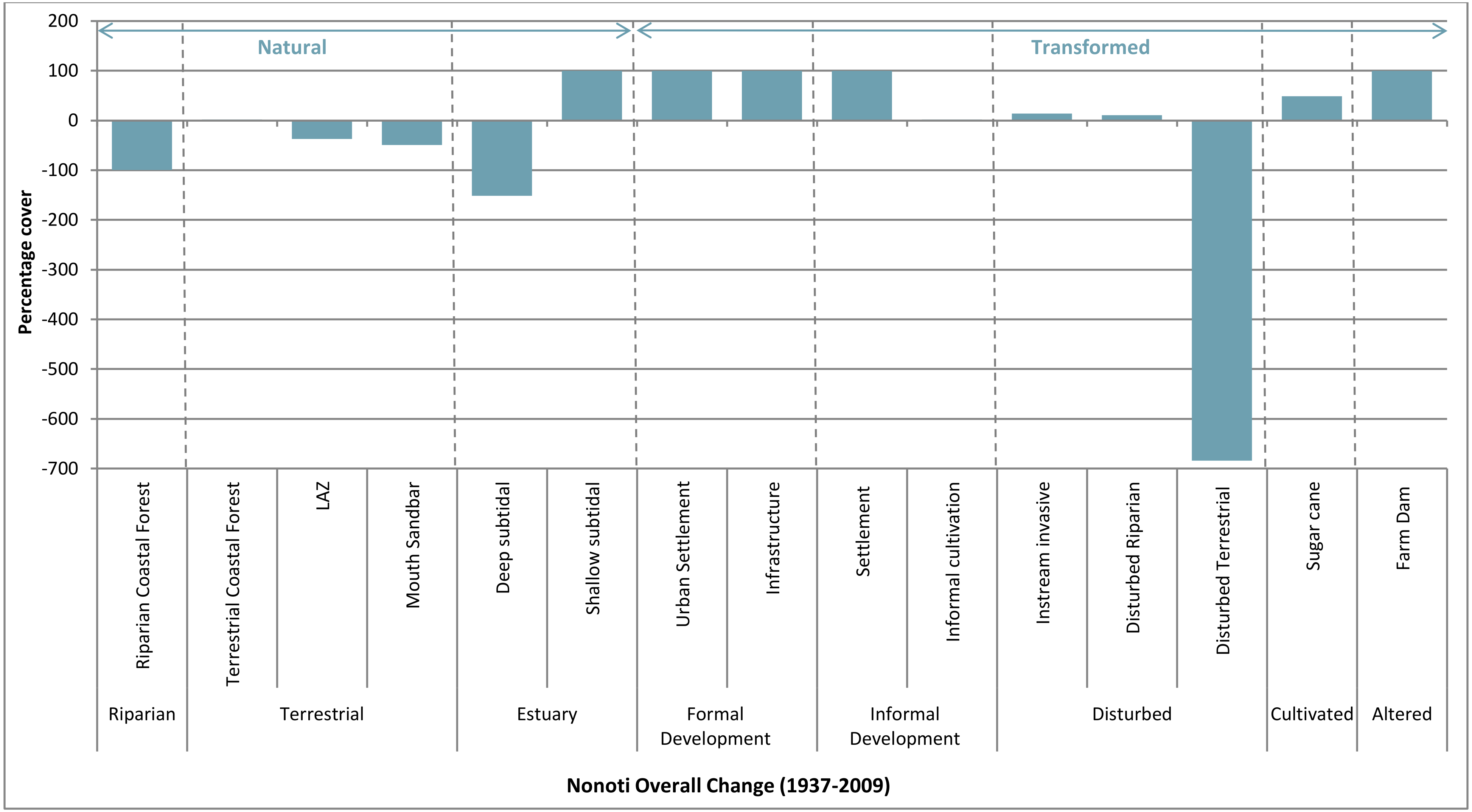


Figure 5.4. Overall change in land cover contributions in and around the Nonoti Estuary

From 1997, the area under sugarcane cultivation started to indicate a decrease (Appendix 5.1) and by 2009 contributed only 50% to land cover. This decrease highlights a shift towards alternative land uses. Disturbed riparian increased, likely showing a shift from unfavourable cultivation in the riparian zone (as highlighted above). Notably, there was an increase in land used for informal cultivation and informal settlements. From 1997 there is also the emergence of formal development with the N2 freeway being a prominent change. It is anticipated that pressure for formal development around this estuary will increase given national and provincial demand for coastal land, driven by people's desire to be near the coast for residential and tourist-related activities.

The Nonoti beach is also highlighted as a tourism project for the district, with the aim of developing a mass beach tourism resort in the iLembe region. A feasibility study has already been completed and the development is being included in the Environmental Management Framework (EMF) for the region (iLembe District Municipality 2012). The Nonoti Estuary also falls within one of the sites identified for the iLembe Agricultural Farms Project, the aim of which is to identify subsistence farms and convert them to commercially viable farms through the provision of infrastructure, identification of agricultural co-operatives and assistance with capacity building and skills development (iLembe District Municipality 2012).

5.3 Zinkwazi Estuary

Figure 5.6 shows land cover percentage contributions per year, highlighting the change over time for the period 1937 to 2009, while Figure 5.7 shows the actual percentage change over the period (1937-2009). It is evident that the dominant land cover during this time is sugarcane farm lands, increasing from 35% in 1937 to around 70% in 2009. This change mirrors decreases in riparian coastal forest and riparian disturbed land cover.

Land cover per year is presented in Appendix 5. Notable changes are the development of the N2 freeway (between 1989 and 2000), built in the early 1990s and the residential expansion and formalising of the town near the Zinkwazi Estuary mouth, post 1972.

There have been a number of changes in land cover around the Zinkwazi Estuary for the period 1937 to 2009, as is evident from Figure 5.7. However, for the period of this assessment land cover is dominated by *transformed* land cover (Figure 5.7) including formal development, disturbed, cultivated and altered land cover classes. This shows that the estuary has been under pressure for a number of years as a result of human activities including sugarcane cultivation and residential developments. The ratio of transformed to natural uses remains consistent at about 90:10% for the 72 year period under review (Figure 5.6). While inter-class conversions are evident, in order to gain a better understanding as to the actual changes on the ground, consideration needs to be given to the intra-class transformations.

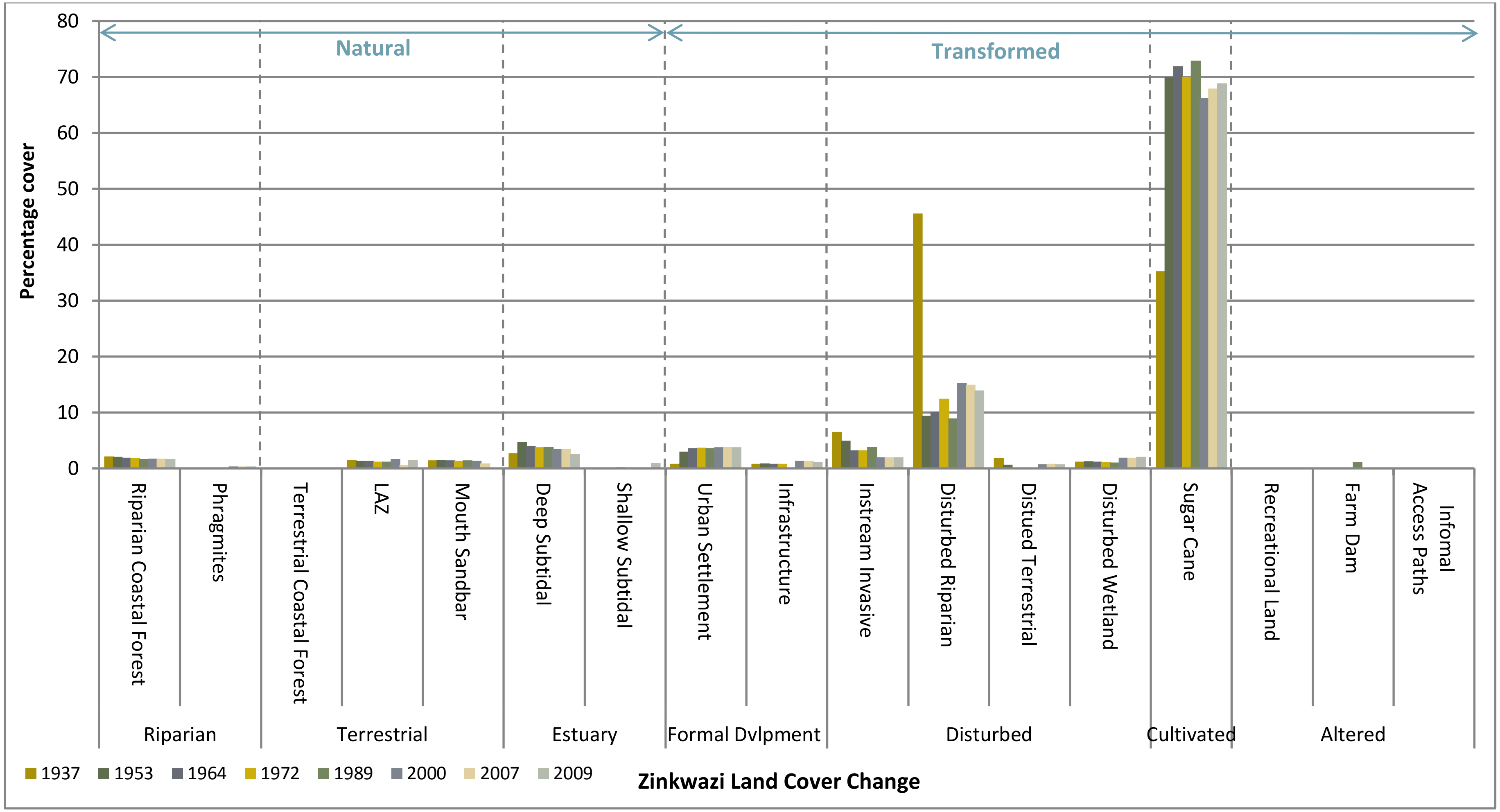


FIGURE 5.6. PERCENTAGE LAND COVER CONTRIBUTION AND CHANGE OVER TIME IN AND AROUND THE ZINKWAZI ESTUARY

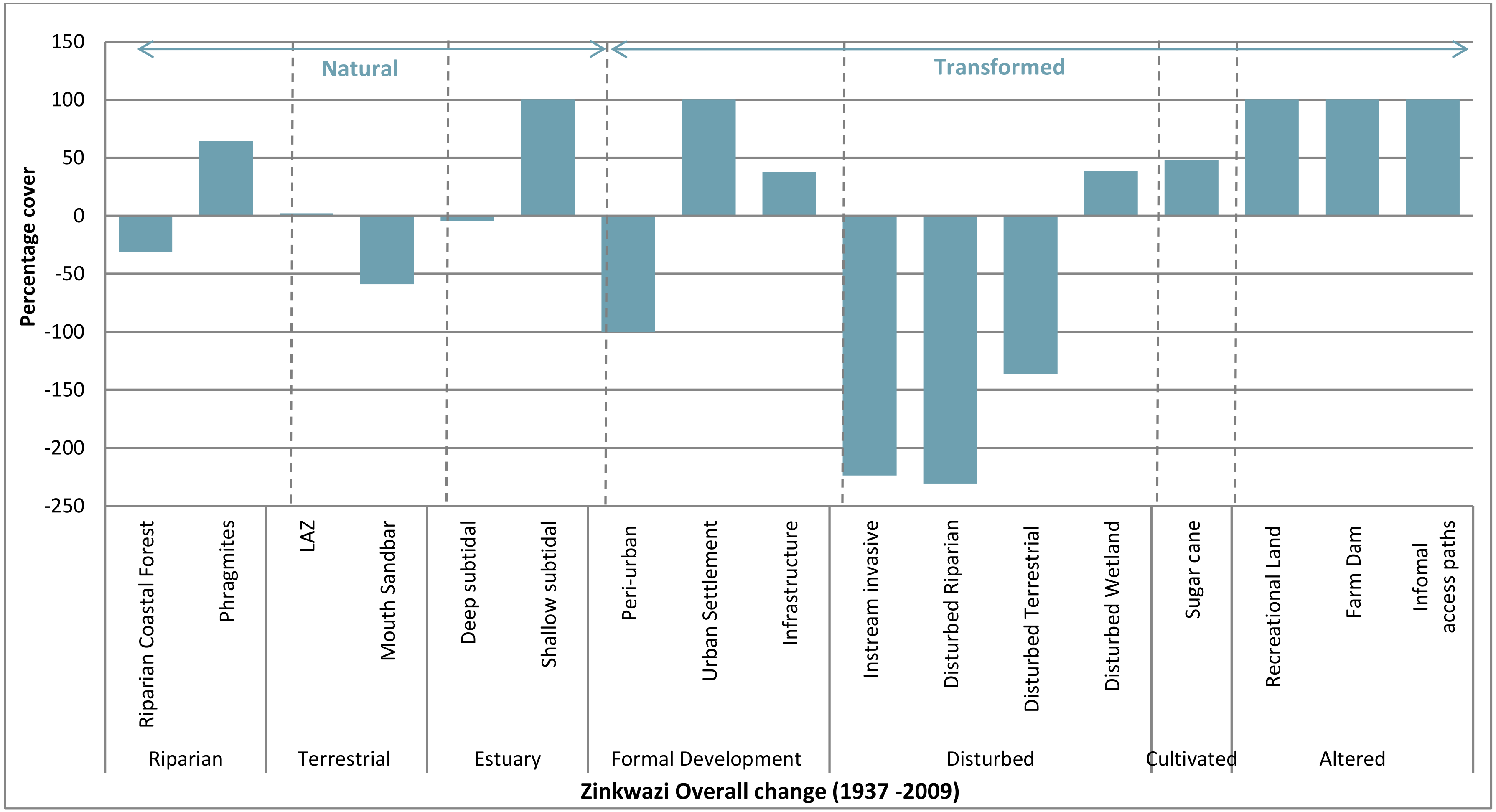


Figure 5.7. Percentage land cover change per class over the period 1937-2009 in and around the Zinkwazi Estuary

One of the key changes evident around the Zinkwazi Estuary (Figure 5.8) is the increase in area under sugarcane cultivation, which increased by 48% between 1937 and 2009 (Figure 5.7). The increase in cultivation is largely driven by increased demand for sugarcane coupled with increased efficiency in farming techniques making it feasible to have more land under cultivation. Sugarcane production around this estuary peaked between 1937 and 1953, increasing from 35% under cultivation to 70%, associated mainly with a decrease in disturbed riparian land from 46% to 9% (Figure 5.6). As described for the Nonoti Estuary, increased sugarcane cultivation introduces a range of indirect impacts on the estuary and is a large pressure on other natural resources such as water which could alternatively be used by other land uses.

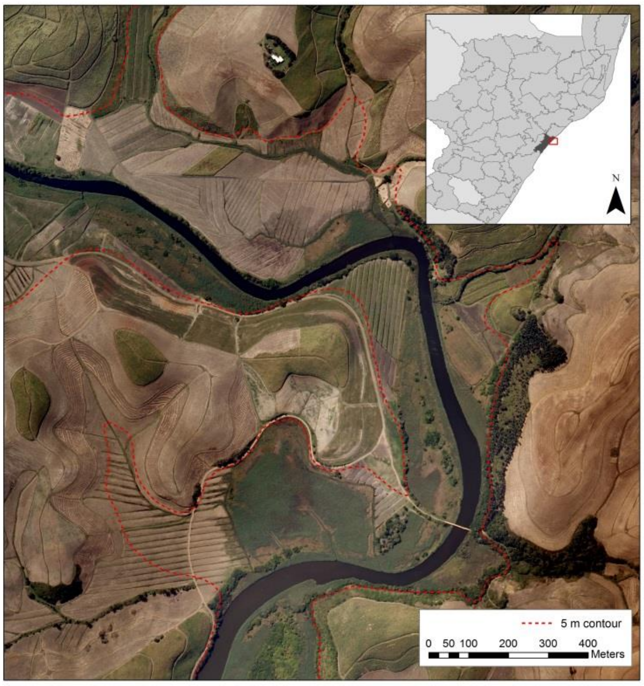


FIGURE 5.8. CULTIVATION WITHIN THE ESTUARINE FLOODPLAIN AND WETLAND AREAS OF THE ZINKWAZI ESTUARY.

From the 2000s sugarcane cultivation showed a decrease to 67% by 2009. This slight decrease highlights a shift towards urbanisation (urban settlement) and the development of supporting infrastructure. Notably the development of the N2 freeway is evident between 1989 and 2000 (Appendix 5). To date, this section of coast has seen rapid development, being recognised as an international coastal resort destination (iLembe District Municipality 2012); the expansion of the town of Zinkwazi near the estuary mouth (Appendix 5) is evidence of this change. Demand for coastal land relates to people's desire to be near the coast for residential and tourist related activities. Importantly this is the general trend for the KZN coastal environment, with land under sugarcane cultivation decreasing from 382 000 ha in 2009 to 317 000 ha in 2010, where the largest declines were recorded for the coastal mills of Amatikulu (24%), Darnall/Gledhow/Maidstone (30%), Sezela (26%) and Umzimkulu (24%) (Singels *et al*., 2011)

Additional development pressure has been identified by the KwaDukuza Municipality's Integrated Development Plan (IDP) as the area is located within the provincial coastal development corridor which runs between the eThekwini Harbour, the King Shaka International Airport and the Richards Bay Harbour (KwaDukuza Municipality 2012).

Common to both the Nonoti and Zinkwazi Estuaries, pressure for development is further exacerbated by the fact that the area falls within the iLembe District priority area for tourism, which stretches from the town of Ballito to north of the Thukela Mouth (iLembe District Municipality 2012) which is an area where future development will be encouraged. Albeit following principals of sustainable development (iLembe District Municipality 2012), this is likely to create additional pressure on an already stressed estuarine environment. Importantly, the KwaDukuza Municipality Integrated Development Plan (IDP) recognises that development in this area should, as far as possible, be limited and a low density approach should be applied, with development taking place in the form of limited individual and unique clusters allowing for adequate public access to the coast (KwaDukuza Municipality, 2012). However, the KwaDukuza Municipality Spatial Development Framework (SDF) also highlights this area as a future growth area, falling within the Darnall Node (Figure 5.9). This node is a medium- to long-term economic growth node for the region that will be developed as a mixed use area focused on recreation and tourism (KwaDukuza Municipality 2009; KwaDukuza Municipality 2012).

Of concern is that the SDF proposes higher density residential areas along seaward fronting areas and river edges, specifically with respect to the Zinkwazi Estuary. Here, additional development is also proposed that will see the expansion of the existing town inland (Figure 5.10), resulting in the further loss of sugarcane and natural land. Importantly, land on the northern bank is identified as open space (Figure 5.10), with no plans for development at this stage.

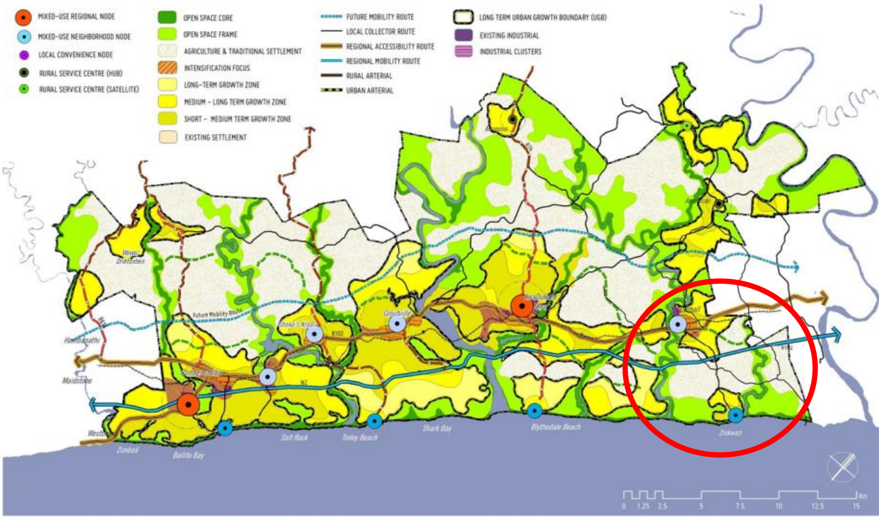


FIGURE 5.9. SPATIAL DEVELOPMENT PLAN FOR THE KWADUKUZA LOCAL MUNICIPALITY, SHOWING THE PROPOSED DEVELOPMENT GROWTH ZONES (KWADUKUZA MUNICIPALITY 2009)

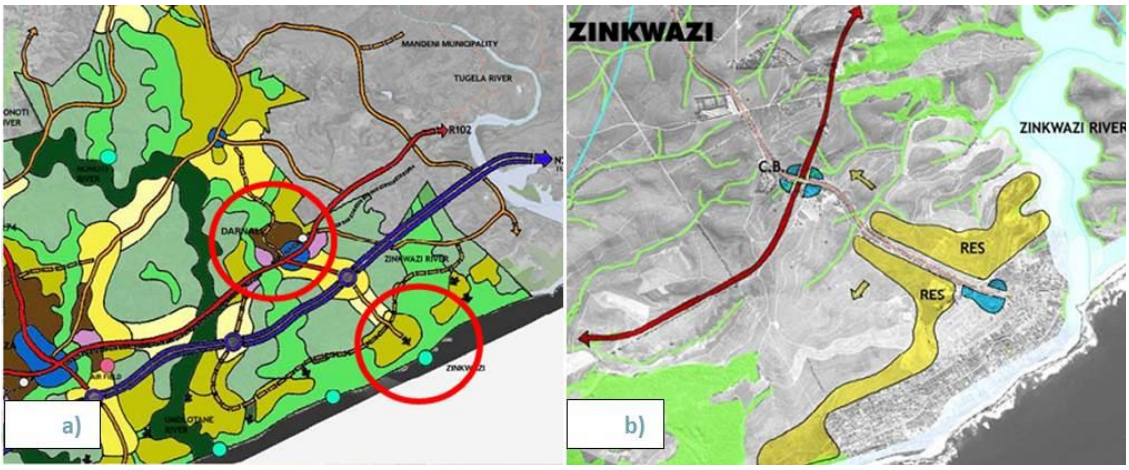


FIGURE 5.10. KWADUKUZA LOCAL MUNICIPALITY DARNALL GROWTH NODE. A) SHOWING THAT THE ZINKWAZI ESTUARY FALLS WITHIN THIS NODE B) SHOWING THE PROPOSED EXPANSION OF ZINKWAZI TOWN (KWADUKUZA MUNICIPALITY 2009)

6. PHYSICO-CHEMICAL HABITATS OF NONOTI & ZINKWAZI ESTUARIES

Introduction

Location and topography

The province of KwaZulu-Natal (KZN) is bounded by the Mozambique border to the north and the provincial border of the Eastern Cape to the south. From Umhlanga Rocks to the Thukela River the continental margin rises steeply into the interior (EMATEK CSIR 1995) (average gradient greater than 1:100 (Cooper 1990)). Rivers in this area therefore have a high sediment supply (Cooper 1990). The topography is characterised by deeply dissected spur and valley landscapes with deeply incised meander drainage courses (EMATEK CSIR 1995).

The marine environment

The KZN coastline is bounded by the Indian Ocean. The warm (approx. 6°C warmer than surrounding water, Palmer et al. 2011) western boundary Agulhas Current closely follows the continental shelf. Sea temperatures in this region are fairly stable and average 21°C. Directly north of the study systems (the Nonoti and Zinkwazi estuaries) is the Thukela River which strongly affects the coastal environment through its high discharge of sediment. Sediment discharge by the Thukela is in the region of 6.79×10^6 m^3yr^{-1} (Bosman et al. 2007), and the plume can stretch into the Agulhas current (Burke & Gunnell 2008). From the north, the otherwise narrow (3-12km) continental shelf broadens to over 45km to form the Thukela shelf and this contributes to the creation of a semi-permanent gyre over the shelf (Gründlingh & Pearce 1990). The coastline is characterised by crenulate bays with rocky headlands and the dominant swell direction is from the southeast (Roussouw 1989). As a result, longshore transport occurs in a northerly direction (Smith et al. 2010), although the volume of sediment transported is relatively low (Day 1981, Ngubane et al. 1997). The spring tidal range is 1.84m, with a mean of 1.59m (Moes & Roussouw 2008).

Beaches in this region of KZN are classed as homeostatic to eroding (Tinley 1985). Nonoti beach is fairly inaccessible and has a steep profile rising to 8.9m amsl (EMATEK CSIR 1995). Zinkwazi beach also has a steep profile (9.8m amsl), and is characterised by fairly rough surf conditions, moderate currents and coarse sediment. Geologically, the stretch of coastline from Durban to Mozambique is dominated by seabed sandstones, mudstones and shelly limestones of the Cainozoic era and recent aeolianites (King 1972; Ngubane et al. 1997).

Climate and rainfall

Coastal KZN has a humid, subtropical climate. Daily temperatures range between 16-25°C in winter (May to August) and 23-33°C in summer (November to February). Prevailing winds during summer along the coast are onshore north easterlies, with wind direction shifting to north or south west in winter. The windiest period along this section of coastline is spring to the end of summer (September to February) (EMATEK CSIR 1995).

In a country otherwise considered semi-arid, KZN is wet with an average rainfall in excess of 1000mm per year, and experiences high humidity and few dry months. It is a summer rainfall area. Rainfall data from Zinkwazi Park recorded over the years 1983-2011 consistently indicates higher rainfall in the months of September-February (spring and summer, high flow period) compared to March-August (autumn and winter, low flow period) (Figure 6.1). Average annual high flow rainfall was 727.1 ± 242.4 mm and average annual low flow rainfall 396.5 ± 218.8 mm (Table 6.1.). Extreme rainfall events such as tropical cyclones and cut off low pressure systems do periodically affect the province and can account for some years of exceptionally high seasonal rainfall, including cyclone Domoina (January 1984), the cut off lows in September 1987 and February 1988 and an unusual baroclinic system in July 1996 (Table 6.1, Figures 6.1 and 6.2). The years 1987 and 2004 in particular experienced higher than average rainfall in the high flow months, whilst 2006 had an exceptionally wet low flow period (Table 6.1, Figures 6.1 and 6.2). The year 1983 was the driest in the period recorded (Table 6.1, Figure 6.1).

TABLE 6.1. TOTAL ANNUAL RAINFALL RECORDED AT ZINKWAZI PARK AND PRESENTED FOR HIGH FLOW (SEPTEMBER-FEBRUARY) AND LOW FLOW (MARCH-AUGUST) PERIODS (SOURCE: K. ACHTZEHN).

Year	High flow	Low flow		Year	High flow	Low flow
1983	366.75	146		**1998**	575	236.5
1984	777.5	472.5		**1999**	736.5	426
1985	855.25	545.25		**2000**	800.5	475.05
1986	684	387.5		**2001**	670.75	352.5
1987	1382.75	1147.8		**2002**	521.05	220
1988	1084	627		**2003**	410.3	148
1989	1171	660		**2004**	1226.25	675
1990	667.5	311		**2005**	558.5	229.5
1991	808.75	539		**2006**	751	444.5
1992	428.5	160.75		**2007**	644	266
1993	691.75	391.25		**2008**	599.5	253.4
1994	540	228.25		**2009**	880.55	623.75
1995	508.75	172.5		**2010**	588	237.75
1996	654.5	303.5		**2011**	877.5	554
1997	624.8	264				
Average	727.1	396.5		**Standard deviation**	242.4	218.8

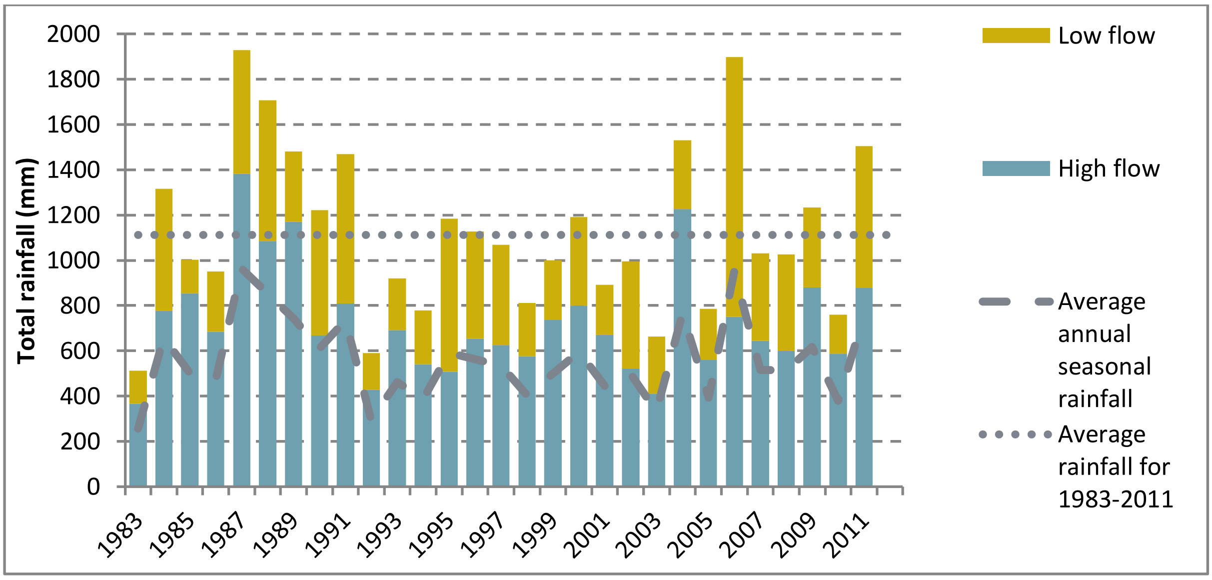


FIGURE 6.1. TOTAL ANNUAL RAINFALL FOR THE PERIOD 1983-2011 RECORDED AT ZINKWAZI PARK, DISPLAYING SEASONAL CONTRIBUTION TO TOTAL (SOURCE: K. ACHTZEHN). HIGH FLOW CORRESPONDS TO SEPTEMBER-FEBRUARY, AND LOW FLOW MARCH-AUGUST.

Physico-chemical environment of TOCEs

Salinities in TOCEs are generally low compared to permanently open estuaries and adjacent marine systems. This is particularly true of KZN TOCEs. Harrison (2003) found that salinities in subtropical South Africa TOCEs generally did not exceed 15 psu (average). However broad salinity fluctuations do occur and they depend on the state of the mouth and freshwater inputs from precipitation and land derived runoff (Day 1981b, Whitfield 1992, Harrison 2004). Uniform oligohaline (0-4.9 psu) to mesohaline (5-17.9 psu) conditions prevail during the closed and semi-closed phases of these estuaries with sporadic saline input via marine overwash (Whitfield 1992, Whitfield & Bate 2007, Whitfield et al. 2008, Perissinotto et al. 2010). During the open phase typical horizontal salinity gradients are often present (Whitfield & Bate 2007, Whitfield et al. 2008). Strong vertical salinity stratification can also result from low freshwater input entering the estuary as surface water, flowing over and trapping bottom saline water (Whitfield & Bate 2007, Perissinotto et al. 2010). Conversely, during flood conditions, TOCEs behave like river mouths where salinity gradients are absent and become largely freshwater environments (Branch & Branch 1985, Whitfield 1992, Perissinotto et al. 2010).

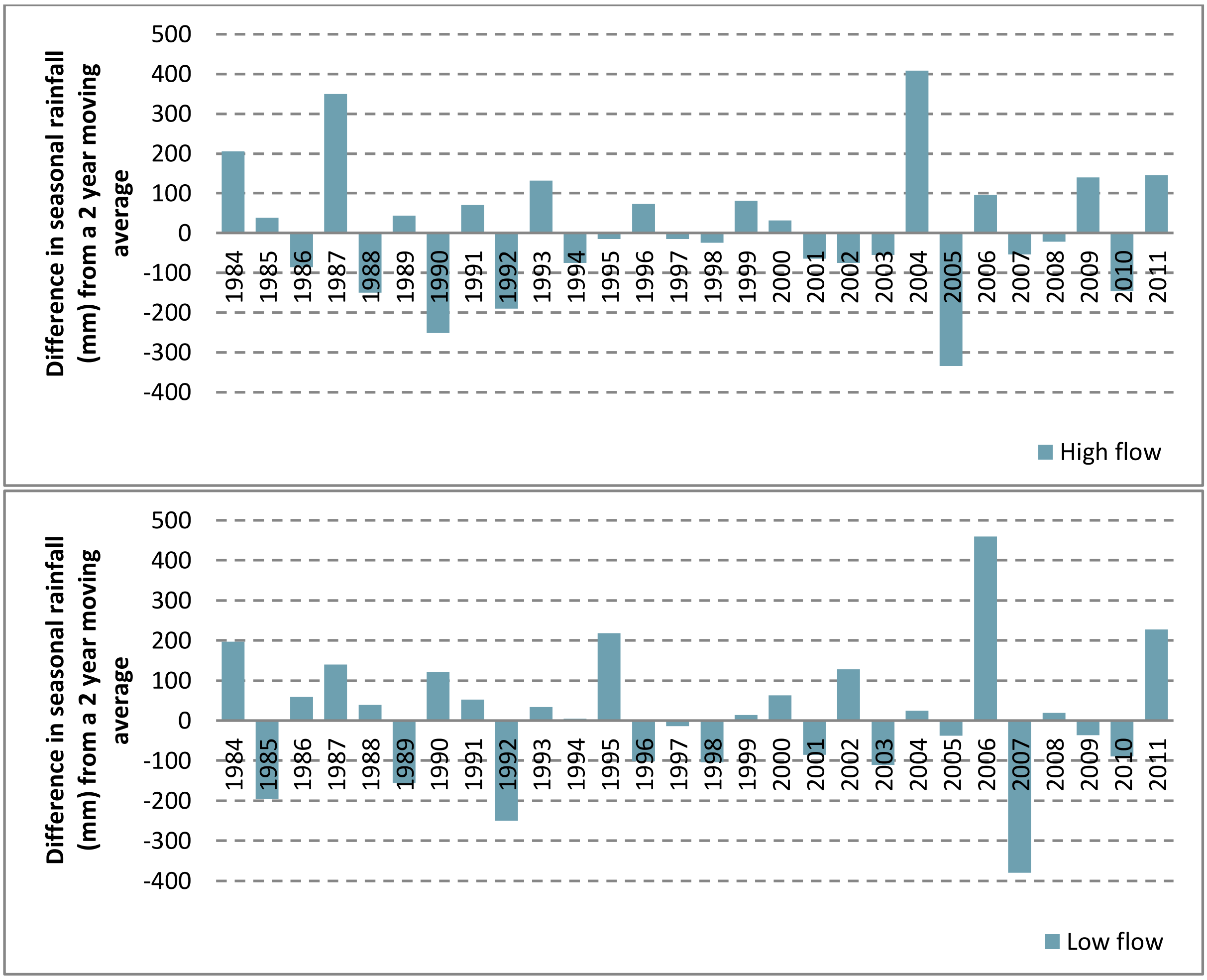


Figure 6.2. Seasonal rainfall recorded from Zinkwazi Park for the period 1984-2011, plotted as difference from a two year moving average (Source: K. Achtzehn). High flow corresponds to the months September-February, and Low flow March-August.

Dissolved oxygen levels in TOCEs are also determined by the state of the mouth. During the open phase, estuary water is relatively well oxygenated (Harrison 2004, Whitfield & Bate 2007). However, during the semi-closed state, increased water depth may result in stratification and reduced dissolved oxygen levels (<3 mg/L) in bottom waters. This is exacerbated by poor wind-induced mixing, poor water circulation and decomposition of organic detritus (Harrison 2004, Whitfield & Bate 2007, Perissinotto et al. 2010). Oxygen-deficient bottom waters can be replenished by oxygen-rich water during marine overwash (Whitfield & Bate 2007). Closed systems generally have uniform oxygen concentrations, however this is largely dependent on depth and water circulation (Day 1981b, Harrison 2004, Whitfield & Bate 2007, Perissinotto et al. 2010). Anoxic or hypoxic conditions are common in narrow and well-sheltered TOCEs of KZN that have been closed for an extended period of time (Perissinotto et al. 2004, 2010). This can impose extreme physiological constraints on the residing estuarine organisms.

6.1 Methods

Bottom sediment characteristics and water column measurements of the ambient physico-chemistry were taken as surrogates of habitat conditions in the Nonoti and Zinkwazi estuaries during this study. They were measured at sites throughout each of the study estuaries. Sites were selected in each estuary at varying intervals from the mouth to the systems headwaters. The intention was that the full axial length of each system would be sampled to include the full range of physico-chemical and habitat types within each estuary (Figures 6.3 and 6.4, Tables 6.2 and 6.3). Data were collected in July 2012 during winter low flow conditions and again in February 2013 during summer high flow conditions.

At each sites sediment samples were collected for analysis of granulometry and organic content and physico-chemical water quality parameters were measured *in situ* using a multiparameter water quality sonde (see later). Data were analysed according to region of the estuary (lower, middle or upper reaches). Division of each estuary into the test factor ‘Estuary Reach’ was based on *a priori* classification of the physico-chemical and sediment data using the Euclidean Distance measure of similarity, specifically for abiotic data. The resultant classification matrix was ordinated using non-metric multidimensional scaling (NMDS). Samples (sites) that grouped together (that is, were similar) were considered to be similar in habitat (according to the parameters measured) and thus were classified as being in the same estuary reach.

FIGURE 6.3. MAP OF THE NONOTI ESTUARY SHOWING SITES WHERE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS WERE MEASURED AND SEDIMENTS COLLECTED (SOURCE: GOOGLE EARTH).

TABLE 6.2. SITE NUMBERS, GEOGRAPHICAL LOCATIONS AND ESTUARINE REACHES WHERE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS WERE MEASURED AND SEDIMENTS COLLECTED IN THE NONOTI ESTUARY.

Site no.	Latitude	Longitude	Reach		Site no.	Latitude	Longitude	Reach
1	S29 19.074	E31 24.442	L		11	S29 18.762	E31 24.701	M
2	S29 18.987	E31 24.489	L		12	S29 18.720	E31 24.614	M
3	S29 18.938	E31 24.555	L		13	S29 18.720	E31 24.677	M
4	S29 18.887	E31 24.601	L		14	S29 18.666	E31 24.605	M
5	S29 18.842	E31 24.623	M		15	S29 18.573	E31 24.523	U
6	S29 18.802	E31 24.618	M		16	S29 18.525	E31 24.443	U
7	S29 18.803	E31 24.653	M		17	S29 18.428	E31 24.350	U
8	S29 18.803	E31 24.698	M		18	S29 18.334	E31 24.250	U
9	S29 18.762	E31 24.616	M		19	S29 18.428	E31 24.054	U
10	S29 18.763	E31 24.660	M		20	S29 18.632	E31 23.898	U

FIGURE 6.4. MAP OF THE ZINKWAZI ESTUARY SHOWING SITES WHERE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS WERE MEASURED AND SEDIMENTS COLLECTED (SOURCE: GOOGLE EARTH).

TABLE 6.3. SITE NUMBERS, GEOGRAPHICAL LOCATIONS AND ESTUARINE REACHES WHERE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS WERE MEASURED AND SEDIMENTS COLLECTED IN THE ZINKWAZI ESTUARY.

Site no.	Latitude	Longitude	Reach		Site no.	Latitude	Longitude	Reach
1	S29.28069	E31.44232	L		16	S29.25946	E31.43474	M
2	S29.28034	E31.44221	L		17	S29.25680	E31.42862	M
3	S29.27933	E31.44228	L		18	S29.25411	E31.42268	U
4	S29.27876	E31.44181	L		19	S29.24963	E31.42325	U
5	S29.27851	E31.44273	L		20	S29.24783	E31.42283	U
6	S29.27786	E31.44154	L		21	S29.24742	E31.42070	U
7	S29.27773	E31.44218	L		22	S29.27519	E31.43980	L
8	S29.27758	E31.44272	L		23	S29.27263	E31.43670	M
9	S29.27705	E31.44174	L		24	S29.26983	E31.43299	M
10	S29.27621	E31.44085	L		25	S29.26511	E31.43976	M
11	S29.27368	E31.43886	M		26	S29.25850	E31.43857	M
12	S29.27188	E31.43437	M		27	S29.25785	E31.43239	M
13	S29.26844	E31.43325	M		28	S29.25718	E31.42423	U
14	S29.26599	E31.43550	M		29	S29.25210	E31.42461	U
15	S29.26235	E31.43970	M		30	S29.27827	E31.44231	L

Sediment characteristics

Sediment samples were collected using a Zabalocki-type Eckman grab which samples a uniform area of estuarine sediment to an average 4cm depth. Samples were taken for sediment granulometry as well as for analysis of organic content. The latter were preserved with 4% formaldehyde to prevent further production, or consumption, of organic matter by invertebrates within the sample. Sample processing and analysis was outsourced to an external laboratory (Environmental Mapping and Surveying, Durban).

Sediment Granulometry

A wet sieving method was used to fractionate sediment samples into distinct grain size categories (the Wentworth scale, Figure 6.4). Dry weights of sediments in each grade were determined and various statistics characterising sediment granulometry calculated (e.g. mean and median particle size, sorting and skewness).

TABLE 6.4. THE WENTWORTH SCALE OF SEDIMENT GRADES.

Size diameter (mm)	Description
>2	> Very coarse sand
2-1	Very coarse sand
1-0.5	Coarse sand
0.5-0.25	Medium sand
0.25-0.125	Fine sand
0.125-0.0625	Very fine sand
<0.0625	Mud

Organic Content

The percentage organic content of the sediments was determined using the Hydrogen Peroxide digestion method (Schumacher 2002). Concentrated hydrogen peroxide (H_2O_2) was added to a known weight of sediment and heated to increase peroxide digestion of the organic material. Once frothing ceased and digestion was complete, each sample was dried and weighed. The amount of organic material removed by hydrogen peroxide digestion was calculated as the difference between the initial and final weight measurements of the sample and expressed as a percentage of the total sample. The resultant content was classified according to the ranges as suggested by Schumacher (2002, Table 6.5).

TABLE 6.5. SEDIMENT ORGANIC CONTENT CLASSES (SCHUMACHER 2002).

Organic content (%)	Description
>4	High
2-4	Medium
1-2	Moderately low
0.5-1	Low
<0.5	Very low

Water physico-chemistry

Water parameters (depth (m), salinity (psu), dissolved oxygen (mg/L), turbidity (NTU), pH, temperature (°C), conductivity ($mS.cm^{-1}$) and total dissolved solids (mg/L)) from surface to bottom waters were measured *in situ* at each site using a YSI® data logging multiprobe 6600. Parameters were recorded as a continuous profile through the water column.

6.2 Nonoti Estuary

Mouth condition

Mouth condition data for the Nonoti Estuary has been recorded by Ezemvelo KZN Wildlife (EKZNW) on a weekly basis for the period 1996 until present. Although there are large gaps in the dataset, it appears that the mouth of the Nonoti Estuary is predominantly closed. Open mouth events are a function of freshwater flows, and the duration of time the mouth remains open is determined by the amount of freshwater flow as well as the availability of sediment in the nearshore marine environment and wave and current conditions which act to move it onshore. Although the incomplete dataset hinders accurate comparison, during years of low rainfall (e.g. 1998; 1999, which correspond to low runoff and freshwater inflow) the mouth would be expected to open less frequently than during years of high rainfall (Figure 6.5). As discussed previously, rainfall is highest during the late spring and summer months in KZN and one would therefore expect most of the open mouth events to be recorded during these periods. This proved true with 70.7% of all open mouth events since 1996 having occurred in the spring and summer months (15% and 55.7% respectively). 61.4% of the closed mouth phases occurred in autumn and winter (23.7% and 37.7% respectively, Table 6.6).

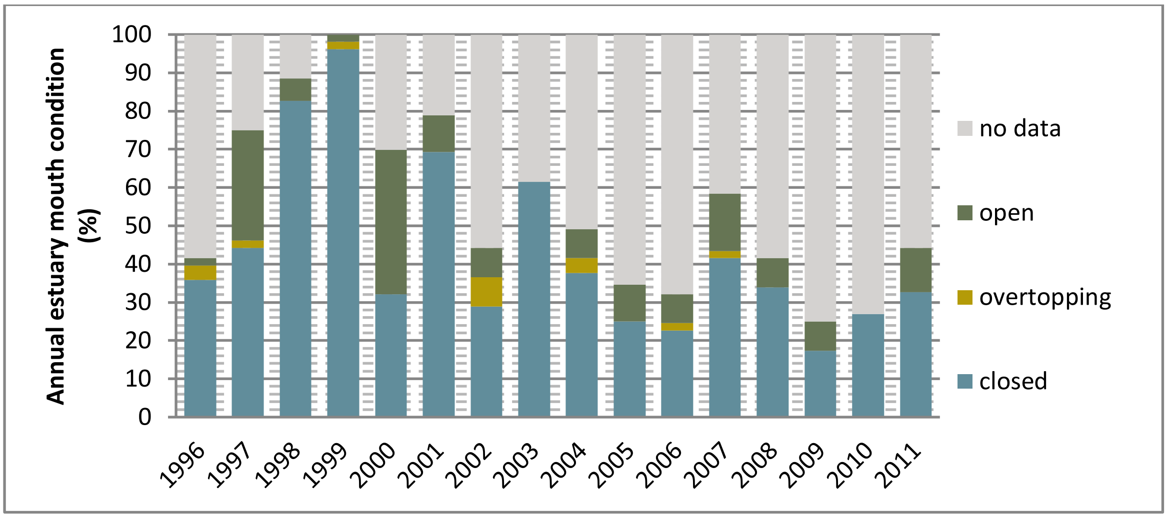


Figure 6.5. Mouth state of the Nonoti Estuary as recorded on a weekly basis (Source: EKZNW).

Table 6.6. Seasonal distribution of the total annual open and closed mouth event counts for the Nonoti Estuary for the period 1996-2011, where data are available (Source: EKZNW).

	Annual total counts			Open mouth events (%)				Closed mouth events (%)			
	Weeks	Open	Closed	Su	Au	Wi	Sp	Su	Au	Wi	Sp
1996	53	1	19	0	0	100	0	21.1	10.5	42.1	26.3
1997	52	15	23	13.3	6.7	20	60	39.1	13.0	34.8	13.0
1998	52	3	43	66.7	33.3	0	0	23.3	27.9	18.6	30.2
1999	52	1	50	0	100	0	0	24	24	26	26
2000	53	20	17	60	40	0	0	11.8	0	76.5	11.8
2001	52	5	36	100	0	0	0	19.4	36.1	36.1	8.3
2002	52	4	15	100	0	0	0	20	26.7	0	53.3
2003	52	0	32					28.1	34.4	18.8	18.8
2004	53	4	20	100	0	0	0	0	35	35	30
2005	52	5	13	40	60	0	0	30.8	0	46.2	23.1
2006	53	4	12	50	0	0	50	8.3	0	75	16.7
2007	53	8	22	25	0	0	75	18.2	40.9	31.8	9.1
2008	53	4	18	50	50	0	0	11.1	11.1	61.1	16.7
2009	52	4	9	75	0	0	25	11.1	44.4	33.3	11.1
2010	52	0	14					35.7	21.4	21.4	21.4
2011	52	6	17	100	0	0	0	0	52.9	47.1	0

Sediment characteristics and bathymetry

Geographic Information System (GIS) maps with interpolated sediment distributions and sediment data are provided in Appendix 6. The Nonoti Estuary can be divided into three main regions based on sediment granulometry. The lower reaches of the system that run parallel with the coast were dominated by very coarse to medium grained sand during both high and low flow seasons (Lower, NS1-4, Figure 6.6). This reflects the input of marine sediments to this section of the estuary. The system widens into a belly in the middle reaches (Mid, NS5-12 and Mid-Upper, NS13-14). Sediments in this section are much finer, being dominated by mud (70.1-97.6% during low flow, and up to 98.6% during the high flow season, Table 6.7; Figure 6.6). This reflects the hydrodynamics of this section and probably also relates to flocculation where fresh and saline waters meet. Fine sediments therefore settle and accumulate. Upstream, of this area in the upper reaches the estuary's sediments are characterised by a mixture of coarse and medium grained sands (NS15-20, Table 6.7; Figure 6.6). The only noticeable difference in this general pattern between high and low flow periods was at NS14 where a shift from organically-rich mud in the low flow period to coarse grained sand in the high flow period occurred (Figure 6.7).

In most cases the sediments were well sorted. Exceptions were at site NS19 (upper reaches) which was characterised by a mixture of very coarse to medium sand size classes in both seasons, and NS13 (middle reaches) in summer 2013 (high flow) which was a mixture of coarse sand, fine sand and mud size fractions.

TABLE 6.7. SEDIMENT CHARACTERISTICS (GRANULOMETRY) OF THE NONOTI ESTUARY DURING LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEBRUARY 2013) FLOW PERIODS. VCS=VERY COARSE SAND, CS=COARSE SAND, MS=MEDIUM SAND, FS=FINE SAND, VFS=VERY FINE SAND.

		Lower reaches		Middle reaches				Upper reaches	
		(NS1-4)		Mid (NS5-12)		Mid-Upper (NS13-14)		(NS15-20)	
		Low flow	High flow	Low flow	High flow	Low flow	High flow	Low flow	High flow
Range (%)	Gravel	1.6-5.6	1.3-5	0.0-0.4	0.0-0.0	0.0-0.1	0.0-0.6	0.3-5.3	0.7-4.3
	VCS	19.2-55.1	32.2-43.7	0.1-1.2	0.0-0.1	0.0-0.4	0.17-0.2	4.7-31.6	5.1-27.8
	CS	1.8-11.2	4.6-6.6	0.3-2.7	0.4-1.7	0.3-2.0	36.7-83.0	13.6-53.3	16.7-57.7
	MS	36.8-64.6	46-59.4	0.3-2.8	0.0-0.8	0.2-0.7	1.4-4.6	25.4-56.1	26.7-53.1
	FS	0.1-0.8	0.03-0.4	0.4-7.6	0.3-6.7	0.9-14.5	10.7-21.2	1-18.6	0.5-5.2
	VFS	0.1-0.2	0-0.3	0.7-13.1	0.6-6.6	2.2-12.2	0.6-11.0	0-1.6	0-0.2
	Mud	0.3-2.5	0.05-1	80.4-97.6	85.5-98.6	70.1-96.4	0.3-29.6	0.5-1.8	0.2-0.5
	Sorting	0.56-0.64	0.5-0.6	0.3-1.1	0.3-0.6	0.3-0.9	0.4-1.2	0.6-1	0.5-0.9
Mean size fraction		Coarse sand	Coarse sand	Mud	Mud	Mud	Fine sand	Coarse sand	Coarse sand

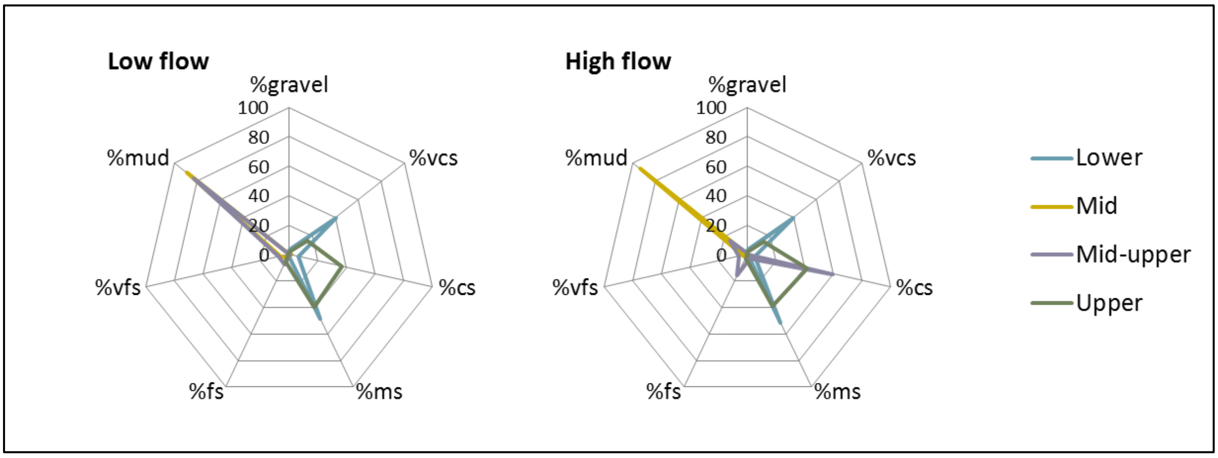


FIGURE 6.6. SEDIMENT GRAIN SIZE DISTRIBUTION IN THE NONOTI ESTUARY DURING LOW (WINTER, JULY 2012, LEFT) AND HIGH (SUMMER, FEBRUARY 2013, RIGHT) FLOW PERIODS, BY REGION OF THE ESTUARY. VCS=VERY COARSE SAND, CS=COARSE SAND, MS=MEDIUM SAND, FS=FINE SAND, VFS=VERY FINE SAND.

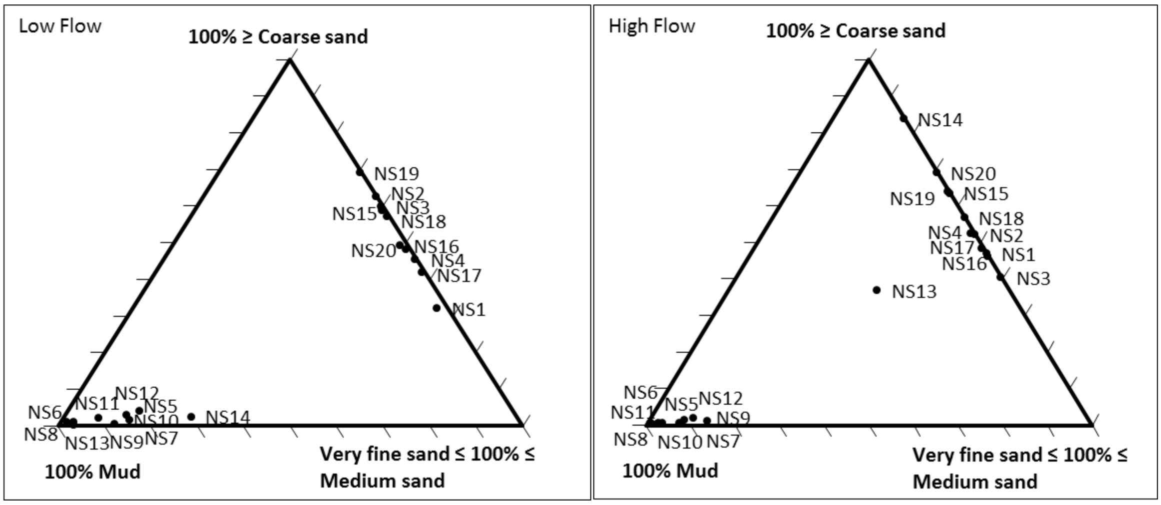


FIGURE 6.7. SEDIMENT CHARACTERISTICS OF SITES SAMPLED ON THE NONOTI ESTUARY IN LOW FLOW (LEFT, JULY 2012) AND HIGH FLOW (RIGHT, FEBRUARY 2013) PERIODS.

Total organic content in the sediments of the Nonoti Estuary followed closely trends in sediment grain size, particularly those of fine grained sands and muds. Regions dominated by mud and very fine sand components had highest organic content. This is typical of estuarine sediments. Organic matter often behaves similarly to fine sediment particles in terms of suspension and deposition. The lower (NS1-4) and upper reaches (NS15-20) therefore had a very low organic content while the middle reaches had much higher total organic content (Table 6.8).

Table 6.8. Total organic carbon content of sediment in the Nonoti Estuary, by region, for low (winter, July 2012) and high (summer, February 2013) periods.

			Total organic content (%)		
			Range	Average	Category
Lower reaches	(NS1-4)	Low flow	0.1-0.3	0.2	Very low
		High flow	0.0-0.2	0.09	Very low
Middle reaches	Mid (NS5-12)	Low flow	4.3-6.8	5.8	High
		High flow	6.0-9.0	7.4	High
	Mid-Upper (NS13-14)	Low flow	7.1-8.5	7.8	High
		High flow	0.03-2.4	1.2	Moderately low
Upper reaches	(NS15-20)	Low flow	0.06-0.4	0.2	Very low
		High flow	0.0-0.1	0.08	Very low

The average depth of the Nonoti Estuary is ~2m. The mouth region is shallow but the system deepens quickly. The deepest sections are in the far upper reaches of the estuary (Figure 6.8). The system was deeper under low flow conditions than it was under high flow condition. This is an artefact of higher water levels brought about by back flooding, and possibly a high beach barrier during the winter months.

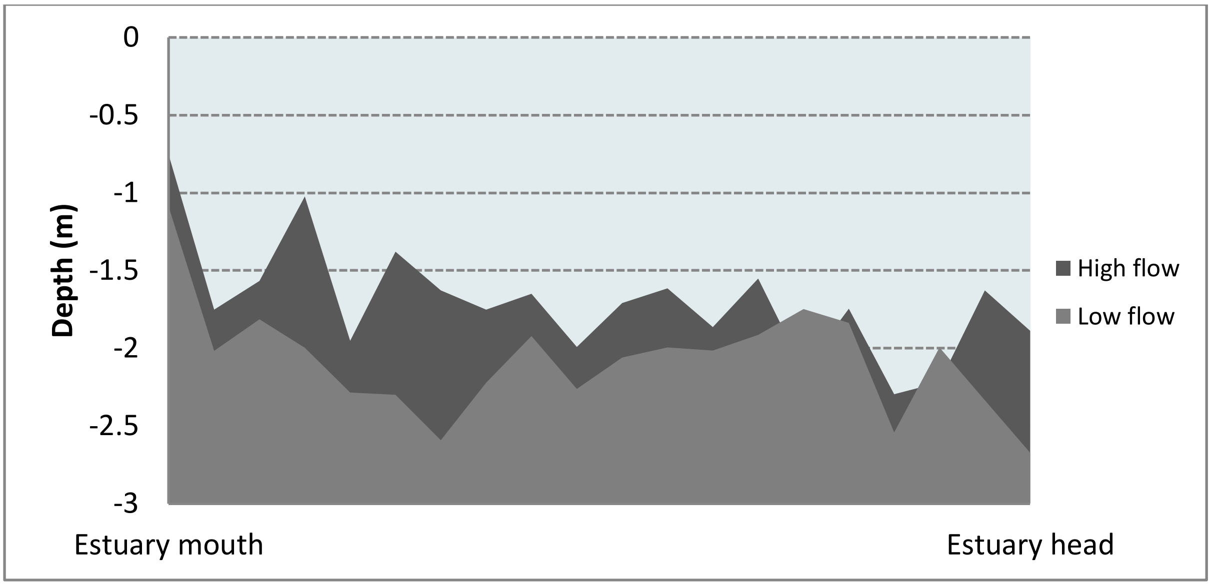


Figure 6.8. Bottom profiles of the Nonoti Estuary during high (summer, February 2013) and low (winter, July 2012) flow periods.

Water physico-chemistry

Water quality parameters were measured in both low flow and high flow conditions in the Nonoti Estuary. Average values (bottom waters) are summarized in Table 6.9 and selected variables plotted for both flow seasons in Figure 6.9. Maps with these data interpolated are included in Appendix 6. Physico-chemical conditions varied spatially, affected by the marine-freshwater gradient, and temporally with the main driving force behind these differences likely to have been changes in freshwater inflow and mouth open frequency.

TABLE 6.9. AVERAGE VALUES OF SELECTED PHYSICO-CHEMICAL PARAMETERS RECORDED IN BOTTOM WATERS OF THE NONOTI ESTUARY DURING LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEBRUARY, 2013) FLOW PERIODS.

	Lower reaches (NS1-4)		Mid reaches (NS5-14)		Upper reaches (NS15-20)	
Flow season	Low	High	Low	High	Low	High
Temperature (°C)	17.07	27.47	17.84	25.72	16.59	24.83
Salinity (psu)	8.98	0.84	17.53	7.78	3.71	5.36
Depth (meters)	1.73	1.28	2.16	1.71	2.17	1.99
pH	6.53	8.15	6.97	7.16	6.52	7.10
Turbidity (NTU)	0.93	6.77	11.82	4.66	12.43	11.32
Dissolved oxygen (mg/L)	7.92	7.89	6.91	2.92	4.83	0.65

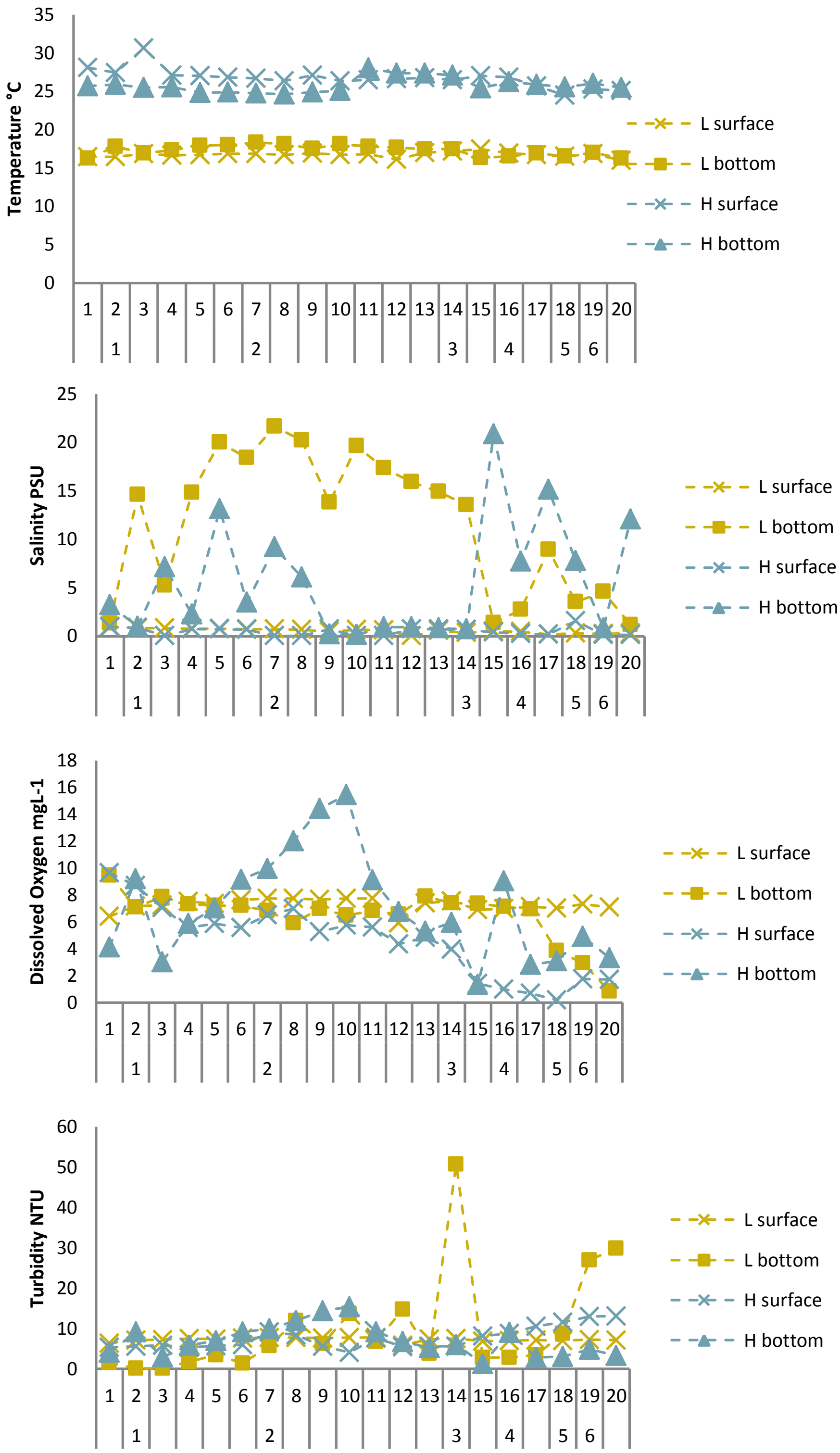


Figure 6.9. Various physico-chemical parameters measured in the Nonoti Estuary during low (L, July 2012) and high (H, February 2013) flow periods. Sites 1 - 20 where physico-chemical water quality parameters were measured (Table 6.2). Corresponding macrobenthos sampling sites 1-6 indicated.

In addition to the above, an analysis of mid-depth waters at sites sampled for fishes was conducted. While losing some of the detail evident in the spatially intensive sampling of surface and bottom waters, this has the benefit of revealing pertinent general trends in selected water quality parameters.

Water temperatures during the low flow season in the winter of 2012 varied little between sites and ranged from 15.4 to 16.9°C. In the high flow season in February 2013 the water temperatures were significantly higher and ranged from 25.4 to 27.9°C. Generally waters were warmer in the lower reaches, although not significantly so. Salinity was negligible in mid-depth waters throughout the system during both seasons in the Nonoti estuary, with levels greater than 1 psu not recorded. Salinity was, however, present in the near bottom waters of the system, particularly in the lower, and to a lesser degree in the middle reaches of the system. pH was lower in the low flow season, but not significantly so. It was consistently highest in the lower reaches of the estuary. Turbidities differed significantly between the sampling seasons, although waters were generally clear throughout averaging 1.9 and 4.1 NTU in the low and high flow seasons respectively. In both seasons turbidities ranged from lowest in the lower reaches to highest in the upper reaches of the estuary (Figure 6.10). Dissolved oxygen concentrations did not differ significantly between seasons, although ranges within seasons were marked (low flow range 2.9 – 9.7 mg/L, high flow range 1.2 – 9.2 mg/L). In both seasons significantly higher dissolved oxygen concentrations were measured in the lower reaches (Figure 6.10). Differences between middle and upper reaches were not significant.

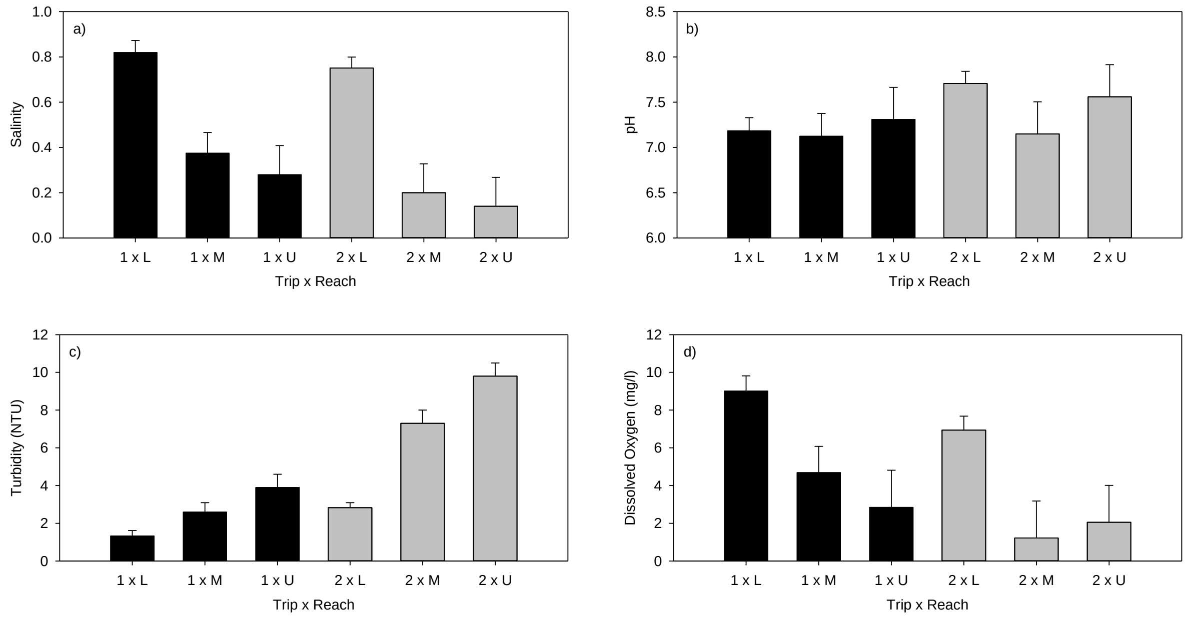


FIGURE 6.10. SELECTED WATER PHYSICO-CHEMICAL PARAMETERS (MEASURED MID-WATER) AVERAGED (+ STANDARD ERROR) ACROSS ESTUARINE REACH (L = LOWER, M = MUDDLE, U = UPPER) DURING LOW FLOW (1) AND HIGH FLOW (2) SEASONS. A) SALINITY, B) PH, C) TURBIDITY, D) DISSOLVED OXYGEN.

Habitat diversity

Vegetation surrounding the Nonoti Estuary is characterised by disturbed riparian and terrestrial plant types, sugar cane cultivation and some terrestrial coastal forest near the mouth (for a more detailed examination refer to figures in Section 5 of this report). Instream invasive plant species including water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and duckweed (*Lemna gibba*) are present and serve to reduce water surface area. Hyacinth in particular can reach very high densities and, in combination with *Echinochloa* grass growing laterally over the water from the banks, can severely reduce open water area, light penetration and water circulation.

A desktop survey using 2010 data for the Nonoti Estuary analysed a total estuarine habitat area of 27ha and assigned the majority of this to estuary channel habitat (Table 6.10). Aquatic macrophytes, reeds and sedges and sand/mud bank habitat types contributed almost 10% respectively to the total estuarine area (Van Niekerk & Turpie 2012) (Table 6.10). Of note also was the presence of swamp forest characterised by the freshwater mangroves *Barringtonia racemosa* and *Hibiscus tiliaceus*.

TABLE 6.10. HABITAT TYPE PREVIOUSLY RECORDED IN THE NONOTI ESTUARY, WITH ESTIMATES OF AREA BASED ON 2010 DATA (VAN NIEKERK & TURPIE 2012).

Habitat type	Species	Begg 1978	Begg 1984	Forbes & Forbes 2011	2010 area (ha)
Alga	*Lyngbya aeruginea-coerulea*	*			
	Oscillatoria tenuis	*			
Aquatic macrophytes	*Ceratophyllum demersum*		*	*	2.5
	Nymphaea sp.		*	*	
	Potamogeton pectinatus	*	*	*	
Estuary channel					18
Grass	*Echinochloa* sp.	*	*	*	
Instream invasives	Hyacinth sp.	*	*	*	
	Lemna gibba		*		
	Pistia stratiotes		*	*	
Reeds & sedges	*Phragmites* sp.	*	*	*	2.5
Sand/ mud banks					3
Swamp forest	*Barringtonia* sp.	*		*	1
	Hibiscus tiliaceus	*		*	

6.3 Zinkwazi Estuary

Mouth condition

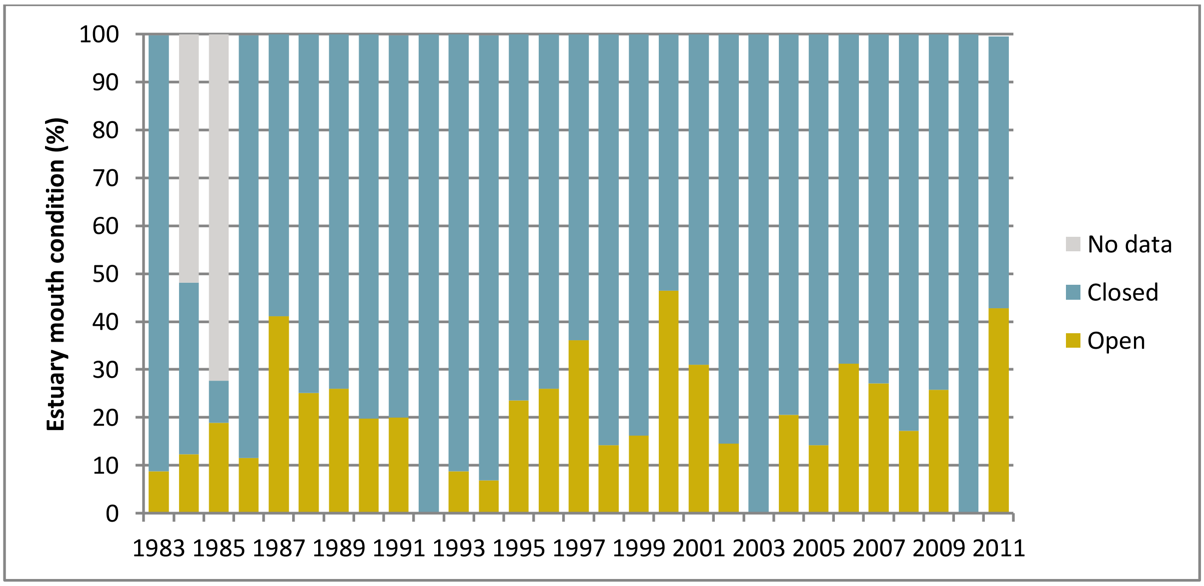


FIGURE 6.11. MOUTH CONDITION OF THE ZINKWAZI ESTUARY FOR THE PERIOD 1983-2011 (SOURCE: K. ACHTZEHN).

Daily mouth condition data has been recorded for the Zinkwazi Estuary from 1983 until present (source K. Achtzehn). These data are summarised in Figure 6.11. Mouth open frequencies in TOCEs are directly linked to rainfall and river flows. Figure 6.12 indicates seasons when mouth breaching occurred. As expected mouth open phases occur predominantly in the seasons of highest rainfall (spring and summer). The estuary did not open at all in 1992, 2003 and 2010. These were years of below-average rainfall (589.25 mm, 558.3 mm and 825.25 mm respectively compared to annual average 1111.25 mm for the period 1983-2011).

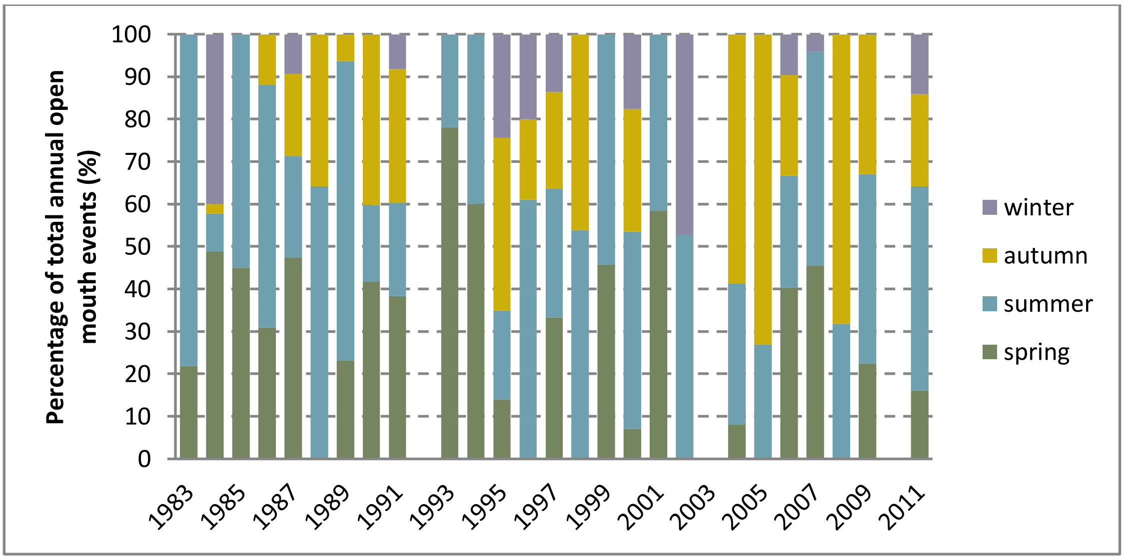


FIGURE 6.12. SEASONAL DISTRIBUTION OF OPEN MOUTH EVENTS FOR THE ZINKWAZI ESTUARY (SOURCE: K. ACHTZEHN). SPRING = SEP-NOV, SUMMER = DEC-FEB, AUTUMN = MAR-MAY, WINTER = JUN-AUG.

Sediment characteristics and bathymetry

Geographic Information System (GIS) maps with interpolated sediment distributions and sediment data are provided in Appendix 6. The sediments of the Zinkwazi Estuary range from muds to coarse sands. Based on a combination of sediment characteristics and physico-chemical characteristics the estuary can be divided into a number of regions. These include the mouth and lower reaches, the middle reaches (in itself comprising lower, mid and upper section) and the upper reaches (Table 6.11; Figure 6.13). The mouth sites were dominated by medium to coarse sands, reflecting the influence of marine sediment in this area. The lower reaches and most of the mid reaches were characterised by mud or fine sands indicating a decrease in current velocity and energy in this area which allows these finer sediments to settle and accumulate. The mid-upper and upper reaches were dominated by medium to coarse sediments (Figures 6.9 and 10). In most cases sediments were larger-grained under high flow than low flow conditions, possibly reflective of faster current speeds related to increased water inflow (Table 6.11). Sediments were also better sorted during high flow than low flow conditions (Table 6.11, Figure 6.14).

Total organic content in the sediments of the Zinkwazi Estuary followed closely trends in sediment grain size, particularly those of fine grained sands and muds. Regions dominated by mud and very fine sand components had highest organic content (Table 6.12). This is typical of estuarine sediments. Organic matter often behaves similarly to fine sediment particles in terms of suspension and deposition. The mouth (ZN1-8) and upper-mid to upper reaches (ZN16-21) were dominated by medium to coarse sand in both seasons and had moderately low to low organic content. The lower and lower-mid reaches were dominated by mud and very fine sands had a higher total organic content (Table 6.12).

TABLE 6.11. SEDIMENT CHARACTERISTICS (GRANULOMETRY) OF THE ZINKWAZI ESTUARY DURING LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEBRUARY 2013) FLOW PERIODS. VCS=VERY COARSE SAND, CS=COARSE SAND, MS=MEDIUM SAND, FS=FINE SAND, VFS=VERY FINE SAND.

		Lower reaches			
		Mouth (ZN1-8)		Lower (ZN5-22)	
		Low flow	High flow	Low flow	High flow
Range (%)	Gravel	0.0-3.9	0.0-5.9	0.0-0.0	0.0-0.05
	VCS	0.1-35.1	0.1-28.7	0.0-0.5	0.06-0.2
	CS	2.2-55.5	2.1-68.1	1.5-10.8	0.6-8.1
	MS	0.4-60.5	0.5-49.7	0.2-2.9	0.2-1.7
	FS	0.8-8.8	0.7-7.6	1.7-8.7	0.7-3.3
	VFS	0.0-7.9	0.0-2.7	3.0-8.8	2.9-6.1
	Mud	0.1-95.6	0.4-95.3	71.6-93.6	83.5-95.5
	Sorting	0.3-1.1	0.3-1.1	0.5-1.2	0.3-0.8
Mean size		MS	CS	Mud	Mud

		Middle reaches					
		Mid-Lower (ZN11-14)		Mid (ZN25-26)		Mid-Upper (ZN16-17)	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Range (%)	Gravel	0.0-0.4	0.0-0.0	0.0-19.5	0.0-8.0	0.2-7.7	0.0-30.5
	VCS	0.0-1.9	0.0-1.0	0.1-4.2	0.1-1.1	0.7-28.6	0.05-28.2
	CS	0.5-17.0	0.2-5.5	4.4-20.0	4.4-13.0	13.0-24.8	4.8-17.8
	MS	0.2-12.7	0.1-4.8	0.3-4.1	0.9-2.0	4.3-45.8	0.3-55.0
	FS	0.9-14.0	0.2-2.6	5.0-67.7	6.3-40.0	2.8-24.7	1.5-22.7
	VFS	2.1-12.0	1.0-9.9	3.2-14.7	5.0-12.4	0.5-10.4	0.2-16.8
	Mud	58.5-96.3	83.3-98.4	2.3-60.0	34.0-73.2	1.5-36.5	0.6-55.4
	Sorting	0.3-1.6	0.3-1.0	0.4-2.7	1.1-1.7	1.0-1.6	0.7-1.4
Mean size		Mud	Mud	FS	VFS	MS	CS

		Upper reaches	
		Upper reaches (ZN28-21)	
		Low flow	High flow
Range (%)	Gravel	1.2-21.8	0.5-16.7
	VCS	3.2-23.8	1.4-9.7
	CS	18.7-54.5	33.3-64.8
	MS	26.3-54.2	17.3-51.8
	FS	1.2-4.8	3.2-12.5
	VFS	0.5-1.4	0.8-1.6
	Mud	0.7-4.8	0.5-1.3
	Sorting	0.8-1.5	0.6-1.3
Mean size		CS	CS

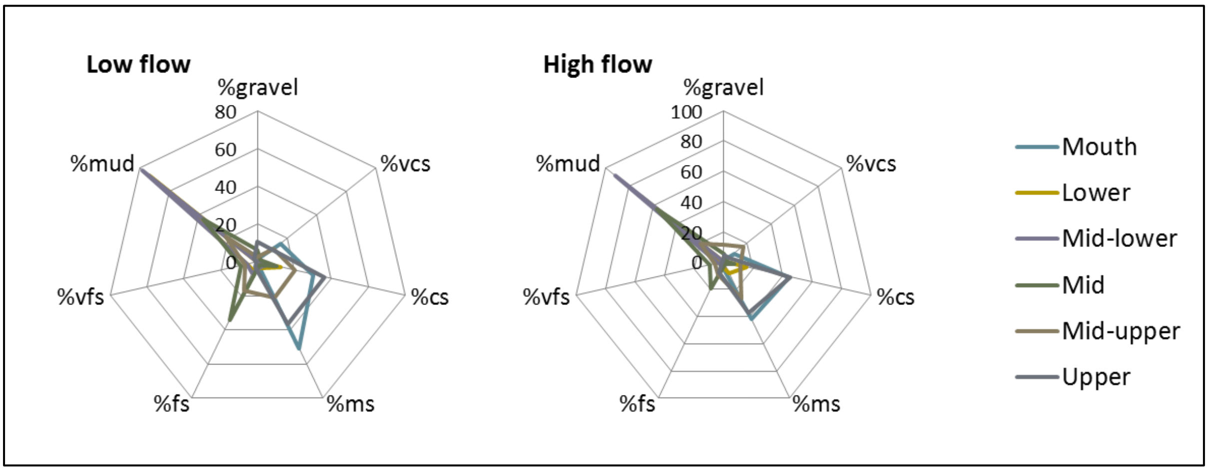


FIGURE 6.13. SEDIMENT GRAIN SIZE DISTRIBUTION IN THE ZINKWAZI ESTUARY DURING LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEB 2013) FLOW PERIODS, BY REGION OF THE ESTUARY. VCS=VERY COARSE SAND, CS=COARSE SAND, MS=MEDIUM SAND, FS=FINE SAND, VFS=VERY FINE SAND.

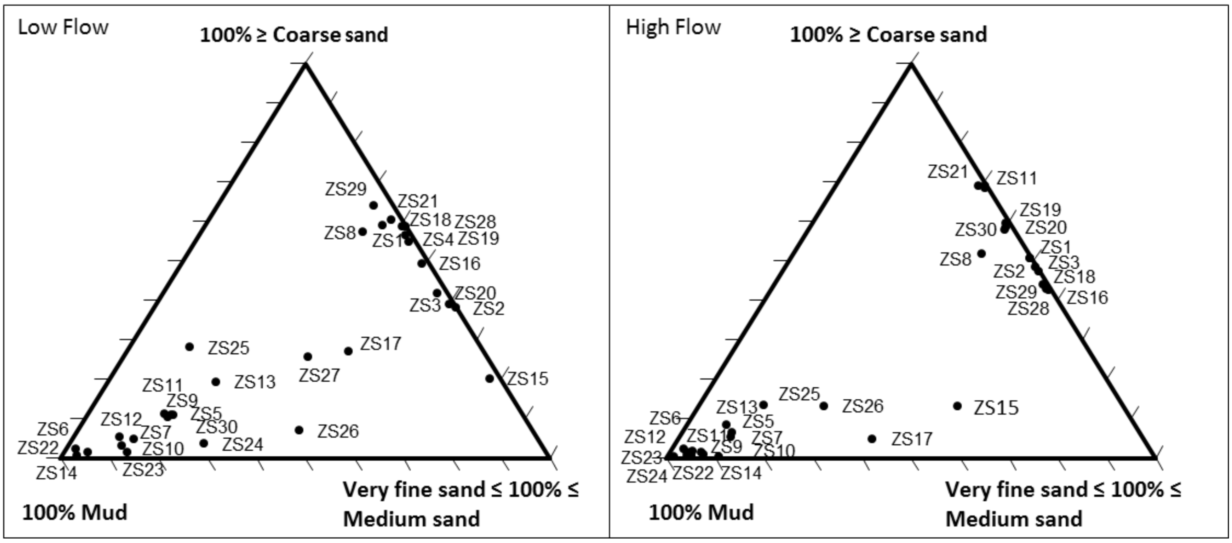


FIGURE 6.14. SEDIMENT CHARACTERISTICS OF THE ZINKWAZI ESTUARY IN JULY 2012 (TOP) AND FEBRUARY 2013 (BOTTOM), BY SITE.

Water physico-chemistry

Water quality parameters were measured in both low flow and high flow conditions in the Zinkwazi Estuary. Average values (bottom waters) are summarized in Table 6.13 and selected variables plotted for both flow seasons in Figure 6.16. Maps with these data interpolated are included in Appendix 6. Physico-chemical conditions varied spatially, affected by the marine-freshwater gradient, and temporally with the main driving force behind these differences likely to have been changes in freshwater inflow and mouth open frequency.

TABLE 6.12. TOTAL ORGANIC CARBON CONTENT OF SEDIMENT IN THE ZINKWAZI ESTUARY, BY REGION, FOR LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEBRUARY 2013) PERIODS.

			Total organic carbon (%)		
			Range	Average	Category
Lower reaches	Mouth (ZN1-8)	Low flow	0.2-4.6	1.5	Moderately low
		High flow	0.1-3.8	0.7	Low
	Lower (ZN5-22)	Low flow	2.0-5.5	3.4	Medium
		High flow	2.9-4.0	3.5	Medium
Middle reaches	Mid-Lower (ZN11-14)	Low flow	2.1-6.8	3.8	Medium
		High flow	2.5-3.7	3.1	Medium
	Mid (ZN25-26)	Low flow	0.2-7.2	3.2	Medium
		High flow	0.2-2.4	1.3	Moderately low
	Mid-Upper (ZN16-17)	Low flow	0.7-2.1	1.3	Moderately low
		High flow	0.2-2.1	0.8	Low
Upper reaches	(ZN28-21)	Low flow	0.2-0.7	0.5	Low
		High flow	0.02-0.2	0.1	Moderately low

Average depth in the Zinkwazi Estuary is ~2m. Deepest areas occur in the transition between mid to upper reaches (Figure 6.15).

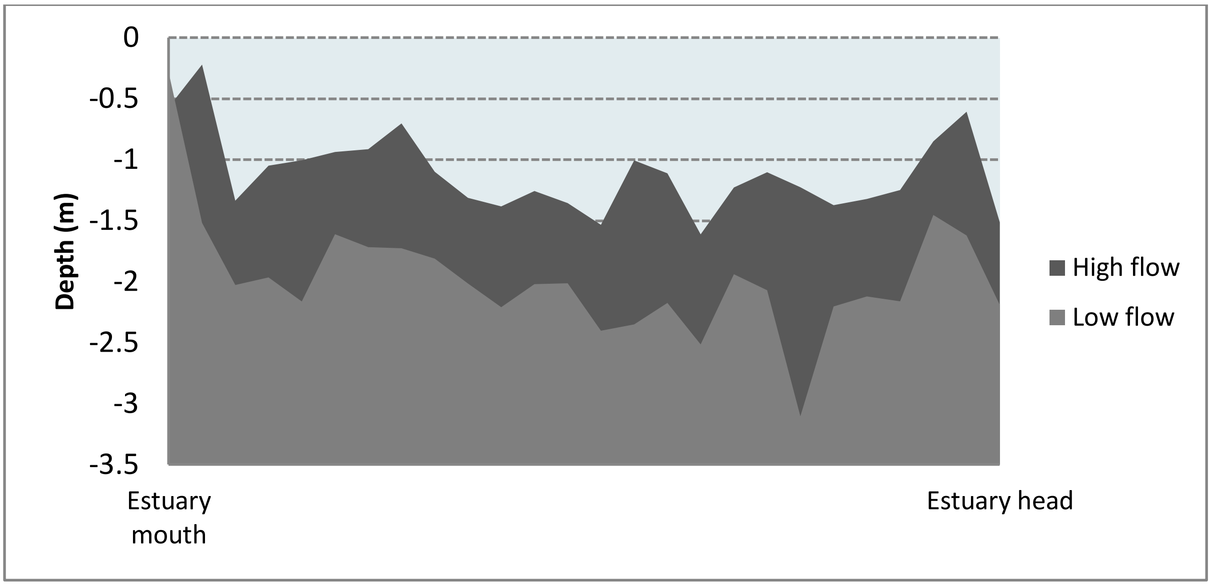


FIGURE 6.15. BOTTOM PROFILE OF THE ZINKWAZI ESTUARY DURING HIGH (SUMMER, FEBRUARY 2013) AND LOW (WINTER, JULY 2012) FLOW PERIODS.

TABLE 6.13. AVERAGE VALUES OF A RANGE OF PHYSICO-CHEMICAL PARAMETERS RECORDED FROM THE ZINKWAZI ESTUARY DURING LOW (WINTER, JULY 2012) AND HIGH (SUMMER, FEBRUARY, 2013) FLOW PERIODS.

		Flow season	Temp (°C)	Salinity (psu)	Depth (meters)	pH	Turbidity (NTU)	Dissolved oxygen (mg/L)
Lower reaches	Mouth	Low	17.11	3.82	1.57	7.60	33.36	8.28
		High	27.11	9.87	0.71	8.57	25.88	8.92
	Lower	Low	17.34	3.82	1.87	7.75	59.00	8.37
		High	27.11	11.48	0.92	8.34	29.40	6.96
Mid reaches	Mid-lower	Low	17.64	3.66	2.08	7.53	28.03	7.25
		High	26.42	16.56	1.32	7.74	39.94	1.70
	Mid	Low	17.25	3.46	2.35	7.35	44.10	6.45
		High	26.43	12.79	1.24	7.57	29.91	1.54
	Mid-upper	Low	17.20	3.40	2.37	7.29	10.03	6.28
		High	26.03	11.68	1.19	7.51	16.97	1.27
Upper reaches	Upper	Low	17.62	3.17	1.96	7.06	11.17	4.75
		High	24.69	2.79	1.15	7.70	270.35	3.33

In addition to the above, an analysis of mid-depth waters at sites sampled for fishes was conducted. While losing some of the detail evident in the spatially intensive sampling of surface and bottom waters, this has the benefit of revealing pertinent general trends in selected water quality parameters.

Water temperatures during the low flow season in the winter of 2012 varied little between sites and ranged from 15.5 to 17.7°C. In the high flow season in February 2013 the water temperatures were significantly higher, as was the range they occurred in (25.6 to 30.6°C). Generally waters were warmer in the lower reaches, although not significantly so. Salinity was present in mid-depth waters throughout the system during the low flow season, ranging from 2.2 to 3.8. Although this range was small there was a distinct trend of higher salinity waters in the lower reaches (Figure 6.17). Salinities were only marginally higher in the high flow season and were highest in the middle reaches of the estuary. pH was significantly higher in the high flow compared to the low flow season (8.2 and 7.3 respectively). It was also consistently highest in the lower reaches of the estuary and lowest in the upper reaches (Figure 6.17). These differences were only significant in the high flow season and then only in lower compared to middle, and lower compared to upper reaches. Turbidities differed significantly between the sampling seasons, averaging 11.4 and 23.9 NTU in the low and high flow seasons respectively. Turbidities ranged from highest in the upper reaches to lowest in the lower reaches of the estuary in the low flow season. This trend was reversed in the high flow season, with highest turbidities in the lower reaches of the system (Figure 6.17). Dissolved oxygen concentration was significantly higher in the Zinkwazi estuary during the high flow season, although actual concentrations varied widely over both sampling trips (low flow range 3.4 - 9.3 mg/L, high flow range 4.6 – 9.9 mg/L). In both seasons there was a trend of highest dissolved oxygen concentrations in the lower reaches, and lowest concentrations in the upper reaches (Figure 6.17). Differences between middle and upper reaches were not significant. Linear regression revealed a significant ($P < 0.001$) and high correlation ($R^2 = 0.806$) between pH and dissolved oxygen (pH = 5.639 + (0.250 x dissolved oxygen (mg/L)) (Figure 6.17).

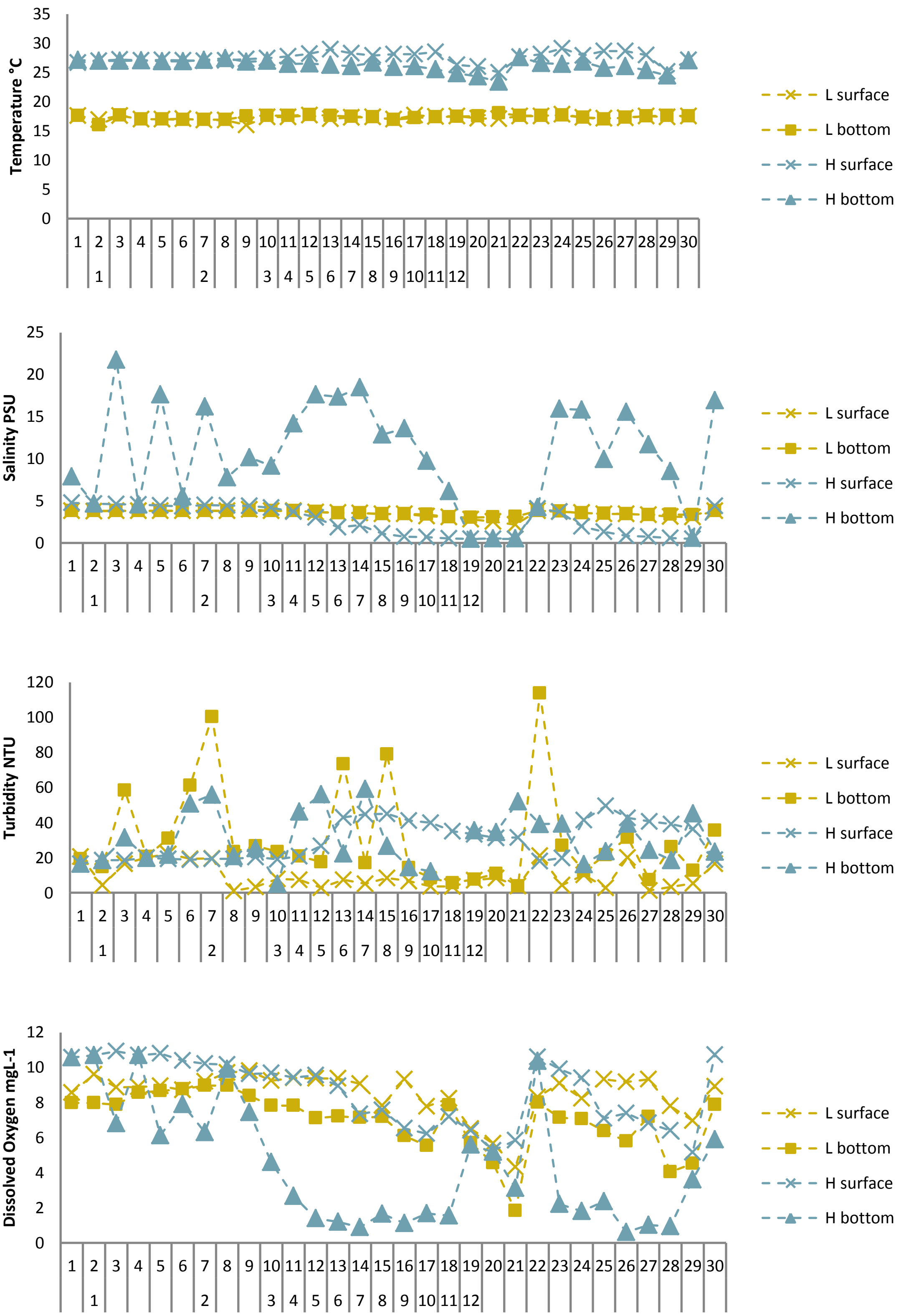


FIGURE 6.16. VARIOUS PHYSICO-CHEMICAL PARAMETERS MEASURED IN THE ZINKWAZI ESTUARY DURING LOW (L, JULY 2012) AND HIGH (H, FEBRUARY 2013) FLOW PERIODS. SITES 1 - 30 WHERE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS WERE MEASURED (TABLE 6.3). CORRESPONDING MACROBENTHOS SAMPLING SITES 1-12 INDICATED.

High dissolved oxygen concentrations (>9 mg/L) at the mouth of the system during the low flow survey were indicative of high photosynthetic activity as a result of algal blooms. Such blooms are generally symptomatic of excessive nutrient inputs. In the high flow survey even higher measurements were recorded over a wider area in the system's lower reaches. The strong positive relationship between pH and dissolved oxygen concentration is compelling evidence of dissolved oxygen concentrations being closely related to algal activity in the estuary. At the same time as increasing oxygen concentrations in water, photosynthesis decreases the amount of free carbonic acid and consequently raises the pH (Skirrow 1965; Wetzel 1983).

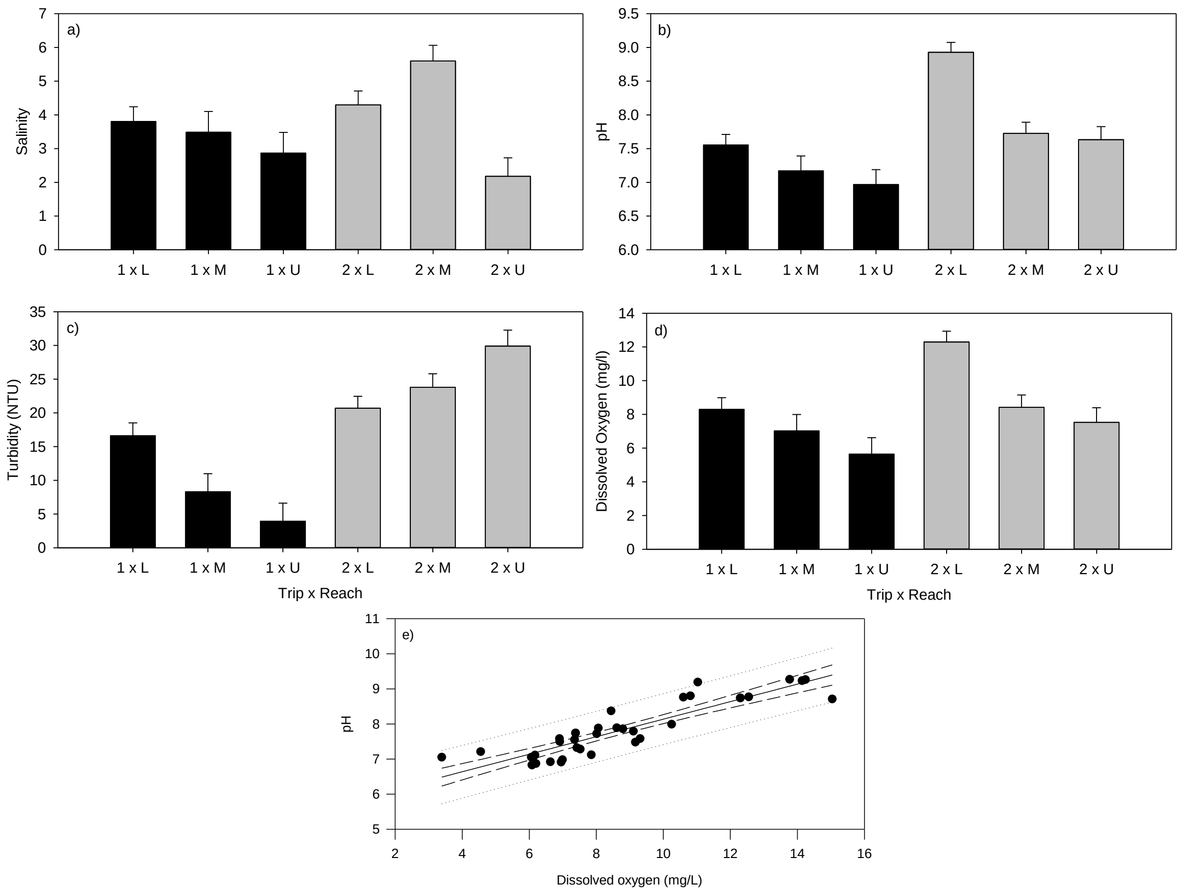


FIGURE 6.17: SELECTED WATER PHYSICO-CHEMICAL PARAMETERS (MEASURED MID-WATER) AVERAGED (+ STANDARD ERROR) ACROSS ESTUARINE REACH (L = LOWER, M = MUDDLE, U = UPPER) DURING LOW FLOW (1) AND HIGH FLOW (2) SEASONS. A) SALINITY, B) PH, C) TURBIDITY, D) DISSOLVED OXYGEN, E) LINEAR REGRESSION PH VS DISSOLVED OXYGEN.

Habitat Diversity

Aerial photographs from 2009 show the only remaining natural vegetation surrounding the Zinkwazi Estuary to be a section of riparian coastal forest which covers the dunes from the estuary mouth extending northwards. Other habitat types include disturbed riparian and terrestrial plant types, extensive sugar cane cultivation and disturbed wetlands and *Phragmites* beds in low-lying areas and along the water (for a more detailed examination refer to figures in Section 5 of this report).

A desktop survey using 2010 data for the Zinkwazi Estuary analysed a total estuarine habitat area of 71.16ha and assigned over 50% of the available habitat to *Phragmites* reeds and sedges (Table 6.14). The Zinkwazi Estuary is subject to sedimentation (Rooseboom, 1975) which creates an ideal environment for reed encroachment, accounting for the high contribution from this group. Swamp forest vegetation was also identified as being common along the estuary, and is characterised by species such as the freshwater mangrove *Barringtonia racemosa*.

TABLE 6.14. HABITAT TYPE AND AREA WITHIN THE ZINKWAZI ESTUARY BASED ON 2010 DATA (VAN NIEKERK & TURPIE 2012).

Reeds & sedges	Channel	Swamp forest	Total
39.51	20.37	11.28	71.16

7. BIOTA OF NONOTI & ZINKWAZI ESTUARIES

Macrobenthos

Classification and characteristics

Macrobenthic organisms comprise a broad assemblage of diverse forms that are related primarily by their spatial distribution and then because of phylogenetic or functional attributes. The fact that these animals spend part or all of their lives in close association with the bottom of estuaries results in unifying consequences both for the animals and for the estuary (Day et al. 1989). Due to the physico-chemical nature and processes taking place in estuaries, benthic organisms are spatially zoned along axial gradients, linking species distribution to the relative inputs of marine and freshwater.

Estuarine benthic communities are divided into micro-, meio- and macrofauna on the basis of size (Kennish 1986). A mesh of width 0.1 mm allows microfauna to pass through, whilst retaining meiofauna. Meiofauna pass through mesh of width 0.5 mm which retains macrofauna (Kennish 1986). The latter are the class of benthic fauna that are routinely sampled for estuarine macrobenthic studies and are the largest and most numerically dominant group occupying estuarine environments. Macrobenthos includes animals of both marine and freshwater origin, typically worms (polychaetes, oligochaetes), crustaceans (amphipods, isopods, crabs, shrimps, prawns) musssels (bivalves), snails (gastropods), and insect larvae (Day 1981, Perissinotto et al. 2004, 2010).

Benthic invertebrates are practically non-motile and relatively long-lived possessing adaptations to tolerate the extreme fluctuations characteristic of estuaries. Distribution of these organisms, often based on physiological tolerances, is important to understand as they constitute an important component of estuarine function by providing a link between primary production in the water column (phytoplankton) and consumption at higher trophic levels up to birds and benthic feeding fish (Baird & Ulanowicz 1993, Clark 1999, McLusky & Elliott 2004). A further functional role is that macrobenthos is a good ecosystem health bioindicator, responding rapidly to relatively small-scale perturbations and is thus useful in assessing ecosystem integrity (MacKay 1996). Macrozoobenthos exhibits complex spatial and temporal variations in community characteristics (including species composition, distribution, abundance, biomass and feeding guild structure) in response to both natural and human-induced environmental changes (Gray 1981, Day 1981, Kennish 1994, De Villiers et al. 1999, Clarke and Warwick 2001, Bursey & Wooldridge 2003, McLusky & Elliott 2004, Dolbeth et al. 2007). Indirect functional roles of macrobenthos include influencing the biochemistry of the sediment through activities such as feeding, bioturbation, and tube construction, leading to enhanced decomposition and remineralisation of detritus, aeration of anoxic sediments and release of nitrogen products for benthic and pelagic primary productivity (Alongi 1998, McLusky & Elliott 2004).

From descriptions of soft-sediment benthic communities, a condition of static equilibrium can be inferred from factors such as climatic changes, habitat modifications and variations in recruitment and survival (Boesch et al. 1976). However, more long-term analyses of macrobenthic communities have revealed that strongly seasonal patterns exist and benthos in some systems exhibit various forms of cyclical dynamics ranging from one year to half a century (Eagle 1975, Boesch et. al 1976). A range of complex factors are responsible for short and long-term variations in estuarine benthic populations. The variability of environmental factors presents major problems to animals from adjacent freshwater or marine conditions colonising estuaries. For this reason, the number of marine species which live in estuaries decline rapidly from the estuary mouth into the middle reaches. Similarly, the number of freshwater species also declines rapidly from the head of the estuary towards the mouth (McLusky 1974).

Factors affecting macrobenthic communities

A number of physical factors dominate the estuarine environment. For example the substrate, the extent of tidal influence, wave size, the strength of currents, the role of these in sedimentation, the pattern of salinity distribution and retention of water by the sediments, the supply of dissolved oxygen, the temperature and the concentration of certain ions (McLusky 1974). Physical and chemical environmental factors that affect estuarine benthos are salinity gradients, shelter from wave action, fluctuations in temperature and oxygen levels, the nature of the substratum and the input of detritus (Metzeling 1993). Other factors structuring marine benthic communities are food availability, depth, latitude and various biotic interactions (Rosenberg et. al. 1992). Physico-chemical variables are direct factors influencing benthic organisms, in so far as they affect the physiological processes of any life stage of an organism (Boesch et. al. 1976). The components of estuarine fauna are separated by means of their tolerance to salinity, although they are also affected by the aforementioned factors. In tolerable salinity and temperature ranges it is substratum type that becomes the determining factor in benthic distribution (Day 1981). The spatial and temporal heterogeneity of estuarine macrobenthic distributions is determined primarily by longitudinal salinity gradients and sediment compositions within a system (Day 1981, Attrill et al. 1996, Whitfield & Bate 2007). However, the relative importance of these two abiotic variables in structuring macrobenthic communities differs within regions of a particular estuary and between systems (Teske & Wooldridge 2003, Whitfield & Bate 2007). Nonetheless, it is important to note that other biotic and abiotic variables also play a role in structuring macrobenthic communities (Teske & Wooldridge 2003).

Cooper, Ramm & Harrison (1995), argue that in an estuary, the fauna are influenced by the salinity characteristics, period of connection with the sea, turbidity (controlled by catchment geology and flow), substrate and availability of nutrients (controlled to a large extent by cycles of breaching and flushing). The substrates within estuaries are usually different from adjacent marine coasts, in that they usually have sandy and muddy components. This is typical of most southern African estuaries (Blaber 1980). Although nutritionally rich, these muds are difficult areas to colonise, as locomotion both through and over the substrate may be difficult. Also, fine silt in suspension can clog the filtering mechanisms of many of the animals who use this as their method of feeding. Muds rich in organic debris play host to a proliferation of microbes, who in turn may consume much of the available oxygen, and even produce large quantities of hydrogen sulphide. Anthropogenic activities may directly or indirectly affect the distribution of macrobenthos in that one, more or a combination of the above factors may be altered, through pollution or through habitat modification by poor land management practices.

Non-environmental factors affecting the distribution of macrobenthos are food availability, protection from predation and competition (van de Bund & Groenendijk 1994) or the product of two or more of these processes (Flint & Kalke 1986). Although long-term environmental fluctuations and spatial heterogeneity in sediment characteristics have been shown to influence estuarine-wide community patterns, subtle biological factors are also thought to significantly affect community organisation changes in soft sediment habitats (Flint & Kalke 1986), but are not easy to monitor and study in routine baseline ecological surveys.

Ichthyofauna

Classification and characteristics

Estuarine fish communities typically comprise of marine and freshwater forms as well as species that breed and complete their life cycles within estuaries. Fish speciation in estuaries has been less extensive than in other aquatic habitats and estuarine breeders usually represent a relatively small part of the fish fauna (Whitfield 1998). These species are usually not very mobile and are commonly small-bodied, reaching sexual maturity at lengths less than 70 mm (Whitfield 1990, 1994d). Marine and freshwater fishes that enter estuaries are generally more mobile and often free to move between these brackish water environments and more stable marine or riverine environments. However, relatively few marine or freshwater fishes make regular use of estuarine habitats compared with marine shelf waters or fresh inland waters. Of an approximate 1 500 fish species that occur in South African continental shelf waters (Wallace et al. 1984), 155 associate with estuaries and only 50% of these may be regarded as having a strong association (Whitfield 1998). Only 11 of the 270 recorded freshwater species (Skelton 1993) enter estuaries, and four of these, all freshwater eels, merely pass through these coastal systems between freshwater and marine habitats (Whitfield 1998). This relatively low species diversity is a feature shared by estuaries in many parts of the world (Haedrich 1983, Whitfield 1994b).

The affinities of most important families found in estuaries are marine, and of the three broad categories of fishes that occur in estuaries, marine types dominate by species and abundance (Haedrich 1983). The main feature of this component in South African estuaries is that the juveniles are predominantly estuarine, while the adults are primarily marine (Wallace 1975, Whitfield & Marais 1999). In fact, the great majority of fishes in estuaries the world over are usually juveniles of euryhaline marine species (Haedrich 1983, Potter et al. 1990). It is therefore not surprising that the major significance of estuaries has often been attributed to their role as nurseries to fishes. Juvenile fishes probably benefit most from conditions of reduced risk of predation and elevated food abundance offered by estuarine habitats. By virtue of their smaller size and weaker swimming capabilities they are potentially at higher risk of being preyed upon than larger fishes. At this stage of their life cycles, rapid growth out of critically small size classes is important for many species.

The degree to which fishes are dependent on estuaries differs among species. Whitfield (1998) categorised fishes commonly occurring in southern African estuaries on the basis of their association with different aquatic environments, as well as the degree to which they depend upon these systems (Table 7.1). Approximately half of the 155 indigenous species occurring in southern African estuaries may be regarded as having a strong estuarine association (categories Ia, Ib, IIa, IIb and Vb, Whitfield 1998). These species do not support commercial fisheries to the same degree as those occurring in estuarine habitats in other parts of the world, but they are nevertheless important in a national context. In 2002, the total value of estuarine and estuary-dependent fisheries in South Africa was estimated to be R1.251 billion (Lamberth & Turpie 2003). The recreational angling species also have commercial value in terms of generating tourism (rental of holiday accommodations) as well as sales of equipment (fishing gear, boats and outboard engines etc.) (Wallace et al. 1984). Estuarine fish are also important in subsistence fisheries. The traditional trap fishery at Kosi Bay (Kyle 1995) is perhaps the best example of a formally recognised subsistence fishery in Kwazulu-Natal, but subsistence fishing in estuaries in both rural and urban areas of the province is becoming increasingly important.

Table 7.1: Estuarine association categories (EAC's) of fishes that utilise southern African estuaries (from Whitfield 1998).

EAC	Description
I	Estuarine species which breed in estuaries:
Ia	Resident species which have not been recorded spawning in marine or freshwater environments
Ib	Resident species which have been recorded spawning in marine or freshwater environments
II	Euryhaline marine species which breed at sea but with juveniles that show varying degrees of dependence on estuaries:
IIa	Juveniles dependent on estuaries as nursery areas
IIb	Juveniles occur mainly in estuaries but are also found at sea
IIc	Juveniles occur in estuaries but are usually more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems
IV	Euryhaline freshwater species. Includes some species which may breed in both freshwater and estuarine environments
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments:
Va	Obligate catadromous species which require a freshwater phase for their development
Vb	Facultative catadromous species which do not require a freshwater phase for their development

Beyond their importance in subsistence and recreational fisheries, the fish assemblages in southern African estuaries have components of significant conservation value. Thirty-eight species are endemic (i.e. only recorded on the African continent and/or adjacent waters south of 20°S, Whitfield 1998) and over thirty are listed on International Union for Conservation of Nature and Natural Resources Red Lists (IUCN 2013).

Ichthyofauna diversity in subtropical estuaries is higher than that in the temperate systems to the south (Whitfield 1998). Most fishes in KwaZulu-Natal systems are of tropical or subtropical Indo-Pacific origin and the east coast of South Africa represents a subtraction zone in their distribution (Wallace 1975). The occurrence of these species southwards, and that of more temperate forms northwards, fluctuates with season (Blaber 1981, Whitfield 1998). Seventy-two of the 142 species that occur in subtropical systems are strongly associated with estuaries (Whitfield 1998). In other parts of the Indo-Pacific, where precipitation exceeds evaporation, high runoff results in estuarine zones extending onto wide, shallow continental shelf areas (Haedrich 1983). These waters are extensively used by estuarine fishes (Blaber 1997). However, in South Africa the brackish, shallow and turbid conditions which permit the nursery role of estuaries, are not found in the inshore waters of the narrow continental shelf (Blaber 1981). Furthermore, available knowledge of ocean currents off the KwaZulu-Natal coast and reproductive biologies of its estuarine fishes, suggests that larvae spawned in local nearshore marine waters are retained in these waters by gyres and counter currents. Thus, recruitment of fishes from subtropical and tropical areas north of South Africa is probably limited, and KwaZulu-Natal estuaries may be largely reliant on locally spawned recruits (Wallace & van der Elst 1975). These estuaries therefore represent habitats that are essential for local populations of estuarine-dependent species near the southern limits of their distribution ranges. The status of these estuaries and their ability to function as nursery areas has important implications for population numbers of estuarine fish species in KwaZulu-Natal.

Factors affecting fish communities

Whitfield (1992) characterised South African estuarine systems into five categories; estuarine bays, permanently open estuaries, river mouths, estuarine lakes and temporary open closed estuaries (TOCEs). Fish assemblages within these systems differ markedly (Whitfield 1998). This is in no small part due to different physico-chemical conditions in these different types of estuarine system. Important factors influencing fish distribution and abundance within South African estuaries have been identified and include turbidity (Cyrus & Blaber 1987a, b, c), salinity and freshwater inflow (Whitfield et al. 1981, Whitfield 1994c, Ter Morshuizen et al. 1996) and habitat structure (Beckley 1983, Hanekom & Baird 1984, Whitfield 1986, Paterson & Whitfield 2000, Weerts and Cyrus 2002). Freshwater inflows and mouth status have an overriding influence on most of these physico-chemical and habitat variables. As the majority of fishes in South African estuaries recruit into systems from marine spawning grounds mouth status clearly also has a direct influence on estuarine fish communities. It is the primary determinant of connectivity with the marine environment. Fish communities in permanently open estuaries and TOCEs differ significantly as a result of open systems being more accessible to marine estuarine fishes (Whitfield 1998). Even within TOCEs with differing mouth open frequencies fish differ considerably (Weerts 2011).

7.1 Methods

The macroinvertebrate and ichthyofauna biological baselines of the Nonoti and Zinkwazi Estuaries were established by following a similar, generic stepped approach. The methodology involved field collections and/or measurements of material, followed by laboratory preparation and analysis including microscopy and data handling.

Field sampling

The two surveys per system were conducted in a winter, low flow period (07.2012) and a summer, high flow period (02.2013). In KwaZulu-Natal during low surface inflow, rainfall is limited and the majority of Temporarily Open/Closed Estuaries (TOCEs) tend to close, water levels become raised and backflood into marginal marshy areas. All biological material was collected at the same time to represent the ecology of each estuary at a particular reference point in time.

Macrobenthos

Sites were selected within each estuary at varying intervals from the lower reaches (vicinity of the mouth) to upper reaches (head - area of maximum discernable saline penetration) depending on the axial length of the system and the salinity gradient. This profile was adopted in order that the full range of physico-chemical and habitat types within each system could be represented. Six macrobenthic sampling sites were selected to represent the habitat gradient from mouth to head of the Nonoti Estuary (Figure 7.1). Table 7.2 presents the spatial location of the sampling sites for the Nonoti, with reference to the comparative physico-chemical and sediment stations sampled (See Section 6). The length of the Zinkwazi Estuary and its relatively longer salinity gradient necessitated a more intensive sample survey. Twelve stations from mouth to head were selected (Figure 7.2) and the same locations were used during both surveys (Table 7.3)

Figure 7.1. A map of the Nonoti Estuary with six macrobenthic collection sites indicated (Source: Google earth).

Table 7.2. Macrobenthic site numbers and geographical location for the Nonoti Estuary, as they relate to physico-chemical sites.

Site number		Site position	
Macrobenthos	Physico-chemistry	Latitude	Longitude
1	2	S29 18.987	E31 24.489
2	7	S29 18.803	E31 24.653
3	14	S29 18.666	E31 24.605
4	16	S29 18.525	E31 24.443
5	18	S29 18.334	E31 24.250
6	19	S29 18.428	E31 24.054

At each site a Zabalocki-type Eckman grab (area 0.0236m^2) was used to sample the invertebrates with five randomly placed replicate samples collected per site. The majority of invertebrate infauna reside in the top 10cm of the sediment, the grab 'bite' depth was measured, if <5cm, the sample was discarded and the procedure repeated until five comparable replicate samples were collected. Where the majority of sediments at a station were of a fine grain size (i.e. pass through a 0.5mm mesh) the entire sample was agitated to bring animals into suspension and washed through a collection net. Animals and other biological material retained were bottled and fixed in 4% formaldehyde with the vital dye Phloxine B added to aid identification in the laboratory. Where sediment grain size was too large for this procedure of entire decanting, a small amount of formaldehyde (~5ml) was added to the collected sample and agitated to encourage benthic organisms to leave burrows and tubes and swim in the suspension. Whilst being continuously stirred, the supernatant was poured through a 0.5mm collection mesh. This process of elutriation was repeated five times as this has been shown to be effective in removing >95% of fauna from a sample (Blaber et al. 1983). The remaining sediment and coarse vegetable matter was then sieved through a 1mm mesh and examined visually. Larger animals such as molluscs and crabs that were too heavy to be lifted into suspension through elutriation were picked out before the remaining sediment was discarded. Each replicate sample was bottled and preserved as before.

FIGURE 7.2. A MAP OF THE ZINKWAZI ESTUARY WITH MACROBENTHIC COLLECTION SITES INDICATED (SOURCE: GOOGLE EARTH).

TABLE 7.3. MACROBENTHIC SITE NUMBERS AND GEOGRAPHICAL LOCATION FOR THE ZINKWAZI ESTUARY, AS THEY RELATE TO PHYSICO-CHEMICAL SITES.

Site number		Site position	
Macrobenthos	**Physico-chemistry**	**Latitude**	**Longitude**
1	2	S29.28034	E31.44221
2	7	S29.27773	E31.44218
3	10	S29.27621	E31.44085
4	11	S29.27368	E31.43886
5	12	S29.27188	E31.43437
6	13	S29.26844	E31.43325
7	14	S29.26599	E31.43550
8	15	S29.26235	E31.43970
9	16	S29.25946	E31.43474
10	17	S29.25680	E31.42862
11	18	S29.25411	E31.42268
12	19	S29.24963	E31.42325

Ichthyofauna

Two methods of sampling the ichthyofauna of the estuaries were employed; seine netting and gill netting. The seine net used was a 30 m x 1.7 m x 15 mm bar mesh seine, fitted with a 5 mm bar mesh purse. Seine netting was carried out during daylight hours and was performed in shallow areas with banks free of vegetation or obstructions and that allowed retrieval of the net. Where possible replicate hauls (generally two) were made at the sampling sites. Gillnets comprised monofilament panels of 45 mm, 75 mm and 100 mm stretchmesh. Each net was 10 m in length and 1.7 m deep. Gill nets were deployed in open, mid-channel waters. Typically three nets were deployed at each sampling site.

Sites where fishes were sampled in the Nonoti Estuary are shown in Figure 7.3 (seine nets) and Figure 7.4 (gill nets). Sites were categorised as occurring in lower, middle or upper reaches of the system based on a subjective spatial analysis of sampling effort and habitat characteristics. Reaches were categorised as:

- Lower estuary: From estuary mouth to ~1 km upstream. Width of open channel varied, typically between 60 m and 200 m, except in the mouth region where the system was obviously narrower.
- Middle estuary: From ~ 1 km to ~4 km upstream. Width of open channel varied between 30 m and 30 m.
- Upper estuary: From ~4 km to ~7 km upstream. Width of open channel varied between 10 m and 30 m.

Figure 7.3. Sites sampled with seine net on the Nonoti Estuary in June 2012 (left, low flow season) and February 2013 (right, high flow season). L = lower reaches, M = middle reaches, U = upper reaches. Images from Google Earth.

FIGURE 7.4. SITES SAMPLED WITH GILL NET ON THE NONOTI ESTUARY IN JUNE 2012 (LEFT, LOW FLOW SEASON) AND FEBRUARY 2013 (RIGHT, HIGH FLOW SEASON). L = LOWER REACHES, M = MIDDLE REACHES, U = UPPER REACHES. IMAGES FROM GOOGLE EARTH.

Sites where fishes were sampled in the Zinkwazi Estuary are shown in Figure 7.5 (seine nets) and Figure 7.6 (gill nets). As was done for the Nonoti sites were categorised as occurring in lower, middle or upper reaches of the system based on a subjective spatial analysis of sampling effort and habitat characteristics. Reaches were categorised as:

- Lower estuary: From estuary mouth to ~1 km upstream. Width of open channel varied, typically between 60 m and 200 m, except in the mouth region where the system was obviously narrower.
- Middle estuary: From ~ 1 km to ~4 km upstream. Width of open channel varied between 30 m and 30 m.
- Upper estuary: From ~4 km to ~7 km upstream. Width of open channel varied between 10 m and 30 m.

Whenever possible fishes caught were identified in the field, measured to the nearest centimetre standard length (SL) and returned live to the water. Fishes that could not be positively identified (or representative specimens thereof) were preserved in alcohol or 10% formalin and returned to CSIR laboratories for species designation and measurement. Smith & Heemstra (1991) was used as a taxonomic reference, with species names updated where appropriate.

Habitat variables were noted at each of the sites samples for fishes. At each site, immediately prior to sampling, physico-chemical water quality characteristics were measured *in-situ* using a Yellow Spring Instrument Multiparameter Water Quality Sonde 6600 v2 (YSI). Measurements were taken mid-depth. The nature of the substrate was also characterised as being comprised predominantly of mud, mixed sediment (sandy-mud to muddy sand) or sand.

FIGURE 7.5. SITES SAMPLED WITH SEINE NET ON THE ZINKWAZI ESTUARY IN JUNE 2012 (LEFT, LOW FLOW SEASON) AND FEBRUARY 2013 (RIGHT, HIGH FLOW SEASON). L = LOWER REACHES, M = MIDDLE REACHES, U = UPPER REACHES. IMAGES FROM GOOGLE EARTH.

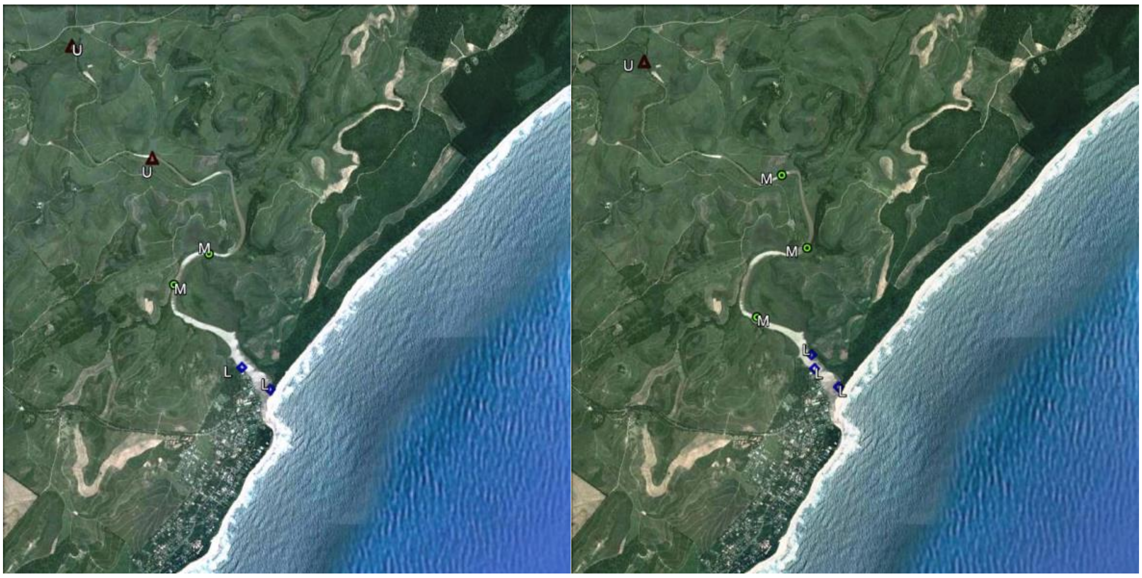


FIGURE 7.6. SITES SAMPLED WITH GILL NET ON THE ZINKWAZI ESTUARY IN JUNE 2012 (LEFT, LOW FLOW SEASON) AND FEBRUARY 2013 (RIGHT, HIGH FLOW SEASON). L = LOWER REACHES, M = MIDDLE REACHES, U = UPPER REACHES. IMAGES FROM GOOGLE EARTH.

Avifauna

Avifauna were not surveyed as part of this study, however data on birds associated with each estuary were obtained from the Zinkwazi Blythedale Conservancy who are trained in bird identification. Multiple counts were conducted on an *ad hoc* basis, with species, number of individuals and area of the estuary recorded.

Laboratory

Macrobenthos

Preserved invertebrates samples were sorted to separate the animals from the abiotic and detrital material, counted and identified to the lowest taxonomic level possible using a combination of a ZEISS® fully automated SterREO Discovery V12 stereomicroscope with photomicroscopy capabilities and a Zeiss® AxioImager M1 compound microscope through AxioImager ® 4.9 software. Taxonomic densities were expressed as the mean number of individuals per square metre, of the five replicate samples taken at each site. Although there was incidental sampling of planktonic species, these were not included in the data for further analyses.

Published and electronic identification keys and species descriptions of various invertebrate groups were used to assist in species identification. All taxa were verified using the World Register of Marine Species (WoRMS www.marinespecies.org). Male amphipods of the genus *Grandidierella* are morphologically easily distinguishable, but females are difficult to separate. For the purposes of analysis, females were grouped as a multispecific taxon - *Grandidierella* spp. which was enumerated individually from the males to account for this uncertainty. The mean faunal abundance (density) for each site/flow period/estuary was expressed as individuals per square metre (indiv.m^{-2}). Taxonomic classification and microscopy photographs of taxa found per estuary are provided in Appendix 7. These will serve as identification reference materials for comparative purposes with future studies.

Ichthyofauna

Smith & Heemstra (1991) was used as a taxonomic reference, with species names updated where appropriate.

Data analysis

Macrobenthos

Statistical testing for differences between community data and indices was conducted on normalised (√√-transformed) non-means data from species by sample matrices for each estuary. The factors used to test differences between samples were **'Flow Period'**, **'Estuary Area'**, **'Station'**. A significance level of $p<0.05$ was taken in all cases.

To provide a clear spatial and temporal analysis of community change macrobenthic data were subject to multivariate methods of classification using the Plymouth Routines in Multivariate Ecological Research (PRIMER) statistical software package Version 6 (Clarke & Warwick 2001). The analysis comprised the community classification method using Bray-Curtis similarity coefficients and ordination using non-metric multidimensional scaling (NMDS). This method uses some function of the dissimilarity measure between each pair of stations and reconciles the result on a two-dimensional map. The calculation of NMDS algorithm is an iterative process involving a number of random starts in order to obtain the best two-dimensional configuration. A stress value is then used to indicate the validity and usefulness of the configuration. Generally, stress increases with reducing dimensionality and increasing quantity of data, a value < 0.05 gives an excellent representation with no misinterpretation, >0.05 to <0.10 is a good ordination with no real prospect of misleading misinterpretation, >0.10 to <0.20 is a potentially useful 2D picture but reliance should not be placed on values at the upper end of the range and a stress value of >0.30 suggests that points are close to being arbitrarily placed in the 2D ordination. The distances between samples on the ordination attempt to match the corresponding dissimilarities in community structure. Nearby points have similar communities while sample points situated far apart have few species in common or the same species at very different levels of abundance.

A prerequisite to interpreting community differences between sites is that there are statistically significant differences to interpret (Clarke & Warwick 2001). A summary statistic was computed directly from the underlying (rank) similarity matrix containing the community level data through a simple non-parametric permutation procedure termed ANOSIM (analysis of similarity). To provide some statistical basis for the groups identified in the Bray-Curtis classification and NMDS ordination, the data were put through a permutation procedure that is applied to the original similarity matrix. The analysis of similarity compares every sampling site over the sampling period to yield a test statistic (R) and a level of significance. To interpret this, R is taken as the degree of similarity between scenarios (sites times) and ranges between 1 and –1. Its deviation from zero is the significant level and a negative R statistic suggests that the similarity across the different sites were higher than those within sites. Typically:

- R = 1 only if all replicates within sites are more similar to each other than any replicates from different sites
- R = approximately zero if the similarities between sites will be the same on average

Diversity indices were used to describe species-abundance relations, in place of distribution models, as recommended in Ludwig & Reynolds (1988). The major criticisms of those indices, that they confound a number of variables (species richness, evenness and the homogeneity of the sampling area) and are not easy to interpret, was acknowledged. For this reason, indices of richness and evenness were included in describing the biota, as well as diversity indices. The indices used were:

- Richness Index
    - Margalef's (1961) Index

- Diversity Indices
    - Shannon's Index – based on theory of Shannon and Weaver (1963)
    - Simpson's Index – a measure of species dominance

- Evenness Index
    - Pielou's (1986) Index

Diversity and other indices were calculated using the routine DIVERSE in PRIMER.

The groupings identified in cluster and NMDS procedures were further investigated to determine the discriminating species. These species could potentially be the set of indicators used to monitor a particular suite of ecological objectives or criteria that in future may be set for each estuary. SIMPER is a PRIMER routine that calculates the contribution each species makes to the average similarity within a group. Through this process species are identified that typify (or discriminate) between groups.

The BEST routine in PRIMER was used to relate biological samples to environmental variables (see Section 6). This multivariate technique calculates a Spearman's Rank Correlation co-efficient for each series of 'matching'. The highest co-efficient value (closest to 1) represents the suite of variables best explaining the biotic community sampled.

The ambient environmental conditions of an ecosystem dictate the types of fauna that occur there, and how and where they are distributed. The river flow, tidal range and sediment distributions in estuaries are continually changing and consequently estuaries are never 'steady-state' systems (McLusky & Elliott 2004). Bottom sediment characteristics and water column measurements of the ambient physico-chemistry were taken as surrogates of local habitat conditions in each estuary, during each survey.

Ichthyofauna

To allow meaningful comparison of fish abundances at different sites fish catches were standardised to catch per unit effort (CPUE). In the case of seine nets CPUE was reflected as fish caught per haul. Times of deployment and lifting of gill nets was recorded in the field so that soak time could be calculated and CPUE expressed as fish caught per 100 m of net per 12 (daylight) hours. Soak times were however much lower than 12 hours (typically only 2 hours) which reduced the number of fishes caught (and harmed) in gill nets, and also allowed the nets to be moved to different sites several times over the course of a day in the field.

Fish abundances were analysed in terms of taxonomic and ecological groupings. Taxonomic groupings were typically at the level of species, although in some cases fishes were aggregated at the level of genus, or even family. Mullet less than 40 mm SL for example occurred in abundance on occasion. These fishes often occur as juveniles in estuaries as mixed shoals and are difficult to distinguish to species level in the field. Rather than sacrifice large numbers of them they were returned to the water live and recorded as "mullet fry" (Mugilidae spp.). Ecological grouping was achieved by assigning fishes catch to guilds based upon their primary estuarine use. Guilds were based on categorisations of Whitfield (1990, 1998) who characterised southern Africa's estuarine fishes according to their affinities for these environments. The categories were modified to be consistent with a more recent and global approach suggested by Elliot el al. (2007). Fish were therefore categorised as estuarine species (ES), marine migrants (MM) or marine stragglers (MS). Definitions of these functional groups (following Elliot et al. 2007) are provided in Table 7.4, with Whitfield's (1990, 1998) corresponding estuarine association indicated.

Table 7.4. Estuarine use functional group (EUFG) categorisation used for fishes sampled in this study. Definitions follow Elliot el al. (2007), corresponding estuarine association category (EAC) proposed by Whitfield (1990, 1998) listed.

EUFG	Definition	EAC
Estuarine species (ES)	• Estuarine residents (ER): Estuarine species capable of completing their entire life cycle within the estuarine environment • Estuarine migrants (EM): Estuarine species that have larval stages of their life cycle completed outside the estuary or are also represented by discrete marine or freshwater populations	Ia, Ib
Marine migrants (MM)	Species that spawn at sea and often enter estuaries in large numbers, particularly as juveniles. Some of these species are highly euryhaline and move throughout the full length of the estuary. This category can be subdivided into: • Marine estuarine opportunist (MMO): marine species that regularly enter estuaries in substantial numbers, particularly as juveniles, but use, to varying degrees, nearshore marine waters as an alternative habitat • Marine estuarine dependent (MMD): marine species that	IIa, IIb, Vb

EUFG	Definition	EAC
	require sheltered estuarine habitats as juveniles but live along coasts where there are no such habitats and these species are thus dependent on the habitats of that type that are present in estuaries	
Marine stragglers (MS)	Species that spawn at sea and typically enter estuaries only in low numbers and occur most frequently in the lower reaches where salinities are approximately 35 psu. These species are often stenohaline and associated with coastal marine waters	IIc, III
Freshwater migrants (FM)	Freshwater species found regularly and in moderate numbers in estuaries and whose distribution can extend beyond the oligohaline sections of these systems	IV

Avifauna

Data obtained were analysed by season (where sufficient data were available), as well as by feeding guild (whether diet consisted mainly of fish, invertebrates or vegetable matter as indicated in Hockey et al., 2005) as this reflects estuary use and habitat availability.

7.2 Nonoti Estuary

Macrobenthos

Historical information

Macrobenthic invertebrates previously recorded from the Nonoti Estuary are indicated in Table 7.5, together with an indication of relative abundance. Only species of the Macrura and Brachyura are recorded from Begg's (1984a) catch of 1982 because of differences in the sampling gear used between authors. That is, Begg (1984a) recorded bycatch from a fish trawl whereas Forbes and Forbes (2011) used a Van Veen benthic grab to specifically sample the macrobenthos. Of the decapod bycatch, Begg's overall catch was dominated by the crabs *Rhyncoplax bovis* and *Varuna litterata* (over 70% of total catch) whilst the freshwater *Macrobrachium equidens* was the most abundant prawn species caught. In 2010, the macrobenthos of the Nonoti Estuary was dominated by oligochaetes in both seasons. These worms were particularly abundant in areas with high detrital matter (mid to upper reaches). Also of importance in terms of abundance were the highly invasive gastropod *Tarebia granifera*, the mussel *Brachidontes virgiliae* and the polychaete *Ceratonereis keiskama*. Ten taxa in total were sampled in the most recent survey, with seven and eight taxa sampled in each season, respectively (Table 7.5). Although the taxon lists for this estuarine type usually are not abundant (Stow 2011), these data still indicate that the Nonoti Estuary is not a diverse or productive system in terms of the macrobenthic fauna. Forbes and Forbes (2011) noted also that densities and diversity decreased upstream, particularly in summer. The types of fauna found (particularly the oligochaetes and insects) indicated that the system was predominantly influenced by freshwater.

Table 7.5. Invertebrate species previously recorded from the Nonoti Estuary (Sources: Begg 1984a, Forbes & Forbes 2011).

		Jan-Aug 1982	Mar-10	Aug-10
	Species	**Percentage of catch (%)**		
Amphipoda	*Grandidierella* sp.			0.06
Bivalvia	*Brachidontes virgiliae*		7.92	16.67
Gastropoda	*Tarebia granifera*		17.51	30.91
Hirudinea			0.11	
Insecta	Diptera Chironomidae		1.11	8.66
Oligochaeta			61.34	33.06
Polychaeta	*Ceratonereis keiskama*		11.90	10.53
	Desdemona ornata			0.06
	Unid. Polychaeta A			0.06
Tanaidacea	*Apseudes digitalis*		0.11	
Macrura	*Metapenaeus monoceros*	7.15		
	Caridina typus	7.15		
	Macrobrachium equidens	14.29		
Brachyura	*Rhyncoplax bovis*	49.97		
	Varuna litterata	21.44		
	Mean total ind.m^{-2}		**2381**	**4398.33**

Abundance and numbers of species

Thirty individual taxa were sampled in this study (See Appendix 7 for taxon lists and relative contribution per station, per flow period). Many more taxa were sampled during the low flow (26 taxa) than high flow survey (17 taxa). The lower reaches (sites 1 and 2) showed the greatest discrepancies in numbers of taxa. To note is that during the low flow survey (07.2012) the system was closed and had backfilled substantially suggesting that the fauna (although primarily freshwater influenced) were a relatively stable community. In 02.2013, during the high flow survey, the system had recently breached and thus likely had purged surficial sediments from the lower reaches, thus transporting resident macrobenthic fauna out to sea. Macrobenthos requires some time (depending on the scale of perturbation) to re-establish (Stow 2011).

The general trend was for taxa to decrease from lower to upper reaches in the low flow survey as follows: 11 taxa at site 1, 14 at site 2, 8 at site 3, six at site 4, five at site 5 and four at site 6 (Appendix 7, Figure 7.7). Site 3 supported the most taxa (eight) during high flow and this was comparable to the numbers found in the low flow survey (Figure 7.7). The taxonomic derivations of the taxa were from three Phyla, with the majority classified as Arthropoda (Class Crustacea (six taxa) and Class Insecta (eight taxa)). Of the Annelida three polychaete worm taxa were found, and far fewer than the seven Oligochaeta taxa and one Hirudinea taxon (leech). Few Mollusca taxa were sampled in the study. Of the four taxa of Gastropoda, the invasive *Tarebia granifera* was prevalent in both surveys in the lower/mid reaches of the Nonoti Estuary. The significance of *T.granifera* in the system is further discussed in Section 9. The Polychaeta, Amphipoda and the mussel *Brachidontes virgiliae* are truly estuarine species that are ubiquitous in other TOCEs in this biogeographical zone (MacKay 1996, Stow 2011). The prevalence of insect larvae and the oligochaete worms also indicate the predominant freshwater influence during this study. In particular, these fauna were more abundant in the low flow survey. For example, *Chironomus* midge larvae contributed 69%, 97% and 57% to the total abundance of sites 2, 4 and 6 at that time. The possible influence of more saline conditions is indicated by the significant contributions of the polychaetes *Ceratonereis keiskama* and *Prionospio cf. multipinnulata* in the lower reaches at sites 1 and 2 during the high flow survey when the system was open (Appendix 7). Although the numbers of different tax were greater in this survey they compare well with the study of Forbes and Forbes (2011).

In terms of overall abundance, the low flow survey sampled more macrobenthos in the system than what was sampled in March 2010 (Forbes & Forbes 2011). The most abundant samples were in the lower reaches (Figure 7.7) at the mouth (site 1 – 8323 indiv.m^{-2}) during low flow followed by site 3 (middle reaches – 5040 indiv.m^{-2}. The greatest ranges in abundance between low and high flow periods were at sites 1, 3 and 4, respectively. The upper reaches during both surveys were equally depauperate in abundance (Appendix 7). A mean of approximately 2933 indiv.m^{-2} per station of several taxa were sampled throughout the system in 07.2013, compared with ~717 indiv.m^{-2} per station during 02.2013 in the high flow survey.

Aggregation of data into large taxonomic groups namely; Crustacea, Mollusca, Annelida, Insecta and Hirudinea showed that the Mollusca (almost exclusively *Brachidontes virgiliae*) dominated these macrobenthic Classes at 6955 indiv.m^{-2} (Table 7.6. This brack-water mussel is almost exclusively found in the less saline reaches of estuaries. Table 7.6 also presents the invasive *Tarebia* snail as a separate classification. Unexpected, is the prevalence of this species in the lower to middle reaches, particularly in the high flow (site 3 – 1789 indiv.m^{-2}) when the bottom habitat was less stable due to outflow and also where there was the likelihood of some saline penetration via bottom waters with tidal flow, upstream.

There was a notable absence of Tanaidacea and Cumacea in the system, which are common as the more abundant groups in other similar estuaries (Stow 2011). These classes support some typically estuarine species and occur in large relative numbers in the Mhlanga, Siyaya and Nhlabane Estuaries for example. The Siyaya and Nhlabane are comparable to the Nonoti with respect to size and estuarine type, ecological status and the tendency to turn brackish or even fresh subsequent to prolonged mouth closure and isolation from the marine environment (MacKay 1996, MacKay & Cyrus 2001).

Only one previously unrecorded species to KZN estuaries was identified during this survey, the Spionidae polychaete, *Prionospio cf. multipinnulata*. Members of this family are common in soft sediments (Beesley et al. 2000) and are important selective and non-selective deposit feeders in marine and estuarine systems. The sediment characteristics of site 2 do not explain the exclusive occurrence of this species at this station during two surveys. However, a selection for more saline and coarser sediments as typified by the lower reaches of the Nonoti Estuary can inferred. This species has not previously been recorded in the literature for South African waters, but has now been found in more than eleven other estuaries of this type along the KwaZulu-Natal coastline (F MacKay *pers. obs*., Stow 2011). Taxonomic verification is underway and this could possibly be the first document of a new species or previously unrecorded distribution of an existing, species.

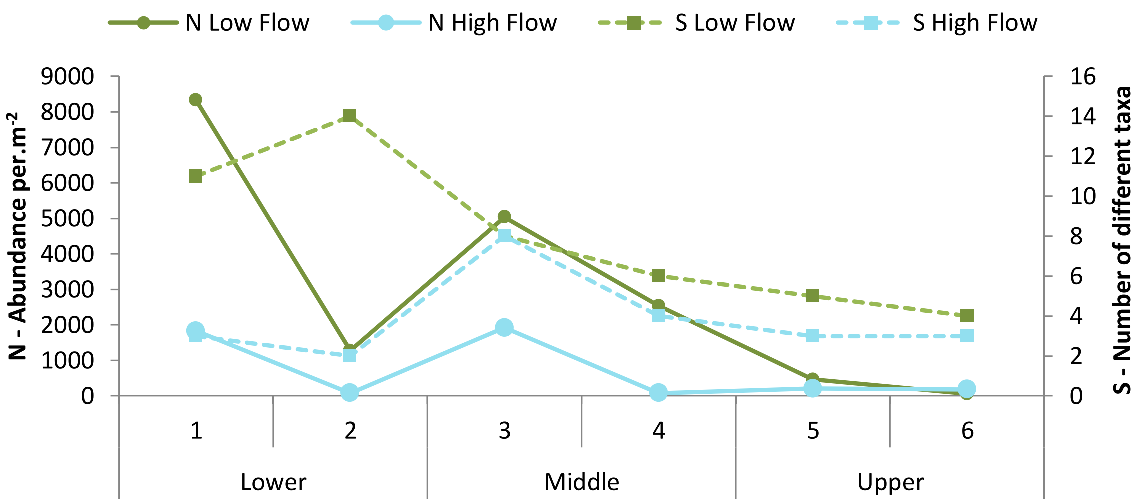


Figure 7.7. Plot of abundance per m^{-2} (N) and number of different taxa (S) for each site, in each estuary reach during low and high flow periods in the Nonoti Estuary.

Table 7.6. Aggregation of taxa into larger groups and abundance (per m^{-2}) per flow period, per station in the Nonoti Estuary. The group Mollusca being separated into the invasive component and that which naturally occurs in KZN estuaries.

	Crustacea		Mollusca		Annelida		Insecta		Hirudinea		Mollusca Invasive	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
1	120		6955	42	899	1756	25				324	32
2	42		17		130	76	1016		8		59	5
3		17	17		3696	115	949				378	1789
4			8		52	19	2472					59
5	8	8			42	193	410	8				
6	8	8			8	160	42	17				

Macrobenthic community indices

The community diversity, richness and evenness indices described in Section 7.1 were used to further elucidate patterns of abundance relative to the number of taxa occurring at the test model factors presented in Section 7.1 (‘*Flow*’, ‘*estuarine reach*’, ‘*site*’). These data are presented in Table 7.7 and Figures 7.8 and 7.9.

Species richness (Margalef’s Index) was highest in the low flow survey (2.921), in the lower reaches (2.438) at site 2 (2.247) (Table 7.7). The upper reaches (1.456) at site 5 (0.801) were the least species rich. One-way ANOVA proved that these differences were significant ($p<0.05$). Diversity indices are based on the number of taxa and their corresponding abundance. This often results in Shannon-Weiner’s Diversity Indices reflecting a similar pattern to species richness. However, the diversity index may be more influenced by the evenness in the distribution of individuals among species (Pielou's Evenness Index) rather than the actual numbers of species present (Gray 1981). This was not the case in this study at the factor level '*site*' (Figures 7.8 and 7.9). The trend shown by species richness (Figure 7.9) was not mirrored in the indices of diversity (Figure 7.8), evenness and dominance (Table 7.7). The probability that individuals drawn from the same population belong to the same species is reflected in Simpson's dominance index. Individuals at sites 1 to 3 were more evenly spread amongst taxa than those from the upper reaches.

TABLE 7.7. COMMUNITY INDICES OF RICHNESS, DIVERSITY, EVENNESS AND DOMINANCE FOR MACROBENTHOS AT FACTOR LEVELS OF 'FLOW' (L-LOW/H-HIGH), 'ESTUARY REACH' (L-LOWER, M-MIDDLE, U-UPPER) AND 'SITE' (1-6) IN THE NONOTI ESTUARY.

	No. Taxa	Abund. m^{-2}	Margalef Richness	Pielou Evenness	Shannon-Weiner Diversity	Simpson's Dominance
Factor	*S*	*N*	*d*	*J'*	*H'(loge)*	*1-Lambda'*
L	26	5205	2.921	0.5976	1.947	0.8307
H	17	857	2.369	0.4221	1.196	0.6210
L	22	5498	2.438	0.5432	1.679	0.7524
M	17	2636	2.031	0.4710	1.334	0.6918
U	11	960	1.456	0.2460	0.590	0.2584
1	12	9757	1.198	0.5502	1.367	0.6957
2	17	1239	2.247	0.5116	1.450	0.6540
3	13	3692	1.461	0.4815	1.235	0.6416
4	9	1579	1.086	0.3461	0.761	0.3742
5	7	1798	0.801	0.2168	0.422	0.1785
6	7	122	1.249	0.6162	1.199	0.5467

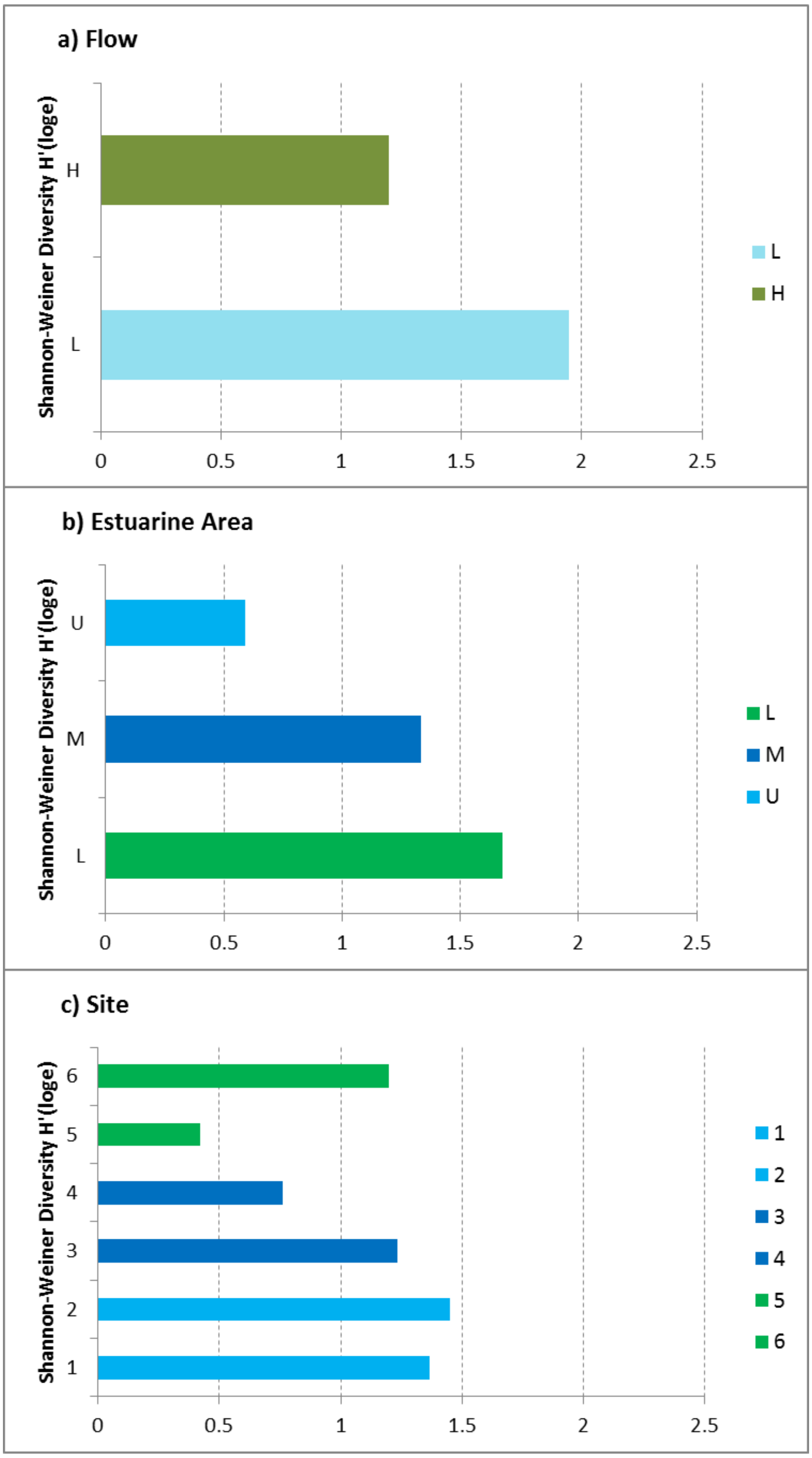


Figure 7.8. Differences in Shannon-Weiner Diversity (H'(loge)) at each factor level ('flow', 'estuary reach' and 'site') in the Nonoti Estuary.

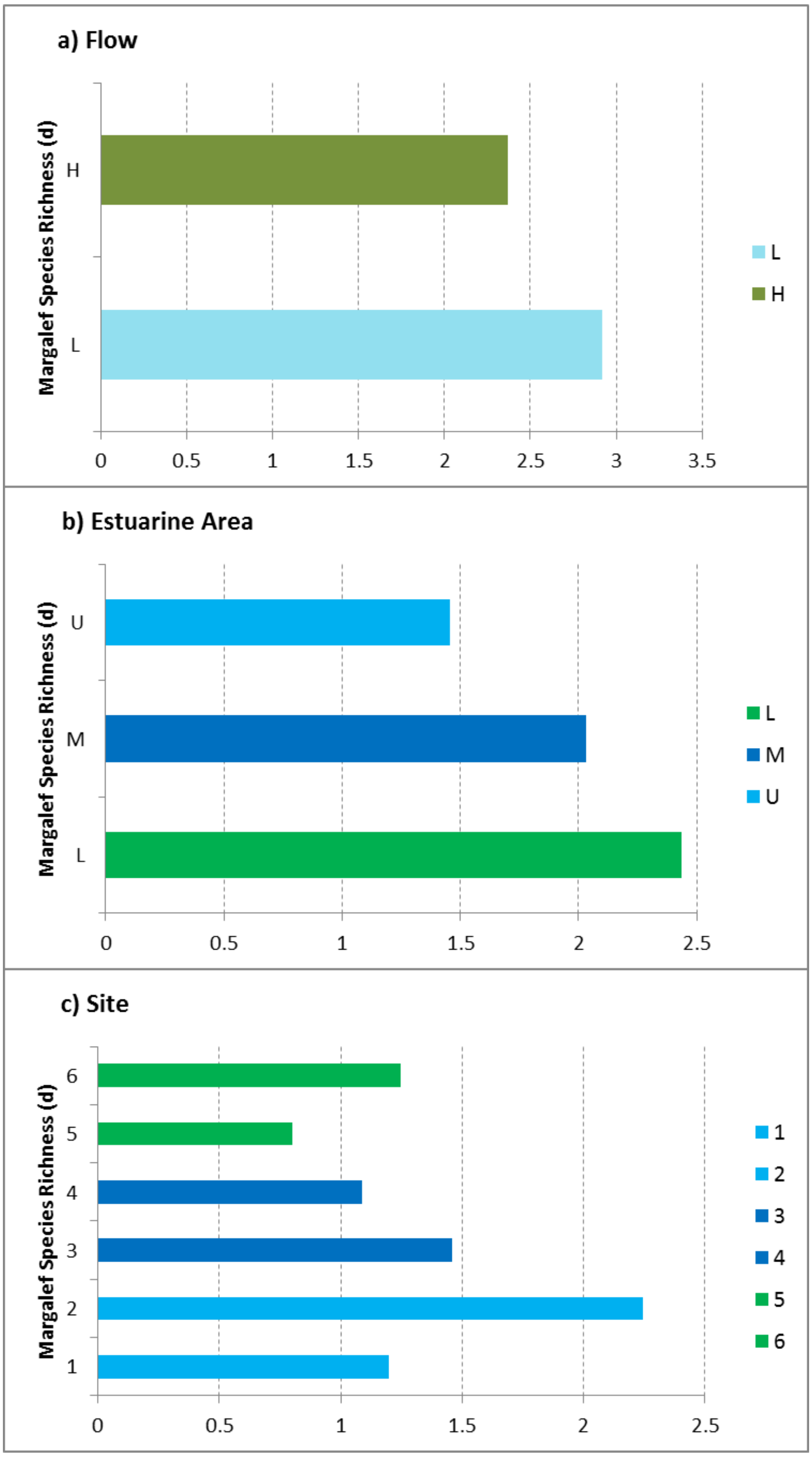


FIGURE 7.9. DIFFERENCES IN MARGALEF SPECIES RICHNESS (D) AT EACH FACTOR LEVEL ('FLOW', 'ESTUARY REACH' AND 'SITE') IN THE NONOTI ESTUARY.

Multivariate classification and ordination

The multidimensional spatial relationships amongst samples are represented in the non-metric multidimensional scaling (NMDS) ordination plot of Figure 7.10. Note that NMDS excludes outlier samples of site 6 (three replicates during low flow), site 2 (two replicates during high flow), site 5 (one replicate during high flow). Samples were plotted in distinct patterns related to sample location along the Nonoti Estuary. Similarly, samples plotted according to the factor '*flow period*' also revealed clear trends (Figure 7.10). The figure inset presents the data means of five replicates per station, per flow period. Here the trends between surveys and within the estuary are clearer. The lower reaches (site 1) are comparable in terms of macrobenthos in the low and high flow. In general there is a trend, represented by a gradient, from lower to upper reaches but with site 6 being less similar in the low flow. In the high flow, site 2 was least similar to the other stations and did not follow the gradient of fauna present from lower to upper reaches, The reason for this is likely the super dominance of the polychaete *Prionospio cf. multipinnulata* at this site. During the high flow, only two taxa were sampled at site 2 including *Prionospio cf. multipinnulata* and the snail *Tarebia granifera*. A very low stress value for both ordinations indicates that the patterns presented are testable for significant differences between some factor levels (*flow*, *estuarine reach*, *site*).

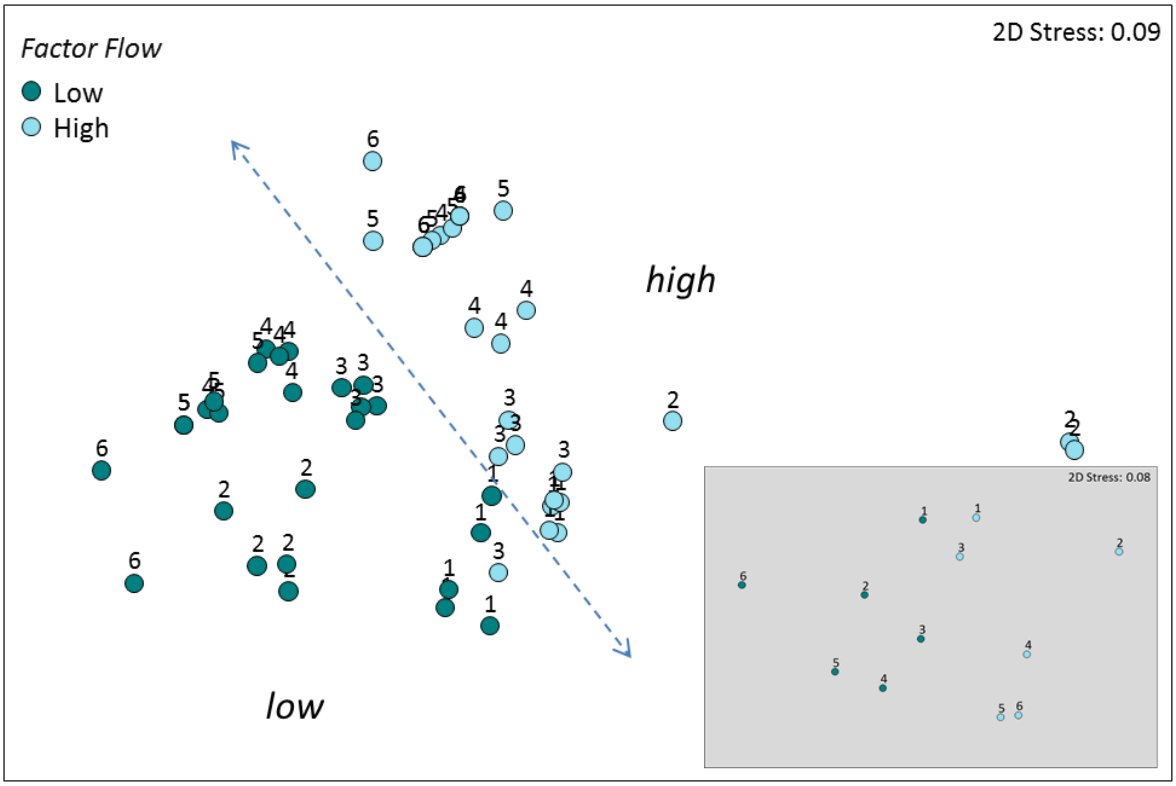


FIGURE 7.10. TWO DIMENSIONAL RESULT OF NMDS ORDINATION OF ABUNDANCE (PER M^{-2}) OF MACROBENTHOS COLLECTED AT SIX SITES (FIVE REPLICATES) IN THE NONOTI ESTUARY DURING LOW AND HIGH FLOW. INSET DEPICTS THE MEAN OF FIVE REPLICATES PER STATION AND ALSO THAT HIGH AND LOW FLOW COMMUNITIES WERE DIFFERENT.

Analysis of similarity between factors: 'flow period', 'estuarine area' and 'site'

The ANOSIM procedure (refer to Section 7.1) was performed to statistically test dissimilarity (if any) between factor levels of '*flow period*' (low/high), '*estuary area'* (lower, middle, upper) and '*site*' (1-6) in the Nonoti Estuary. All R statistics were relatively low (<0.500) suggesting a large amount of variability amongst replicates testing the relevance of factors. However, there were global significant differences amongst surveys, estuarine reaches and sites during this study ($p<0.05$, Table 7.8). This meant that the groups identified according to *flow* and *site* in NMDS ordination (Figure 7.10) and estuarine reach (not depicted as an ordination) were significant. Thus the Nonoti Estuary was spatially and temporally variable in the macrobenthic communities it supported during the high and low flow surveys of this study, with respect to the species sampled, macroinvertebrate abundance, or both of these factors.

Individual one-way statistical comparisons underpinning each global test showed discrepant differences and significance levels for *estuary area* (R statistics range 0.163–0.500, $p<0.05$) and site (R statistics range 0.843– -0.003) and not all individual comparisons were significantly different. That is, sites 4 and 5 were not overall different from sites 2, 3 and 6. Also, sites 4 and 5 were not different overall ($p>0.05$), thereby indicating that these comparisons were not distinct individually in terms of macrobenthic community. The greatest difference occurred between site 1 vs 4 and site 1 vs 6 (R statistics 0.843 and 0.816, $p<0.05$) (Table 7.8).

Factor classification based on species assemblages

The SIMPER procedure (for method refer to Section 7.1) was used to elucidate the macrobenthic species principally responsible for the patterns observed in the NMDS ordination analyses (Clarke and Warwick 2001). The results of these analyses are summarised in Tables 7.9 and 7.10.

The average similarity of contributing species for each factor level was low (<50%) in most cases suggesting that although these analyses list potential taxa as typifying a group, the strength of the assemblages as possible indicators for a group was weak (Tables 7B.4 and 7B.5). For example, a comparison of the average similarity of the factor level 'site' at sites 1 and 6 (Table 7B.5), shows that site 1 (ave. similarity 60.85%) is typified by two taxa, the highest contributor being the estuarine polychaete *Ceratonereis keiskama* (31.87%), followed by *Tarebia granifera* (20.37%). Comparatively site 6 (ave. similarity 17.15) is characterised by a single taxon (*T.granifera*) at 16.09%. Although the contribution levels of *T.granifera* is similar, it is the contribution of the mollusc at site 1 that should carry more weight as an indicator of the local macrobenthic community because of the higher average similarity value for the site.

Chironomus larva sp.1 was the macrobenthic taxon indicative of low flow, whilst the oligochaete Naididae sp.2 indicated high flow conditions (Table 7B4). The middle and upper reaches of the Nonoti Estuary were also characterised by Naididae sp.2 at 18.35% and 14.28%, respectively. The lower, more saline and coarser sand reaches were typified by *Ceratonereis keiskama* (9.91%). Taking all factor levels into account, eight taxa represented the Nonoti Estuary in the study. Four are primarily freshwater in affiliation (oligochaetes, insects and Tarebia granifera) and four are estuarine, brack-water associated.

TABLE 7.8. ANALYSIS OF SIMILARITY (ANOSIM) BETWEEN SAMPLES AGGREGATED AT FACTOR LEVELS OF 'FLOW PERIOD' (LOW/HIGH), 'ESTUARY AREA' (LOWER, MIDDLE, UPPER) AND 'SITE' (1-6) IN THE NONOTI ESTUARY. SIGNIFICANT TEST STATISTICS TAKEN AT P<0.05 FOR GLOBAL TEST OF FACTOR AND INDIVIDUAL PAIRWISE COMPARISONS, WHERE >2 LEVELS OF THE FACTOR EXIST.

Global Test using Factor '*Flow Period*' (**Low/High**)		
Sample statistic (Global R):		0.443
Significance level of sample statistic:		*p<0.05*
Global Test using Factor '*Estuary Area*' (**Upper/Middle/Lower**)		
Sample statistic (Global R):		*0.317*
Significance level of sample statistic:		*p<0.05*
Pairwise Tests	*R*	*Significance*
Groups	*Statistic*	*Level %*
Lower vs Middle	0.315	*p<0.05*
Lower vs Upper	0.500	*p<0.05*
Middle vs Upper	0.163	*p>0.05*
Global Test using Factor '*Site*' (**1-6**)		
Sample statistic (Global R):		*0.455*
Significance level of sample statistic:		*p<0.05*
Pairwise Tests	*R*	*Significance*
Groups	*Statistic*	*Level %*
1 vs 2	0.666	*p<0.05*
1 vs 3	0.447	*p<0.05*
1 vs 4	0.843	*p<0.05*
1 vs 5	0.756	*p<0.05*
1 vs 6	0.816	*p<0.05*
2 vs 3	0.502	*p<0.05*
2 vs 4	0.458	*p>0.05*
2 vs 5	0.289	*p>0.05*
2 vs 6	0.404	*p<0.05*
3 vs 4	0.271	*p>0.05*
3 vs 5	0.408	*p>0.05*
3 vs 6	0.585	*p<0.05*
4 vs 5	-0.003	*p>0.05*
4 vs 6	0.098	*p>0.05*
5 vs 6	0.059	*p>0.05*

TABLE 7.9. CONTRIBUTION OF MOST IMPORTANT TAXA TO THE AVERAGE SIMILARITY OF A FACTOR LEVEL. SAMPLES AGGREGATED AT FACTOR LEVELS OF 'FLOW PERIOD' (LOW/HIGH) AND 'ESTUARY AREA' (LOWER, MIDDLE, UPPER) IN THE NONOTI ESTUARY. ONLY TAXA CONTRIBUTING TO >75% OF THE CUMULATIVE ABUNDANCE OF A FACTOR LEVEL ARE PRESENTED AND HIGHEST CONTRIBUTING TAXON PER FACTOR LEVEL IS INDICATED.

	Factor				
	Flow		Estuary Area		
	Low	High	Lower	Middle	Upper
Ave. Similarity	50.08%	32.39%	24.72%	39.97%	20.51%
Cumulative % Contribution to Tot. Abund.	T=78.03	T=83.22	T=83.77	T=89.24	T=96.64
Chironomus larva sp.1	18.83		1.69	7.66	5.54
Naididae sp.2	3.31	15.41		18.35	14.28
Chironomus PT1	2.51				
Tarebia granifera		6.58	7.50	9.67	
Ceratoneries keiskama			9.91		
Brachidontes virgiliae			1.62		

TABLE 7.10. CONTRIBUTION OF MOST IMPORTANT TAXA TO THE AVERAGE SIMILARITY OF A FACTOR LEVEL. SAMPLES AGGREGATED AT FACTOR LEVELS OF 'SITE' (1-6) IN THE NONOTI ESTUARY. ONLY TAXA CONTRIBUTING TO >75% OF THE CUMULATIVE ABUNDANCE OF A FACTOR LEVEL ARE PRESENTED AND HIGHEST CONTRIBUTING TAXON PER FACTOR LEVEL IS INDICATED.

	Factor					
	Site					
	1	2	3	4	5	6
Ave. Similarity	60.85%	18.04%	49.91%	43.21%	26.81%	17.15%
Cumulative % Contribution to Tot. Abund.	T=85.84	T=83.88	T=87.82	T=84.81	T=91.01	T=93.86
Chironomus larva sp.1		4.99		9.81	13.72	
Naididae sp.2			13.76	26.83	10.68	
Chironomus PT1						
Tarebia granifera	20.37		22.08			16.09
Ceratoneries keiskama	31.87		7.99			
Brachidontes virgiliae						
Desdemona cf. ornata		5.39				
Prionospio cf. multipinnulata		4.75				

Linking Biotic Results to Abiotic Variables

In order to link environmental parameters to macrobenthic population distribution through multivariate analyses, the biotic data matrix was "matched" against the physico-chemical parameters measured at each of six sites. This was achieved using the program BIOENV. The procedure is to calculate a non-parametric Spearman's Rank Coefficient (Section 7.1). The full list of parameters used was derived from all the sediment and physico-chemical analyses measured in the study but excluding co-variates (e.g. conductivity and salinity) or different measures of the same parameter (e.g. dissolved oxygen mg/L and % saturation.

The technique involves the calculation of several permutations of variables until a number of maximum correlation coefficients are reached. The highest must be interpreted as that combination of variables that best explains observed biotic patterns. In the present study, a combination of four variables were responsible, in part, for the differences measured in the macrobenthic distribution pattern at ρ = 0.400 (Table 7.11). These variables were temperature (ºC), % mud and the sediment distribution statistic – sediment sorting. The next highest match ρ = 0.391 (Table 7.11) included an additional parameter, dissolved oxygen (mg/L). The correlation statistic values are relatively low suggesting other environmental parameters are influencing the macrobenthos of the Nonoti Estuary, outside of which that were measured in the study. Salinity was not a primary driver as would typically be expected in an estuary and the presence of mud either favourably influences the distribution of some organisms (Chironomidae (midge)) larvae or precludes the presence of others (e.g. estuarine amphipods and polychaetes). The Nonoti Estuary is influenced and impacted by the presence of large areas and numbers of species of invasive aquatic or plants. The floating macrophytes eventually reach the lower reaches via wind-borne transport or river flow. Here in the presence of salinity (even negligible) species such as *Lemna* and *Eichhornia* perish and sink to the bottom the system. While decaying there is a high biological oxygen demand, in places resulting in very low oxygen saturation in bottom waters (see Section 6).

An adequately oxygenated condition is a minimum requirement for all living organisms. Aquatic organisms are especially vulnerable to low oxygen concentrations as this situation is often coupled with other environmental parameters that are physiologically difficult to contend with, such as high water temperature or toxic chemicals in dissolution. Although temperature differences between stations were not marked, or even too different between surface and bottom waters within a station, these results show that this parameter does play a role in the distribution and community structure of macrobenthic organisms in the system.

TABLE 7.11. COMBINATIONS OF ENVIRONMENTAL VARIABLES YIELDING THE BEST MATCHES OF NONOTI ESTUARY ABIOTIC (PHYSICO-CHEMICAL/SEDIMENT) AND BIOTIC (MACROBENTHOS) SIMILARITIES AS MEASURED BY SPEARMAN'S RANK CORRELATION (Ρ). OVERALL OPTIMUM IS A COMBINATION OF THREE VARIABLES AT Ρ = 0.400.

No. Environmental Variables	3	4	3
Temperature (°C)	X	X	X
Dissolved Oxygen (mg/L)		X	X
Mud (%)	X	X	
Sediment Sorting	X	X	X
Correlation Coefficient (ρ)	0.400	0.391	0.390

Ichthyofauna

Historical information

Very few studies have been conducted of the Nonoti Estuary. The earliest documented survey of the ichthyofauna of the system is that of Begg (1984a), and was part of a wider study of KwaZulu-Natal estuaries. During this study the estuary was sampled three times, in January, April and August of 1982. Only seven fish species were caught with *Gilchristella aestuaria* and *Gerres methueni* occurring in the highest abundance over all three surveys (Table 7.12). The apparent abundance of *Gerres methueni* is likely to be a chance artefact. The species was sampled in only one of the three surveys. *Gilchristella aestuaria* and *Oreochromis mossambicus* occurred with the highest frequency (every trip) and were more likely species which would have dominated fish abundance. Begg's sampling relied on a narrow beam trawl (1 m width) which is suboptimal for fish survey in estuaries. This would have resulted in some sampling bias (and specifically in the system being under-sampled for fishes). Notwithstanding this, a greater diversity of fishes than that reported would be expected from a similar category of estuary. It was apparent from surveys at the time that the Nonoti Estuary was in a poor ecological state (Begg 1978, 1984a).

Forbes & Forbes (2011) sampled the system in March and August of 2010 as part of a consultancy project to assess the estuary's ecological status and the potential impacts of a proposed housing development on the system's south bank. Using more appropriate sampling gear they recorded 12 fish species in the estuary (Table 7.12). One of these was truly estuarine, seven were marine estuarine dependants and three were freshwater migrants. Mugilids (marine estuarine dependants) and *Oreochromis mossambicus* (freshwater migrant) dominated catch abundances. Although an apparent improvement on the ichthyofauna as surveyed by Begg (1984a) the assemblage can still be regarded as poor compared to what would typically be expected from an estuary such as the Nonoti.

Particularly noteworthy was that as early as September 1977 the system was infested with alien water hyacinth (*Eichhornia crassipes*) which was indicative of nutrient enrichment (Begg 1978). In 1982 additional alien floating macrophytes Nile cabbage (*Pistia stratiotes*) and duckweed (*Lemna gibba*) were noted along with "thick stands of antelope grass" at the water's edge (Begg 1984a). Forbes & Forbes (2011) also reported Nile cabbage as present, water hyacinth to be abundant and that antelope grass *Echinochloa* sp. occurred on the water's edge.

Fish surveys in 2012/2013

A minimum of ten species of fish was sampled in the Nonoti Estuary in the two surveys conducted as part of this study. Total numbers of different fish species sampled are shown in Figure 7.11. Marine migrant species (all marine estuarine dependent fishes) dominated the number of taxa encountered. Only one estuarine species (*Ambassis ambassis*) was sampled and that occurred as a single specimen. One freshwater species occurred (*Oreochromis mossambicus*) but in relatively good abundance. No marine stragglers were sampled.

Table 7.12. Fish species recorded from the Nonoti Estuary between January and August 1982 (Begg 1984a) and March and August of 2010 (Forbes & Forbes 2011). Catch data modified to be presented as a percentage of total catch.

		Jan-Aug 1982	Mar 2010	Aug 2010
Family	**Species**	**Percentage of catch (%)**		
Ambassidae	*Ambassis ambassis*		2.4	
Cichlidae	*Oreochromis mossambicus*	19.3	23.4	35.5
	Tilapia rendalli		0.8	
Clariidae	*Clarias gariepinus*		0.8	
Clupeidae	*Gilchristella aestuaria*	29.8		
Gerreidae	*Gerres methueni*	29.8		
Gobiidae	*Glossogobius giurus*	3.5		
	Oligolepis acutipennis	7.0		
	Redigobius dewaali	8.8		
Lutjanidae	*Lutjanus fulviflamma*	1.8		
Megalopidae	*Megalops cyprinoides*		1.6	
Mugilidae	Mullet fry		40.3	
	Liza alata		6.5	58.1
	Liza dumerili		1.6	
	Liza macrolepis		0.8	
	Mugil cephalus		0.8	3.2
	Myxus capensis		12.9	3.2
Teraponidae	*Terapon jarbua*		8.1	

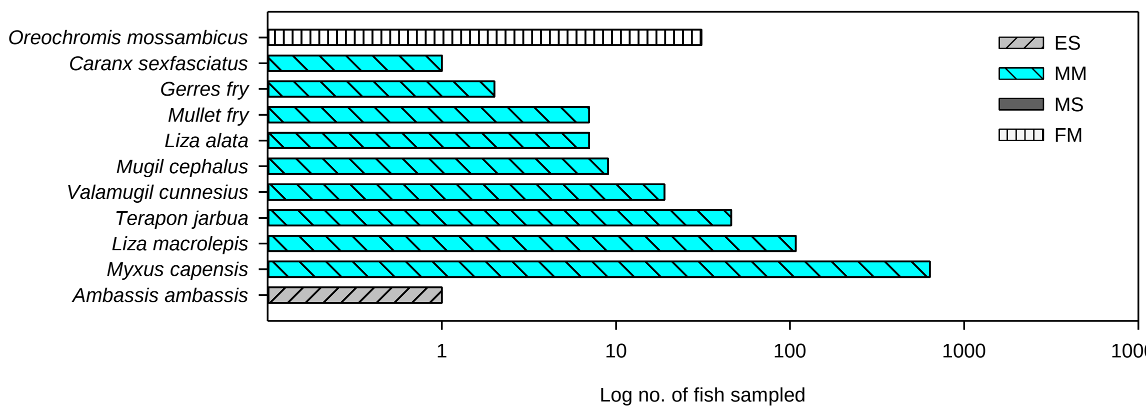


Figure 7.11 Numbers (log10) of fish sampled by all gears in the Nonoti Estuary during low and high flow seasons. Estuarine use functional group as indicated in Table 7.4 (ES = estuarine species, MM = marine migrant, MS = marine straggler, FM = freshwater migrant).

Nine species were sampled by seine net and two were sampled by gill nets. Both gill and seine net catches were dominated numerically by the mullet *Myxus capensis* (juveniles only in the seine nets and adults only in the gill nets). The only other species that occurred in any marked abundance was the mullet *Liza macrolepis*. This species was sampled only as juveniles. All others species contributed <10% to catches.

There was a marked difference in fish assemblages sampled by seine net in the low and high flow season. In the low flow season very few fishes were sampled. Catches were limited to a few mullet fry, even fewer *Gerres* fry and a single *Terapon jarbua*. In total ten fishes were caught in twelve seine net hauls in the low flow season. This represents the lowest seine net CPUE ever returned from a KwaZulu-Natal estuary in the experience of the researchers conducting this work. Seine net catches in the high flow season were much improved (849 fishes in twelve seine net hauls) but still comprised only juveniles of a limited array of species. Most notable was that a single specimen of estuarine resident fish (*Ambassis ambassis*) was caught (in gill nets in the lower reaches during the high flow season).

Physico-chemical conditions in the Nonoti Estuary are not discussed in great detail here, having been reported upon in a stand-alone section of this report (Section 6). Several key findings are, however, worth noting from measurements made in mid-depth waters concurrent with the fish sampling. Limited discussion of physico-chemistry in mid-depth waters is warranted as it pertains to the actual conditions that fishes were sampled in. Salinity, turbidity and dissolved oxygen are water quality parameters best understood in the context of estuarine biology.

Salinities in the Nonoti Estuary mid-depth waters were low. Less than 1 psu was recorded at all sites. Begg (1984) also reported low salinities during surveys conducted in 1982 as did Forbes and Forbes (2011) in 2010. This is a characteristic shared by several TOCEs on the KwaZulu-Natal. It generally occurs in systems perched behind high beach barriers and that open infrequently. South African estuarine fishes are generally more tolerant of low rather than high salinity conditions (Whitfield et al. 1981) but levels recorded in Nonoti waters were probably lower than salinity preferences of several marine estuarine dependent species and even some estuarine species. The fish faunas of such low salinity systems are typically dominated by a few small estuarine fishes (often *Gilchristella aestuaria*) and freshwater migrant species (*Oreochromis mossambicus* in particular). Infrequently several additional freshwater species more typical of coastal lowland freshwaters also occur. These are generally secondary freshwater species such as *Barbus paludinosus*, *Barbus trimaculatus*, *Barbus viviparous* (Weerts *pers. obs*.). These species could occur in the Nonti but might have gone unrecorded as they have strong preferences for vegetated habitats which are not well sampled using seine nets. (In fact some dip netting was done in the system specifically to sample fishes in marginal vegetation.) It is more likely that high total dissolved salt (predominantly salinity) does indeed preclude the use of the estuary by these fishes. Salinities in bottom waters were generally significantly higher than those in surface and mid waters.

Turbidities in the estuary were low during low and high flow surveys, generally well below 10 NTU. Clear waters were also reported by Begg (1984a) and Forbes and Forbes (2011). Turbidities at which changes in fish assemblages from KwaZulu-Natal estuaries are most obvious are 10, 50 and 80 NTU (Cyrus & Blaber 1987a, b). In a regional context the Nonoti Estuary is a clear water estuary (mean turbidity below 10 NTU).

Dissolved oxygen levels varied quite widely across the system. Mid-depth waters in the lower reaches were well oxygenated and supportive of aquatic fauna. The upper reaches however, were characterised by low oxygen tensions, often <4 mg/L. Oxygen concentrations in bottom waters were lower and even in the middle and some lower reaches of the estuary concentrations fell below 4 mg/L. Low oxygen levels are not uncommon in KwaZulu-Natal TOCEs (Begg 1984a, Harrison 2003) particularly in the deep sections of systems protected from wind and where waters are stagnant. This is often brought about by the decay of leaf litter. Anthropogenic inputs often exacerbate the situation. Dissolved oxygen concentrations ≥5 mg/L are generally considered to be protective of aquatic life while concentrations below 4 mg/L can have severe effects on aquatic biota, especially if they persist (USEPA 2003). Most South African estuarine fishes are probably quite tolerant of depressed oxygen concentrations. However, the widespread low oxygen concentrations in the Nonoti Estuary are likely to be limiting to the system's fish fauna. The system has a history of pollution by sugar mills, although by the early 1980s indications were that some recovery had taken place (Begg 1984a). In the present day invasive alien vegetation (water hyacinth and Nile cabbage) are likely sources of significant organic matter that sinks and decays in the bottom waters of the estuary, resulting in deoxygenation of the system. These and other invasive alien species cover much of the system, occurring even in the lower reaches.

Fish abundance and diversity in the Nonoti Estuary is low. This has historically been the case. In a comparative study of some sixty TOCEs in KwaZulu-Natal Begg (1984b) found the Nonoti to support less than one third the number of species (fish, prawns and crabs) found in systems with the highest species diversity. This was attributed to pollution of the estuary (Begg 1979, 1984a). While pollution was a contributing (and possibly the main) factor, the persistently low species diversity in the estuary even after management practices have changed suggests that natural factors might also play a role. The predominantly closed nature of the system is certainly a constraint to recruitment of marine spawned species. Wave overtopping during mouth closure (when high tide and wave conditions result in waves washing over the beach barrier and into the estuary) probably occurs quite infrequently given the high beach barrier. This limits recruitment opportunity for species that specialize in recruitment via wave overwash (e.g. *Rhabdosargus holubi*, Cowley et al. 2001). Very low salinities (especially in mid and surface waters) are suboptimal for many marine estuarine dependant species. Trophic effects are also likely with many of larger estuarine crustaceans (food items for larger marine estuarine dependent fishes) also constrained by limited recruitment opportunity and preferring slightly higher salinities than those that appear to characterise the system.

Even considering the above however, the depauperate fish fauna of the estuary is indicative of a system in poor ecological state. The paucity of estuarine resident species is especially symptomatic. These fishes should not be sensitive to recruitment constraints which might be affecting marine migrants. Water quality, low oxygen concentrations in particular, is a likely cause. Sediment release of hydrogen sulphide which is produced by anaerobic oxidation and is toxic to aquatic fauna might also be problematic. A smell of this gas was noted by fieldworkers during the high flow survey in 2013. Invasive alien macrophytes are likely to be the underlying cause, contributing significant organic matters to the system (see above). Floating forms, which cover much of the system, also contribute to poor circulation and water stagnation, exacerbating the effects of organic decay in the lower waters. High nutrient inputs into the estuary are likely to have initiated, and possibly sustain, the abundance of these alien invasive species.

Avifauna

Records of birds associated with the Nonoti Estuary have been made by Begg (1984a) and Forbes & Forbes (2011) (Table 7.13). Counts are available for autumn (March) and winter (August) of 2010. These show more species, as well as more individuals were recorded in winter than in autumn (n=69 compared to n=23). Of these the most abundant were the African jacana, whitefaced duck and spurwinged goose, all of which are associated with vegetation or the invertebrates in that habitat rather than fishes. This reflects the availability and importance of vegetated aquatic habitat in this system. These species, together with the grey heron were also consistently observed on every sampling trip recorded.

Table 7.13. Water-associated birds previously recorded from the Nonoti Estuary, asterisks indicate presence (Sources: Begg 1984a, Forbes & Forbes 2011).

Species	S.A. Common name	Count (where available)		
		Jan-Aug 1982	Mar-2010	Aug-2010
Actitis hypoleucos	Common sandpiper		1	1
Actophilornis africanus	African jacana	*	8	5
Anas undulata	Yellowbilled duck	*		
Ardea cinerea	Grey heron	*	1	2
Ardea goliath	Goliath heron			1
Ardea purpurea	Purple heron			
Balearica regulorum	Crowned crane			2
Ceryle rudis	Pied kingfisher		2	2
Dendrocygna viduata	Whitefaced duck	*	2	6
Egretta garzetta	Little egret			1
Haliaeetus vocifer vocifer	African fish eagle		2	1
Motacilla aquimp	African pied wagtail			2
Phalacrocorax (c.) lucidus	Whitebreasted cormorant		1	
Phalacrocorax africanus	Reed cormorant		1	3
Plectropterus gambensis	Spurwinged goose	*	3	32
Porphyrio martinicus	Purple gallinule	*		
Scopus umbretta	Hamerkop		1	
Sterna bergii	Swift tern			3
Tringa nebularia	Common greenshank		1	3
Vanellus armatus	Blacksmith lapwing			5

Species contributing greater than 10% to total abundance over the current sampling period are the Egyptian goose *Alopochen aegyptiaca* and the spurwinged goose *Plectropterus gambensis* (18% respectively), the reed cormorant *Phalacrocorax africanus* (15%) and the dabchick *Tachybaptus ruficollis* (10%). The geese species are primarily vegetarians, while the cormorant and dabchick feed primarily on fishes. Overall, 46% of all species counted from the Nonoti Estuary are piscivores while 49% feed primarily on vegetation or invertebrates (Figure 7.12). Historical records from the Nonoti Estuary show the most abundant species to be the African jacana *Actophilornis africanus*, whitefaced duck *Dendrocygna viduata* and spurwinged goose (Begg 1984a, Forbes & Forbes 2011), all of which are associated with vegetation or the invertebrates in that habitat rather than fishes. This reflects the historical and continued availability and importance of vegetated aquatic habitat in this system.

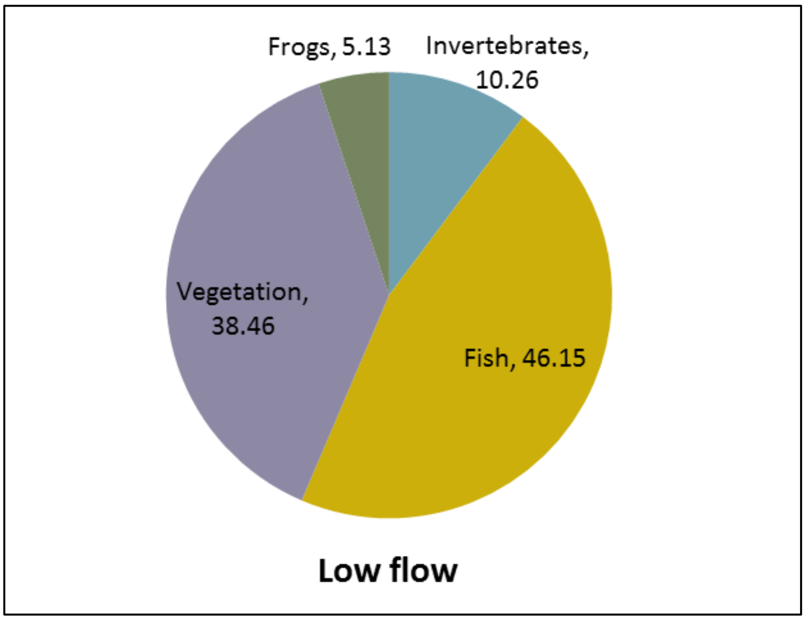


FIGURE 7.12. PERCENTAGE CONTRIBUTION OF THE FEEDING GUILDS IDENTIFIED IN HOCKEY *ET AL*. (2005) TO TOTAL BIRD ABUNDANCE IN THE NONOTI ESTUARY, BY SEASON (N=39, FOUR COUNTS).

7.3 Zinkwazi Estuary

Macrobenthos

Historical information

No published studies exist on the macrobenthos of the Zinkwazi Estuary. The earliest documented account was on the macrocrustacea (Begg 1984a). That study recorded the abundance of decapod species present as bycatch in fish trawl samples from the Zinkwazi Estuary from 1979-1981 (Table 7.14). Species recorded on most sampling occasions (>70%) included the prawn *Metapenaeus monoceros* and the crabs *Hymenosoma orbiculare*, *Rhyncoplax bovis* and *Scylla serrata*. Other species that were caught in high numbers although recorded less frequently include *Penaeus indicus*, *P.japonicas* and *Palaemon concinnus*.

TABLE 7.14. INVERTEBRATES PREVIOUSLY RECORDED FROM THE ZINKWAZI ESTUARY (SOURCE: BEGG 1984A).

	No. caught	% of catch	1979			1980									1981		
			S	O	N	J	F	M	A	M	J	J	A	S	Jan	Ap	Jul
Prawns																	
Acetes natalensis	17	1.31														*	
Caridina nilotica	1	0.08	*														
Caridina typus	2	0.15	*												*		
Macrobrachium equidens	39	3.02	*				*	*									*
Metapenaeus monoceros	274	21.19		*			*	*		*	*	*	*	*	*	*	*
Palaemon concinnus	70	5.41															*
Parapenaeopsis acclivirostris	2	0.15				*	*										
Penaeus canaliculatus	9	0.70					*										
Penaeus indicus	138	10.67			*	*	*	*				*			*	*	*
Penaeus japonicus	183	14.15			*	*	*									*	
Penaeus monodon	21	1.62				*	*			*			*			*	
Penaeus semisulcatus	1	0.08						*									
Upogebia africana	1	0.08													*		
Crabs																	
Calappa hepatica	1	0.08				*											
Hymenosoma orbiculare	266	20.57	*	*	*	*	*	*			*			*	*	*	*
Monomia gladiator	3	0.23					*										
Pilumnus sp.	1	0.08					*										
Portunus pelagicus	2	0.15				*											
Rhyncoplax bovis	192	14.85	*	*	*	*	*				*	*	*	*	*	*	*
Scylla serrata	63	4.87	*		*	*	*	*	*	*		*	*	*	*	*	*
Thalamita admete	3	0.23														*	
Tylodiplax blephariskios	1	0.08		*													
Varuna litterata	3	0.23	*							*					*		

From October 1998 until March 1999 macrobenthic samples were collected from a number of KwaZulu-Natal estuaries along axial gradients from mouth to headwaters. These data have now been worked up in part (F. MacKay *unpublished data,* Stow 2011) along with a repeat collection conducted a decade later in 2009/2010 in some systems, including the Zinkwazi Estuary (Stow 2011). These quantified samples collected using the same protocols followed this survey make for an appropriate comparison of what was more recently found.

In 1998/9 it was found that the Zinkwazi exhibited relatively low faunal abundance (9257 indiv.m^{-2}) compared with macrobenthos found in smaller, similar systems of the same estuarine type such as the Intshambili (35429 indiv.m^{-2}). Then, Polychaeta were the dominant group in the estuary and contributed to 83% of the overall abundance (Stow 2011). At that time Insecta were entirely absent from the macrobenthos, suggesting that the system was subject to a greater saline influence. Stow (2011) collated data from 39 TOCEs in KZN and subjected the data to classification analysis. Results showed that the Zinkwazi and nearby Mdlotane were different (i.e. separate) from the other 37 systems, indicating that the macrobenthos was similar in both, and possibly a unique assemblage from what was found elsewhere. The macrobenthos of the Zinkwasi Estuary was typified by, but not limited to, *Desdemona ornata* (Polychaeta), *Prionospio multipinnulata* (Polychaeta), Oligochaeta spp. and Sabellidae juvenile T1 (Polychaeta). Also the system supported the Crustacea *Apseudes digitalis* (Tanaidacea), *Cyathura estuaria* (Isopoda), Mesopodopsis africana (Mysidacea) and the polychaete *Dendronereis arborifera* which was absent or rare in the other TOCEs (Stow 2011).

A decade later, the mean abundance of macrobenthos was recorded at 8820 indiv.m^{-2}. The system continued to be characterised by *Apseudes digitalis* (Tanaidacea), *Cyathura estuaria* (Isopoda), *Dendronereis arborifera* (Polychaeta) and *Mesopodopsis africana* (Mysidacea), but Chironomini larvae spp. (Insecta) and *Ceratonereis keiskama* (Polychaeta) were absent from the system (Stow 2011).

Abundance and numbers of species

Combining the low and high flow surveys of the Zinkwazi, 60 individual taxa were sampled in the estuary. (See Appendix 7 for taxon lists and relative contribution per station, per flow period). Forty-eight different types of macrobenthic fauna were sampled under the flow conditions when the system was closed and full. Less than half the number (22), were sampled in the high flow, open mouth condition in 02.2013. In 07.2013, the system had recently purged and was shallow and subject to tidal influence. The latter being measurable in bottom waters some distance upstream (see Section 6).

The taxa were spread across five Phyla, the most speciose being the Arthropoda including representatives of Arachnida, Crustacea (Amphipoda, Brachyura, Cumacea, Isopoda, Mysida, Tanaidacea, Decapoda) and Insecta (Diptera, Megaloptera) (Appendix 7). Following on were the Mollusca (15 taxa across the Gastropoda and Bivalvia) and the Annelida (13 taxa across the Oligochaeta and Polychaeta).The general impression was of a typically estuarine fauna with some freshwater associated species that would typically occur in the upper reaches of other TOCEs (MacKay 1996, MacKay & Cyrus 2001).

In terms of trends of taxa occurring along the estuarine gradient from lower to upper reaches, the invasive snail *Tarebia granifera* was found primarily only in the high flow from site 10 where it occurred at 70% of the abundance per site to over 90% of the total abundance of sites 11 and 12 in the upper reaches. Typically there is the expectation that marine fauna do not occur upstream in estuaries and estuarine fauna will predominate the mesohaline areas of a system. From the mid to upper reaches only oligohaline tolerant species should occur and thrive. The mid to upper reaches of the Zinkwazi were dominated by estuarine fauna and this was also in terms of abundance (Appendix 7). The three main contributing species were the polychaete *Prionospio multipinnulata*, the amphipod *Corophium triaenonyx* and the tanaid *Apseudes digitalis*. No other animals other than the polychaete *Ceratonereis keiskama* were sampled at site 1 during the high flow. However, this was at low abundance at 34 indiv.m^{-2} at the site.

The general trend found in TOCEs was also not common in the Zinkwazi during low flow with most taxa being found in the lower reaches (site 1 – 22 taxa, site 2 – 22 taxa) decreasing to the mid reaches, but at sites 8-10, 21, 23 and 29 taxa were found, respectively (Figure 7.13). During high flow the numbers of different taxa were more evenly distributed along the system, but at much lower values. The maximum number of different taxa found at any site during 07.2012 was 10, at site 2. Low flow abundance was consistently greater at all sites except site 10. Sites 1-3 were the greatest in abundance ranging from 25000 indiv.m^{-2} to 18000 indiv.m^{-2}, with sites 6 and 9 in the middle reaches and site 12 showing comparative numbers of macrobenthos (Figure 7.13).

Since Begg's study (1984a) it appears that the macrocrustaceans routinely found in mud and fine sand samples of estuaries (*Hymenosoma orbiculare*, *Rhyncoplax bovis* and *Paratylodiplax blephariskios*) are fewer in number in the system, with *H.orbiculare* being entirely absent this study. The types of fauna found in 2012/2013 are comparable with the study comparing fauna in the decade between 1998/9 and 2009/2010 (Stow 2011). However, if the fauna aggregated to a mean number of individuals per station is considered, for a similar time of year (high flow), only 20% (1834 indiv.m^{-2} per site) was sampled as compared with the two previous surveys. The low flow numbers at 10635 indiv.m^{-2} are more comparable.

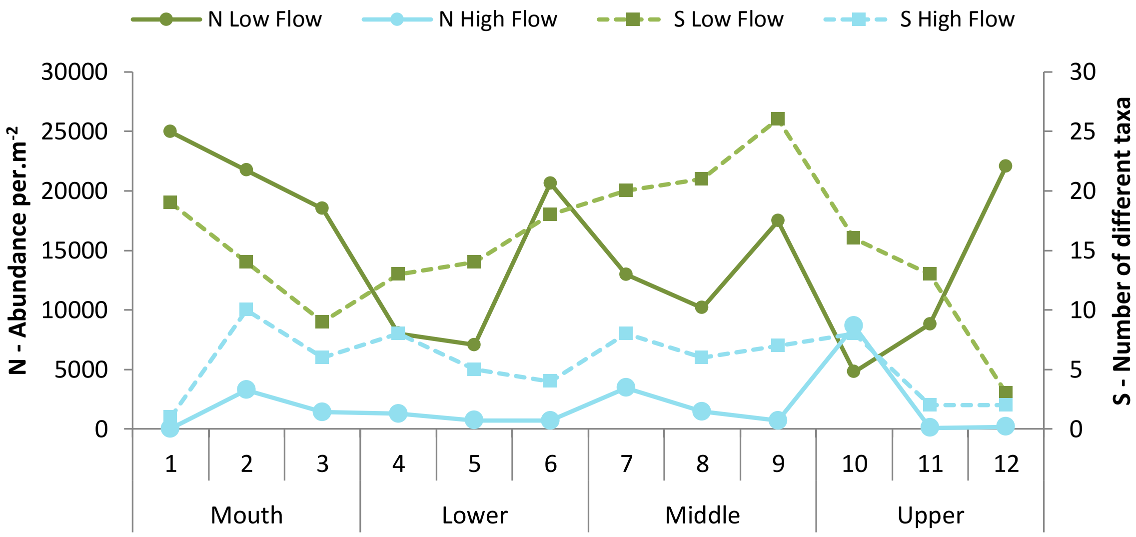


FIGURE 7.13. PLOT OF ABUNDANCE PER M^{-2} (N) AND NUMBER OF DIFFERENT TAXA (S) FOR EACH SITE, IN EACH ESTUARY REACH DURING LOW AND HIGH FLOW PERIODS IN THE ZINKWAZI ESTUARY.

Taxa aggregated into larger groups (Classes) namely Annelida, Cnidaria, Crustacea, Insecta, Mollusca, and Nematoda show that Crustacea and Annelida dominated the low flow survey and that Crustacea in particular were depauperate during the high flow (Table 7.15). Also indicated (separately) is the contribution made by *Tarebia granifera*. This was the only taxon to display an increase in abundance during the high flow survey. The highest individual contribution of a Class was the Crustacea at sites 3 and 4 during the low flow, with 14582 indiv.m^{-2} and 14003 indiv.m^{-2}, respectively. Cnidaria and Nematoda were rarely represented, with the latter present only at site 1, low flow survey.

TABLE 7.15. AGGREGATION OF TAXA INTO LARGER GROUPS AND ABUNDANCE (PER M^{-2}) PER FLOW PERIOD, PER STATION IN THE ZINKWAZI ESTUARY. THE GROUP MOLLUSCA BEING SEPARATED INTO THE INVASIVE COMPONENT AND THAT WHICH NATURALLY OCCURS IN KZN ESTUARIES. UNKNOWN TAXA AND ONE OCCURRENCE OF ARACHNIDA ARE NOT PRESENTED.

	Annelida		Cnidaria		Crustacea		Insecta		Mollusca		Nematoda		Mollusca Invasive	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
1	11841	34	84		5731		17		7367		25			
2	6978	3203	8		10315	67	17		101	8				
3	3274	1411	8		14582	10	36		126					
4	2053	958			14003	334			17					
5	3623	722			592		59		25	8				
6	2696	714			1006		67		19					
7	5532	2929			9041	353	103		118					168
8	917	1436	8		5230	8	445		134				17	19
9	3368	652	143		1517	8	25		434				143	34
10	5488	2428	76	8	2249	8	958		112	25			32	6174
11	1315	8	25		949		84		8				42	92
12	4003				176		202		17					176

Macrobenthic community indices

Community indices of diversity, richness, evenness and dominance at each factor level of testing are presented in Table 7.16 and Figures 7.14 and 7.15. Macrobenthos found during the low flow was significantly more diverse (Shannon-Weiner Diversity 2.106) compared with the high flow (Shannon-Weiner Diversity 2.691). Evenness and Dominance values indicated however that the spread of abundance amongst taxa was uniform. Margalef Richness followed the same trend (Figures 7.14 and 15). With regards to estuarine area, the least diverse reach was the lower reaches with an even spread of index values at other reaches. Species Richness showed that although the index was low in the lower reaches, the upper reaches were most rich in species (Figure 7.15). A variable trend up the system was shown by the indices, but site 10 was significantly more diverse and species rich (Richness 3.597, Diversity 2.070) (ANOVA $p<0.05$).

TABLE 7.16. Community indices of richness, diversity, evenness and dominance for macrobenthos at factor levels of 'flow' (L-low/H-high), 'estuary reach' (Mo-mouth, Lo-lower, Mi-middle, Up-upper) and 'site' (1-12) in the Zinkwazi Estuary.

	No. Taxa	Abund. m^{-2}	Margalef Richness	Pielou Evenness	Shannon-Weiner Diversity	Simpson's Dominance
Factor	*S*	*N*	*d*	*J'*	*H'(loge)*	*1-Lambda'*
L	52	13707	5.354	0.5331	2.106	0.805
H	23	2120	2.872	0.5392	1.691	0.778
Mo	33	11526	3.422	0.5947	2.079	0.818
Lo	20	6562	2.162	0.3880	1.162	0.520
Mi	32	8368	3.432	0.5961	2.066	0.822
Up	38	5198	4.324	0.5550	2.019	0.798
1	23	12621	2.330	0.5867	1.839	0.803
2	23	11810	2.346	0.5027	1.576	0.735
3	14	10147	1.409	0.4227	1.115	0.483
4	12	10122	1.193	0.3639	0.904	0.385
5	13	4859	1.414	0.4080	1.046	0.569
6	13	4704	1.419	0.5253	1.347	0.614
7	21	9895	2.174	0.4892	1.489	0.687
8	21	6493	2.278	0.5873	1.788	0.754
9	23	8715	2.425	0.5177	1.623	0.634
10	34	9647	3.597	0.5870	2.070	0.800
11	17	3557	1.957	0.3817	1.081	0.475
12	14	2390	1.671	0.4457	1.176	0.481

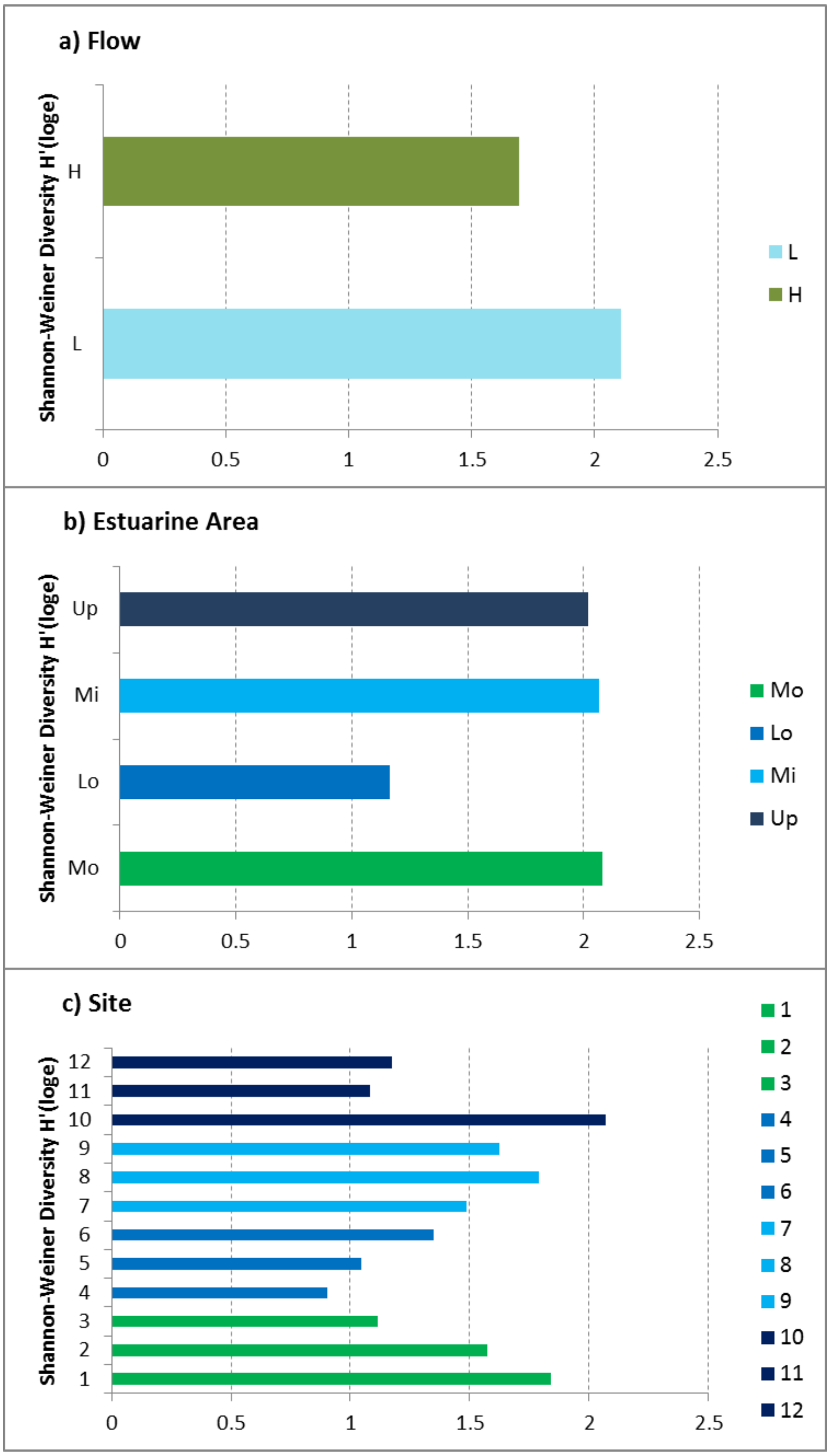


Figure 7.14. Differences in Shannon-Weiner Diversity (H'(loge)) at each factor level ('flow', 'estuary reach' and 'site') in the Zinkwazi Estuary.

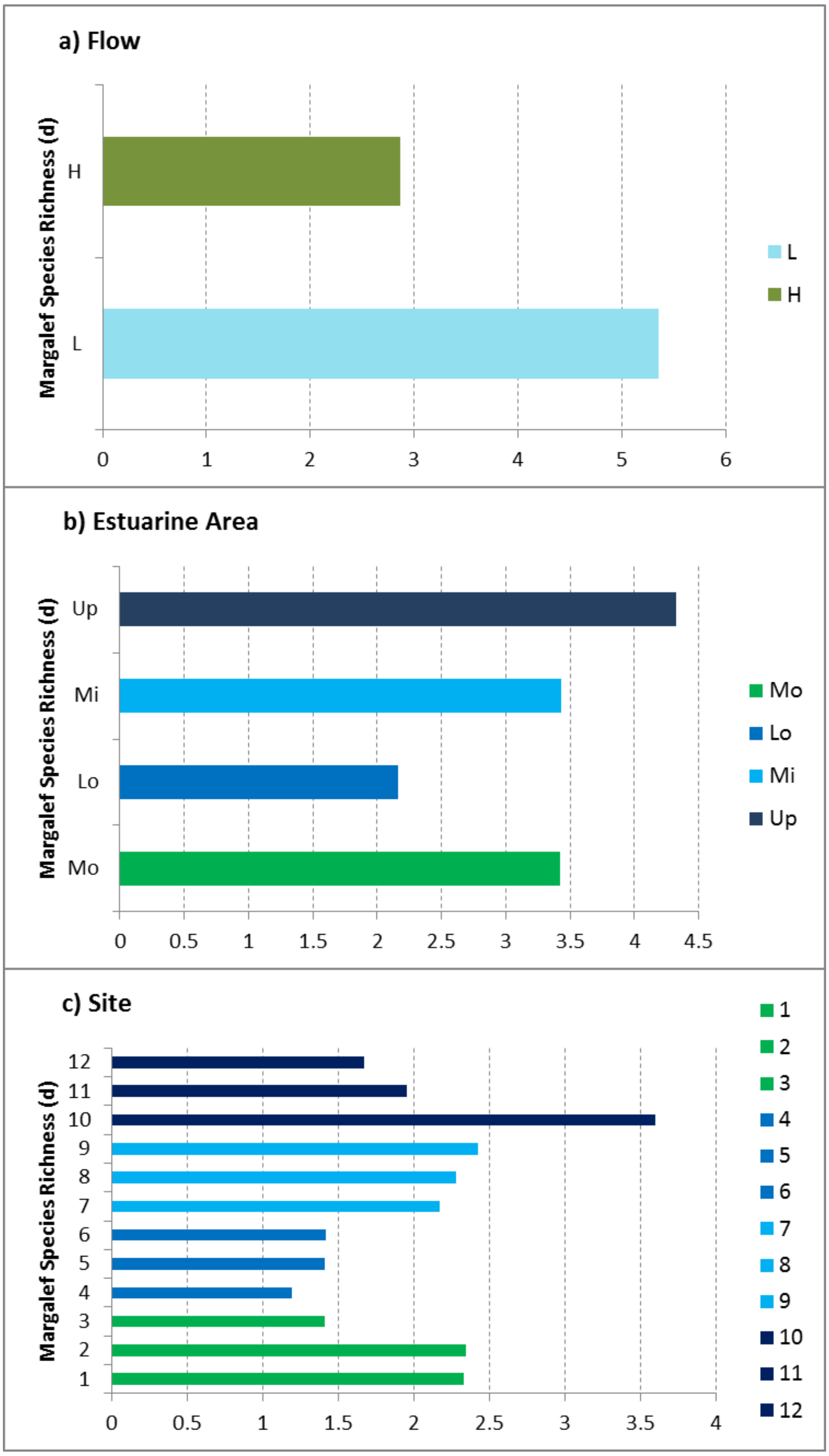


Figure 7.15. Differences in Margalef Species Richness (d) at each factor level ('flow', 'estuary reach' and 'site') in the Zinkwazi Estuary.

Multivariate classification and ordination

To statistically verify the macrobenthic community analyses at the spatial (*site*, *estuary reach*) and temporal (*flow period*) factor levels, abundance models were set up using the data from 12 sites over the two surveys. The Bray-Curtis Similarity co-efficient was applied on transformed data and the similarity matrix put through ordination analysis (Section 7.1). The two dimensional result of the NMDS ordination shows that samples (x5 replicates for each of 12 sites) were plotted separately for each flow survey. The low flow survey being interesting in that a relatively strong estuarine gradient from lower reaches to the head of the Zinkwazi is shown (Figure 7.16). However, site 1 does not fit the pattern, being more closely associated with sites 9 and 10. Site 1 during the high flow survey was the least similar to samples collected during the same period. Sites 10-12 were also less similar to other stations in the system. Coding according to estuarine reach also revealed an unclear pattern. The resultant NMDS plot of estuarine reach is therefore not depicted. Figure 7.16 shows a plot of the means of samples per site as an inset to investigate if the replicate samples collected per station were variable in their capacity to typify a particular site. This was not the case. The NMDS ordination showed that site 1 at the mouth of the Zinkwazi is likely an unstable, unfavourable environment for taxa to settle and become productive. Also, the site is inhabited by at least two taxa in this study (Nematoda and *Ceratonereis keiskama*) that do not occur further into the system.

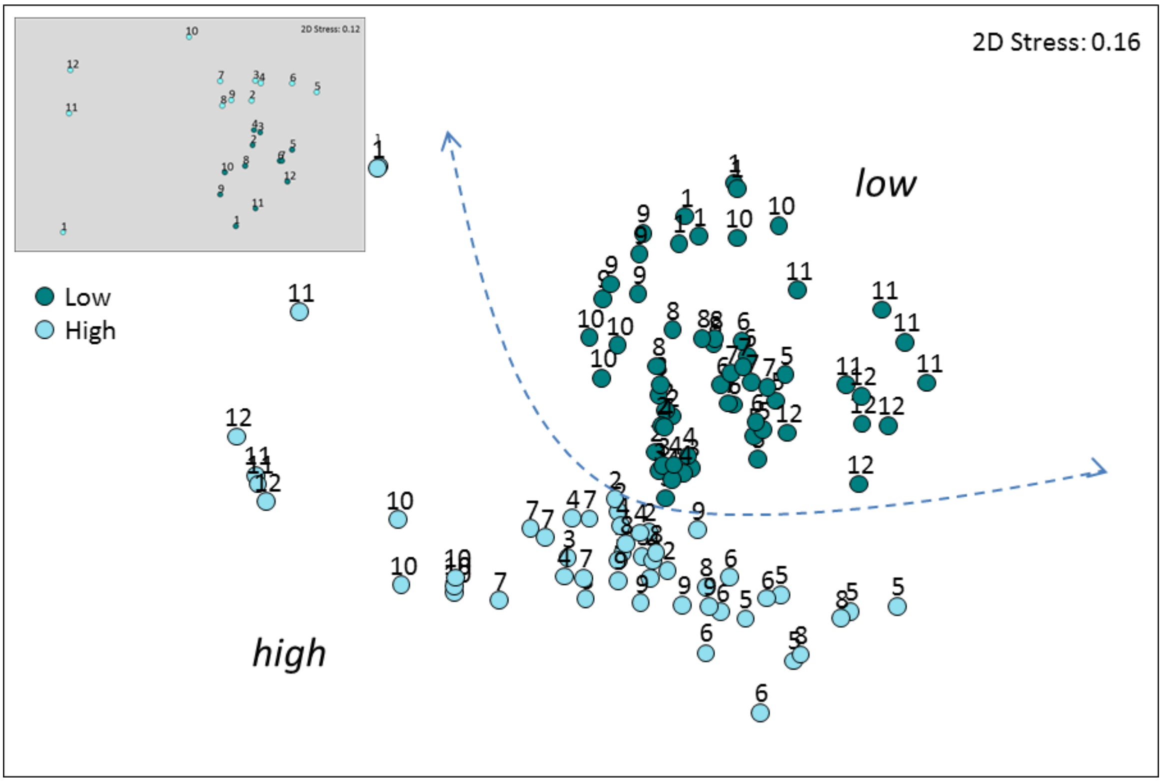


FIGURE 7.16. TWO DIMENSIONAL RESULT OF NMDS ORDINATION OF ABUNDANCE (PER M^{-2}) OF MACROBENTHOS COLLECTED AT TWELVE SITES (FIVE REPLICATES) IN THE ZINKWAZI ESTUARY DURING LOW AND HIGH FLOW. INSET DEPICTS THE MEAN OF FIVE REPLICATES PER STATION AND ALSO THAT HIGH AND LOW FLOW COMMUNITIES WERE DIFFERENT.

Analysis of similarity between factors: 'flow period', 'estuarine area' and 'site'

Analysis of similarity to test for dissimilarity between *flow* periods, *estuary area* and *sites* showed significant differences at all factor levels (Table 7.17). However, all R statistics were relatively low (<0.500) suggesting a large amount of variability amongst replicates testing the relevance of factors. Also, little confidence should be placed on *estuary area* as a significant factor as the global test statistic was particularly low (R<150) as were individual pairwise comparisons. Such results posit that intrasite variability amongst samples was equal, if not higher than intersite comparisons (Clarke & Warwick 2001). Pairwise tests per site yielded some significant dissimilarities between sites, yet others could not on the basis of data collected here, be discerned from each other. For example, site 1 was significantly different from sites 2-7, 10, but site 6 was not different in terms of macrobenthic species, abundance distribution or a combination of these factors from sites 5, 7-9 (Table 7.17).

TABLE 7.17. ANALYSIS OF SIMILARITY (ANOSIM) BETWEEN SAMPLES AGGREGATED AT FACTOR LEVELS OF 'FLOW PERIOD' (LOW/HIGH), 'ESTUARY AREA' (MOUTH, LOWER, MIDDLE, UPPER) AND 'SITE' (1-12) IN THE ZINKWAZI ESTUARY. SIGNIFICANT TEST STATISTICS TAKEN AT P<0.05 FOR GLOBAL TEST OF FACTOR AND INDIVIDUAL PAIRWISE COMPARISONS, WHERE >2 LEVELS OF THE FACTOR EXIST. FOR SITE PAIRWISE COMPARISONS ONLY SIGNIFICANT TESTS WITH R>0.500 PRESENTED. NON-SIGNIFICANT TESTS PRESENTED AT END OF TABLE.

Global Test using Factor '*Flow Period*' (**Low/High**)		
Sample statistic (Global R):		0.449
Significance level of sample statistic:		*p<0.05*
Global Test using Factor '*Estuary Area*' (**Upper/Middle/Lower/Mouth**)		
Sample statistic (Global R):		*0.124*
Significance level of sample statistic:		*p<0.05*
Pairwise Tests	*R*	*Significance*
Groups	*Statistic*	*Level %*
Mouth vs Lower	0.054	*p>0.05*
Mouth vs Middle	-0.031	*p>0.05*
Mouth vs Upper	0.213	*p>0.05*
Lower vs Middle	0.028	*p>0.05*
Lower vs Upper	0.389	*p<0.05*
Middle vs Upper	0.078	*p>0.05*
Global Test using Factor '*Site*' (**1-12**)		
Sample statistic (Global R):		*0.405*
Significance level of sample statistic:		*p<0.05*
Pairwise Tests	*R*	*Significance*
Groups	*Statistic*	*Level %*
1 vs 2	0.771	*p<0.05*
1 vs 3	0.794	*p<0.05*
1 vs 4	0.792	*p<0.05*

1 vs 5	0.691	*p<0.05*
1 vs 6	0.534	*p<0.05*
1 vs 7	0.591	*p<0.05*
1 vs 10	0.534	*p<0.05*
2 vs 10	0.551	*p<0.05*
2 vs 11	0.680	*p<0.05*
2 vs 12	0.718	*p<0.05*
3 vs 5	0.532	*p<0.05*
3 vs 9	0.554	*p<0.05*
3 vs 10	0.565	*p<0.05*
3 vs 11	0.716	*p<0.05*
3 vs 12	0.714	*p<0.05*
4 vs 5	0.503	*p<0.05*
4 vs 9	0.577	*p<0.05*
4 vs 10	0.603	*p<0.05*
4 vs 11	0.716	*p<0.05*
4 vs 12	0.718	*p<0.05*
5 vs 10	0.651	*p<0.05*
2 vs 3	0.125	*p>0.05*
3 vs 4	0.039	*p>0.05*
5 vs 6	0.055	*p>0.05*
5 vs 8	0.124	*p>0.05*
6 vs 7	0.142	*p>0.05*
6 vs 8	0.115	*p>0.05*
6 vs 9	0.127	*p>0.05*
8 vs 9	0.146	*p>0.05*
11 vs 12	0.047	*p>0.05*

Factor classification based on species assemblages

Taxonomic discrimination between *surveys* and estuarine *sites* and *areas* was conducted through SIMPER analysis. The similarity percentages of all taxa typifying each of these test conditions are presented in Tables 7.18 and 7.19. Only taxa representative of >75% cumulative abundance to the test factor are presented. Low flow conditions were typified by six taxa, five being truly estuarine. The largest contributor to overall factor similarity (and thus dissimilarity to other conditions i.e. high flow) was the polychaete *Prionospio multipinnulata*. Although still a discriminating taxon for the high flow condition, the most important discriminating macrobenthic taxon was Oligochaeta sp.1 (Table 7.18). *Prionospio multipinnulata* also dominated the lower middle and upper reaches of the Zinkwazi Estuary.

TABLE 7.18. CONTRIBUTION OF MOST IMPORTANT TAXA TO THE AVERAGE SIMILARITY OF A FACTOR LEVEL. SAMPLES AGGREGATED AT FACTOR LEVELS OF 'FLOW PERIOD' (LOW/HIGH) AND 'ESTUARY AREA' (MOUTH, LOWER, MIDDLE, UPPER) IN THE ZINKWAZI ESTUARY. ONLY TAXA CONTRIBUTING TO >75% OF THE CUMULATIVE ABUNDANCE OF A FACTOR LEVEL ARE PRESENTED AND HIGHEST CONTRIBUTING TAXON PER FACTOR LEVEL IS INDICATED.

	Factor					
	Flow		Estuary Area			
	Low	High	Mouth	Lower	Middle	Upper
Ave. Similarity	50.08%	32.39%	33.26%	47.77%	41.71%	21.82%
Cumulative % Contribution to Tot. Abund.	T=78.03	T=83.22	T=84.59	T=81.00	T=76.53	T=75.12
Prionospio multipinnulata	13.69	7.16	6.13	17.01	11.02	3.43
Apseudes digitalis	6.99		4.71	8.84	3.03	
Desdemona cf ornata	6.03					
Corophium triaenonyx	6.02					1.5
Dendronereis arborifera	3.19	7.00	5.33	8.09	7.75	
Oligochaeta sp.1	3.16	8.87	6.54		6.67	2.86

Thirteen taxa contributed to the average similarity of comparisons between sites (Table 7.19). Again *Prionospio multipinnulata* was the most important typifying taxon for sites 5,6,8,9,11 and 12. *Ceratoneires keiskama* had the highest average similarity of contributing species at site 1 (7.31%), Oligochaete sp. 1 at sites 2 , 3 and 10 (15.81%, 16.70%, 15.28%), *Apseudes digitalis* at site 4 (23.47%) and *Dendronereis arborifera* at site 7 (11.73%).

Notable to both surveys is the complete absence of the estuarine amphipod *Grandidierella lignorum* in the system, which is common in many other TOCEs especially during the low flow, closed phase. Day (1981) reported that *G.lignorum* is an estuarine species, endemic to southern Africa, occurring predominantly in muddy substrata. This species has the ability to extend its distribution to freshwater, which is why it is also found in many of the Zululand coastal lakes. *Grandidierella lignorum* forms that part of the invertebrate benthic community having the ability to burrow into sand and mud substrata of estuaries and coastal lakes (Blaber et al. 1983). Likewise, *Corophium triaenonyx* may extend its distribution to areas of low salinity and both amphipods have been reported as part of the relict estuarine fauna of Zululand coastal lakes. *Grandidierella lignorum* and *C triaenonyx* are able to colonise a wide range of sediment types, but do prefer muddy sand. Both can co-habit the same niche but *G.lignorum* is generally numerically more abundant in many systems (Mackay 1996, Stow 2011).

The polychaete *Ceratonereis keiskama* is part of the endemic estuarine species component of southern Africa and is common in muddy substrata in low salinities. It also occurs in Lake Sibaya and the St Lucia system (Day 1981), and prefers to build burrows in sediments with a low organic content. This species was found exclusively in the lower reaches of the estuary, where the lowest organic contents of sediments were recorded (Section 6). Reavell & Cyrus (1989) reported the occurrence of the tanaid *Apseudes digitalis* in sandy and organically-rich mud substrata from the fresh water coastal lakes in Zululand. This species also has a tubicolous habitat and is usually associated with submergent macrophytes (Reavell & Cyrus 1989). This would explain the abundance of this species into the middle and upper reaches of the estuary where there was a large amount of detritus.

TABLE 7.19. CONTRIBUTION OF MOST IMPORTANT TAXA TO THE AVERAGE SIMILARITY OF A FACTOR LEVEL. SAMPLES AGGREGATED AT FACTOR LEVELS OF 'SITE' (1-12) IN THE ZINKWAZI ESTUARY. ONLY TAXA CONTRIBUTING TO >75% OF THE CUMULATIVE ABUNDANCE OF A FACTOR LEVEL ARE PRESENTED AND HIGHEST CONTRIBUTING TAXON PER FACTOR LEVEL IS INDICATED.

	Factor											
	Site											
	1	2	3	4	5	6	7	8	9	10	11	12
Ave. Similarity	22.75%	66.70%	62.28%	71.05%	49.83%	47.82%	47.99%	46.45%	49.95%	42.22%	20.92%	18.05%
Cumulative % Contribution to Tot. Abund.	T=75.16	T=79.26	T=84.60	T=80.82	T=82.23	T=82.98	T=80.24	T=76.23	T=78.23	T=76.19	T=88.88	T=73.23
Prionospio multipinnulata	2.80	13.02			30.72	20.35	5.95	18.50	13.26	1.87	5.97	5.91
Apseudes digitalis			14.09	23.47	4.93	4.64	10.23					
Desdemona cf ornata								2.95				2.29
Corophium triaenonyx	2.78							3.09	3.29		3.74	
Dendronereis arborifera		8.92	13.11	10.91		9.84	11.73		10.66	2.32		
Oligochaeta sp.1		15.81	16.70	14.61		4.85	6.34	5.15	7.91	15.28		
Tarebia granifera									3.96	12.7	5.59	
Oligochaeta sp.2		15.12	14.22	8.43	5.32		4.25	5.72				
Ceratonereis keiskama	7.31											
Brachidontes virgilae	2.37											
Grandidierella sp. female	1.84											
Prionospio cf. multipinnulata											3.30	2.67
Chironomidae sp.3												2.35

As mentioned *Prionospio multipinnulata* is previously undocumented as a species in KZN estuaries, thus little is known here of its natural habits. However, species in the Genus are known as indicators of perturbation and are characterised as a short-lived, opportunistic invertebrates usually dominating the fauna in areas of organic pollution (Wolff 1983). They are second stage colonists, increasing in abundance with a decline in the abundance of first stage opportunists, after a disturbance (Long & Poiner 1994).

Linking Biotic Results to Abiotic Variables

The structure and composition of the benthos is determined by a number of interacting factors, including biotic interactions and the water quality characteristics of the estuary. A single independent physico-chemical parameter cannot be considered responsible for affecting the nature of the benthos. This is because there is a strong interrelationship between certain physico-chemical parameters, which are usually 'cause and effect' type situations where a change in a certain parameter causes either a direct or indirect effect on another.

Spearman's rank correlation analyses of Zinkwazi sediment characteristics and bottom physico-chemistry relative to the macrobenthos distribution and abundance data showed that combinations of eight abiotic variables were responsible for macrobenthic distribution patterns in this study (Table 7.20). The parameters were temperature (^{o}C), salinity (psu), depth (m), dissolved oxygen (mg/L) and the sediment grain size distribution characteristics of %gravel, %coarse sand, %mud and %sediment organics. The highest correlation co-efficient (ρ = 0.784) was a combination of depth (m), dissolved oxygen (mg/L), %gravel, %coarse sand and %sediment organics (Table 7.20). The next four combinations of best matches are also presented, given that the correlation co-efficients were close in value (ρ = 0.783 and ρ = 0.780). Variations of the eight parameters occur with each combination to yield the next best global maximum co-efficient value. However, only three parameters viz. depth (m), dissolved oxygen (mg/L) and %gravel were consistently put through each test model. These can then be said to be the driver variables of macrobenthos in the Zinkwazi Estuary during this study. Depth is presumably a driver of distribution in that the system fills and purges as the sandbar at the mouth is opened. If this is allowed to occur consistently naturally, the fauna residing there will be resilient and tolerant to these conditions having timed various biological cycles to these events. Unnatural breaching would clearly result in a severe disruption of natural functioning. Dissolved oxygen as a driver, points to the occurrence of hypoxic conditions in the system. This was measured at several sites along the system during this study (see Section 6), in particular in bottom waters upstream in the system.

TABLE 7.20. COMBINATIONS OF ENVIRONMENTAL VARIABLES YIELDING THE BEST MATCHES OF ZINKWAZI ESTUARY ABIOTIC (PHYSICO-CHEMICAL/SEDIMENT) AND BIOTIC (MACROBENTHOS) SIMILARITIES AS MEASURED BY SPEARMAN'S RANK CORRELATION (Ρ). OVERALL OPTIMUM IS A COMBINATION OF FIVE VARIABLES AT Ρ = 0.784.

No. Environmental Variables	5	5	5	4	5
Temperature (^{o}C)		X			
Salinity psu					X
Depth (m)	X	X	X	X	X
Dissolved Oxygen (mg/L)	X	X	X	X	X
Gravel (%)	X	X	X	X	X
Coarse Sand (%)	X		X		
Mud (%)		X	X	X	X
Sediment organics (%)	X				
Correlation Coefficient (ρ)	0.784	0.783	0.783	0.783	0.780

The effect of a changing salinity on this longitudinal, primarily closed system is clear. As waters are more saline, estuarine and even marine organisms will move to reaches that fulfil their salinity tolerance requirements. The opposite will occur, when the Zinkwazi is isolated from the marine environment for long periods resulting in habitat 'shrinkage' which will displace those organisms with low tolerance ranges. Relative to other TOCEs in KZN, many of which have been changed through poor management, inappropriate landuse or pollution, the Zinkwazi still retains some semblance of estuarine function and is represented and dominated by estuarine species. However, the fact remains that it is not in a fully healthy state as evidenced by its susceptibility to invasive species (*Tarebia granifera*) and will be more so if unfettered use of the system (including indirectly through agriculture etc.) is not remediated.

Ichthyofauna

Historical information

Few documented studies of the fish fauna of the Zinkwazi Estuary exist. The systems was sampled "on an irregular basis" between January 1971 and March 1972 (Wallace and van der Elst 1975). Only two species were noted to occur; the mullets *Liza dumerilii* and *Mugil cephalus*. Species lists provided in the Wallace and van der Elst report were probably limited to the common estuarine species and therefore might have omitted occurrences of less common fishes. However it is noteworthy (and perplexing) that many species reported in other systems and that should have occurred in the Zinkwazi were not listed. Begg (1978) cited personal communication with Wallace which referred to "impressive" quantities of the mullet *Liza macrolepis* in the system in November 1976. Begg himself later surveyed the estuary on a monthly basis from September 1979 to September 1980 and in January, April and July 1981 (Begg 1984a). Over the course of these surveys 39 fish species were sampled, with abundance dominated by *Oreochromis mossambicus*, *Gilchristella aestuaria* and three species of estuarine goby (Table 7.21). While this is much more typical of an estuarine fish community than that reported by Wallace and van der Elst (1975) Begg's sampling relied on a narrow beam trawl (1 m width) which is suboptimal for sampling fish in estuaries. As noted above this would have resulted in the system being under-sampled for fishes and in a bias in relative abundance of species. The high frequency of sampling over a prolonged period, however, partially makes negates up the issue of under-sampling. Harrison (2003) sampled the Zinkwazi in 1998 using seine and gill nets (identical to those used in the present study). Thirty-one species were identified and the community was dominated in terms of abundance by *Valamugil cunnesius*, *Ambassis ambassis*, *Pomadasys commersonnii*, *Gerres methueni* and *Oreochromis mossambicus*.

Table 7.21 Fish species recorded from the Zinkwazi Estuary between September 1979 and July 1981 (Begg, 1984a) and in February 1999 (Harrison 2003). Catch data modified to be presented as a percentage of total catch.

		Sep 1979 – Jul 1981	Feb 2010
Family	**Species**	**Percentage of catch (%)**	
Ambassidae	*Ambassis ambassis*	4.4	24.1
	Ambassis dussumieri		1.5
	Ambassis natalensis	1.5	
Anguillidae	*Anguilla bicolor bicolor*	<0.1	
Bothidae	*Bothus pantherinus*	0.4	
Carangidae	*Caranx ignobilis*		1.0
	Caranx sexfasciatus		0.1
	Trachinotus botla	<0.1	
Cichlidae	*Oreochromis mossambicus*	25.1	3.6
Clariidae	*Clarias gariepinus*		0.6
Clupeidae	*Gilchristella aestuaria*	22.2	2.9
Cynoglossidae	*Paraplagusia bilineata*	<0.1	
Eleotridae	*Eleotris fusca*	0.4	
Elopidae	*Elops machnata*	0.1	0.1
Gerreidae	*Gerres methueni*	0.7	4.7
Gobiidae	*Caffrogobius natalensis*	<0.1	

		Sep 1979 – Jul 1981	Feb 2010
Family	**Species**	**Percentage of catch (%)**	
	Favonogobius reichei	0.1	
	Glossogobius biocellatus	<0.1	
	Glossogobius callidus		0.8
	Glossogobius giurus	7.9	0.3
	Oligolepis acutipennis	5.4	0.6
	Oligolepis keiensis		0.8
	Oxyurichthys opthalmonema		0.1
	Psammogobius knysnaensis	10.4	
Haemulidae	*Pomadasys commersonni*	3.1	6.1
	Pomadasys kaakan	0.6	0.4
Leiognathidae	*Leiognathus equula*	0.5	1.3
Lutjanidae	*Lutjanus argentimaculatus*	0.1	0.1
	Lutjanus fulviflamma	0.1	
Monodactylidae	*Monodactylus argenteus*	<0.1	0.4
	Monodactylus falciformis	0.5	1.0
Mugilidae	Mullet fry		3.9
	Liza alata		2.6
	Liza dumerilii		1.0
	Liza macrolepis	0.1	0.7
	Liza richardsonii	0.2	
	Mugil cephalus	2.6	1.8
	Myxus capensis		1.7
	Valamugil buchanani	1.0	1.1
	Valamugil cunnesius	2.4	34.1
Muraenidae	*Thrysoidea macrura*	<0.1	
Platycephalidae	*Platycephalus indicus*	0.1	
Scorpaenidae	*Pterois volitans*	0.1	
Sillaginidae	*Sillago sihama*		0.1
Soleidae	*Solea bleekeri*	4.5	
Sparidae	*Acanthopagrus vegas*	0.2	0.7
	Rhabdosargus holubi	2.9	0.1
	Rhabdosargus sarba	0.7	
Syngnathidae	*Hippichthys heptagonus*	<0.1	
Teraponidae	*Terapon jarbua*	1.5	1.5
Tetraodontidae	*Arothron immaculatus*	<0.1	

Fish surveys in 2012/2013

Thirty-five species of fish were sampled in the Zinkwazi Estuary in the two surveys conducted in 2012 (low flow) and 2013 (high flow). Thirty-three species were sampled by seine net and ten were sampled by gill nets. Total numbers of different fish species sampled are shown in Figure 7.17. Marine migrant species dominated the number of taxa encountered. These were in fact predominantly marine estuarine dependent fishes. The functional group with the next highest number of species were estuarine breeders and residents. These were all small species, mostly gobies. Mozambique tilapia (*Oreochromis mossambicus*) was the only freshwater species sampled, although it did occur in relatively high numbers (Figure 7.17). Only four marine stragglers were sampled and they mostly occurred in low abundance.

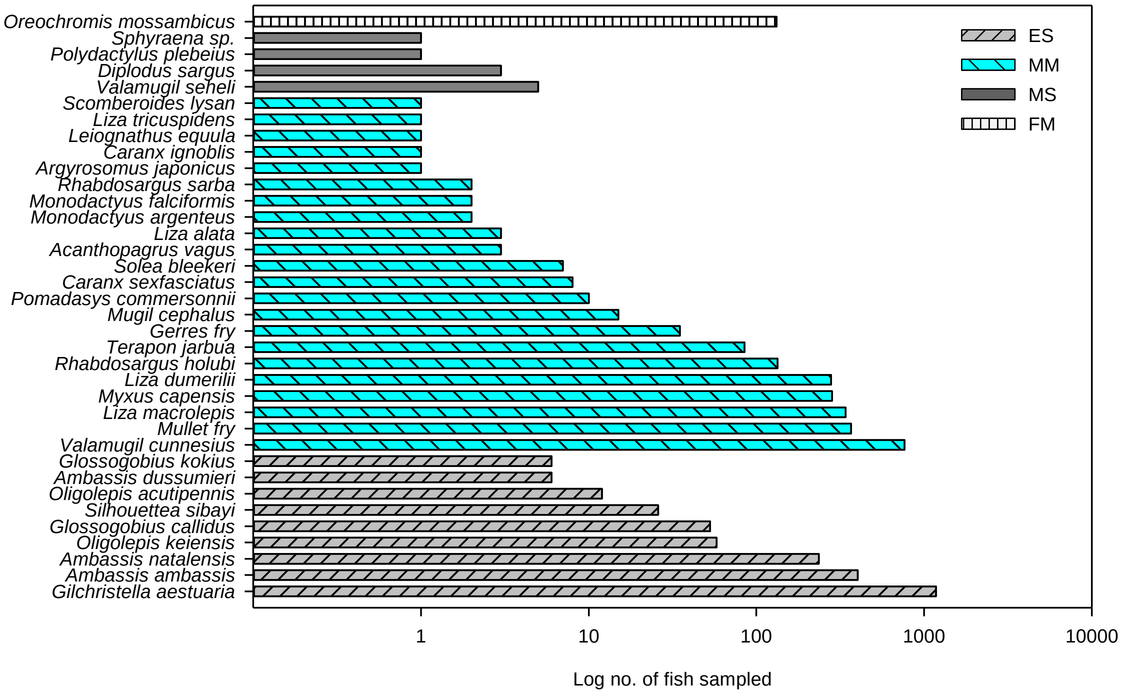


FIGURE 7.17. NUMBERS (LOG10) OF FISH SAMPLED IN THE ZINKWAZI ESTUARY BY ALL GEARS DURING LOW AND HIGH FLOW SEASONS. ESTUARINE USE FUNCTIONAL GROUP AS INDICATED IN TABLE 7.4 (ES = ESTUARINE SPECIES, MM = MARINE MIGRANT, MS = MARINE STRAGGLER, FM = FRESHWATER MIGRANT).

More species (31) were sampled in the high flow survey than in the low flow survey (24). Seine net catches were dominated numerically by *Gilchristella aestuaria* (mostly adults), *Valamugil cunnesius* (juveniles) and *Ambassis ambassis* (adults). These three species comprised over 50% the total seine net catch over the two surveys. They were consistently dominant in both low and high flow seasons although absolute and relative abundances of *G. aestuaria* in particular changed. In the low flow season *G. aestuaria* was by far the most abundance fish comprising 40% of seine net catches but in the high flow season it was the third most abundance fish and comprised 14% of the catch. Gill net catches were dominated by mullet with three species, *Valamugil cunnesius*, *Myxus capensis* and *Liza macrolepis*, comprising over 90% the total catch. *Valamugil cunnesius* dominated in both low and high flow seasons, comprising 43% and 78% of the catch respectively.

Seine net catches were dominated (>75%) by fishes in size classes between 30 and 60 mm SL. This was a reflection of the catch comprising predominantly small bodied estuarine species and young juvenile marine migrant species (Figure 7.18). Gill net catches were dominated (>75%) by size classes between 150 and 190 mm SL, reflecting a dominance of late juvenile and sub-adult marine migrant species.

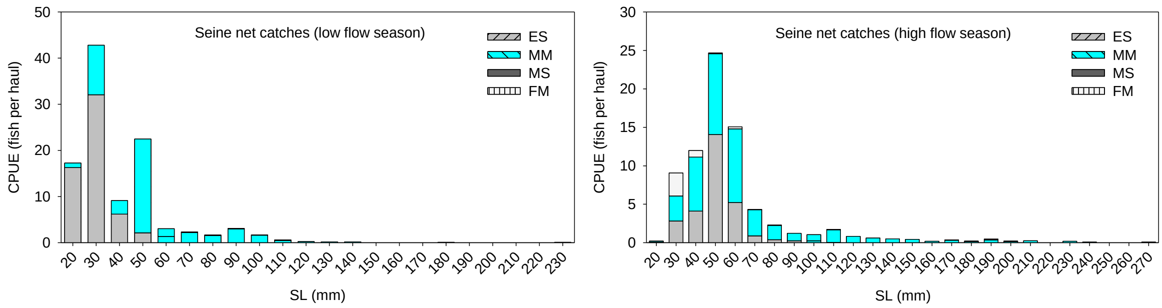


FIGURE 7.18. SEINE NET CATCHES (CPUE) OF SIZE CLASSES OF FISHES CAUGHT IN THE LOW FLOW (LEFT) AND HIGH FLOW (RIGHT) SEASONS IN ZINKWAZI ESTUARY. ESTUARINE USE FUNCTIONAL GROUP AS INDICATED IN TABLE 7.4 (ES = ESTUARINE SPECIES, MM = MARINE MIGRANT, MS = MARINE STRAGGLER, FM = FRESHWATER MIGRANT).

Considerable spatial variability was evident in total catches of fish (by both seine and gill net) with little consistency over the two surveys conducted with the exception that high abundances were recorded near the mouth. Much of the variability in seine net catches was brought about by catches of the numerically dominant families noted above (Mugilidae, Clupeidae and Ambassidae). These are shoaling species and when present in catches they typically occur in high abundance. Mugilids (seven species) generally occurred in highest numbers in the lower reaches. They were distributed throughout the system in both surveys, but occurred more abundantly in the middle and upper reaches in the high flow season compared to their occurrence in these reaches in the low flow season. Clupeids (represented solely by *Gilchristella aestuaria*) occurred throughout the system at all sites in the low flow season. In the high flow season, overall abundance was markedly reduced and frequency of occurrence was sporadic and limited to only 50% of sites sampled (although these were across the whole system, i.e. in all reaches). In the low flow season Ambassids were sampled only in the lower reaches of the estuary. They occurred more frequently and in all reaches of the system in the high flow season. All three South African species of Ambassid were present in the high flow season, but *Ambassis ambassis* dominated (60% abundance) and occurred at almost every site sampled. *Ambassis dussumieri*, by way of contrast, occurred only at the mouth in very low abundance (<2%). In the low flow season *Ambassis natalensis* was the most abundance Ambassid (>96%) and *A. dussumieri* occurred at one site only and in very low abundance (<4%). *Ambassis ambassis*, dominant in the high flow season, was not sampled by seine net in the low flow season. A single specimen was, however, sampled by gill net during the low flow season.

In the low flow *Liza macrolepis* dominated gill net catches in the lower reaches while *Valamugil cunnesius* and to a lesser extent *Myxus capensis* were abundant in the middle and upper reaches. In the high flow season *V. cunnesius* was dominant throughout. Very few species other than mullet were sampled by gill net and they occurred in low relative abundance. In the low flow season these were limited to *Caranx ignoblis* and *Ambassis ambassis*, and in the high flow season *Argyrosomus japonicas*, *Rhabdosargus holubi* and *Oreochromis mossambicus*.

In comparison to gill nets, a relative abundance of species other than mullet were sampled using seine net. Analysis of these catches omitting shoaling families that occurred in abundance (Mugilidae, Ambassidae and Clupeidae, see above) is useful. The abundance of these species masked trends in other species. Very similar absolute and relative abundances estuarine species and marine migrants occurred in the lower and upper reaches of the estuary in the low and high flow season. Catches in the middle reaches of the system however, varied markedly, with freshwater migrants especially more abundant during the high flow survey (Figure 7.19). This was attributable to an abundance of young *Oreochromis mossambicus* (SL 30 - 40 mm) sampled at a single site in the middle reaches of the estuary. Estuarine species were dominated by small gobies, primarily *Glossogobius callidus* in the low flow season and *Oligolepis keiensis* in the high flow season. In the high flow season more marine migrant species occurred and they penetrated further up the system than in the low flow seasn. During both surveys, however, marine migrant species were dominated by *Rhabdosargus holubi*. This species was represented by newly recruited individuals in the high flow season and size classes ranged from 30 to 110 mm SL. In the low flow season only older juveniles were sampled (80 to 100 mm SL).

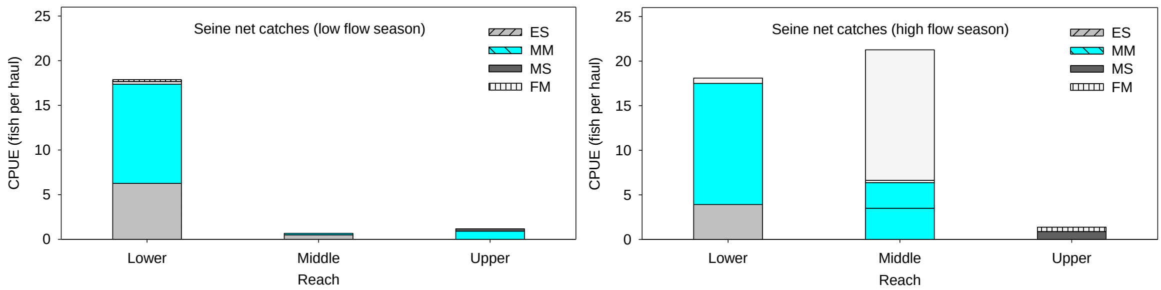


FIGURE 7.19. SEINE NET CATCHES OF FISHES (CPUE, MUGILIDAE, AMBASSIDAE, CLUPEIDAE OMITTED) IN THE LOW FLOW (LEFT) AND HIGH FLOW (RIGHT) SEASONS IN ZINKWAZI ESTUARY. ESTUARINE USE FUNCTIONAL GROUP AS INDICATED IN TABLE 7.4 (ES = ESTUARINE SPECIES, MM = MARINE MIGRANT, MS = MARINE STRAGGLER, FM = FRESHWATER MIGRANT).

Physico-chemical conditions in the Zinkwazi Estuary are not discussed in great detail here, having been reported upon in a stand-alone section of this report (Section 6). Several key findings are, however, worth noting from measurements made in mid-depth waters concurrent with the fish sampling. Limited discussion of physico-chemistry in mid-depth waters is warranted here as it pertains to the actual conditions that fishes were sampled in. Salinity, turbidity and dissolved oxygen are water quality parameters best understood in the context of estuarine biology and discussion is restricted to these parameters.

Salinity was present throughout the system in both low and high flow seasons with water in the lower reaches more saline than those in the upper reaches. This is an expected pattern and is the result of salt water intrusion on a tidal basis under mouth open conditions and during periods of berm overwash. Barrier overwash during mouth closed conditions appears to occur frequently in the Zinkwazi Estuary. It was observed during surveys conducted during this study, and also reported by Begg (1984b) who noted that the sandbar at the mouth of the system was at a lower elevation that at other TOCEs along the KwaZulu-Natal coast. Higher salinities in the high flow period are most likely the result of high mouth open frequency during mouths of higher river flow. Under conditions of very high flow (freshettes and floods) low salinity, and even freshwater, conditions are likely to exist throughout the system.

Salinities recorded in mid-depth waters in low (2012) and high flow (2013) surveys were low (mean values of 3.5 and 4.2 psu respectively) compared to values reported from previous surveys. Begg (1984a) reported mean values of 20.8 (surface waters) and 21.2 psu (bottom waters) over the course of his study spanning 23 months from September 1979 to July 1981. Harrison (2003) visited the system during the summer of 1999 and reported a mean salinity (surface and bottom waters) of 12.3 psu. It is clear that Begg's sampling was restricted to the lower reaches of the estuary, and it is likely that Harrison sampling effort was as well. Harrison's data are from a single sampling event and might be regarded as an artefact of the mouth being open, low freshwater flows and a spring high tide. Begg's (1984a) results however, suggest consistently higher salinities than those reported from the 2012/2013 surveys, even limiting comparison to salinities from the lower reaches of the estuary. Changed management of the estuary mouth might be partially responsible. In previous years the sandbar was frequently breached artificially when backfill water levels threatened to flood sugarcane fields or peripheral properties (Begg 1978). This has practice has subsequently changed and authorisation is now required for artificial breaching (Morant & Quinn 1999).

Salinities in the Zinkwazi Estuary are typical of TOCEs along the KwaZulu-Natal coast. Salinities in subtropical TOCEs are typically lower in winter when these systems are predominantly closed than during summer when higher river flows result in longer and more frequent mouth open phases. Salinities can also be highly variable and strongly related to depth. South African estuarine fishes are generally more tolerant of low rather than high salinity conditions (Whitfield et al. 1981). Salinities during both the low (2012) and the high flow (2013) fish surveys would certainly have been supportive of all estuarine species that occur in KwaZulu-Natal and most marine estuarine dependant fishes as well. However, few stenohaline freshwater or marine fishes would have tolerated salinities present. Several species reported in the system by Begg (1984a) but not sampled during the most recent fish surveys were marine stragglers. These included *Trachinotus botla*, *Thrysoidea macrura*, *Pterois volitans* and *Arothron immaculatus*. These fishes were generally sampled in low relative abundance in the system but their presence might have been related to higher salinities apparently prevalent during Begg's surveys.

Turbidities recorded in mid-depth waters in low and high flow surveys in 2012 and 2013 respectively were also lower than those reported previously, although difference are less marked than was the case with salinity. Turbidities in the mid-depth waters in 2012/2013 surveys averaged 11 NTU in the winter low flow period and 24 NTU in the summer high flow period. Cyrus (1988a) reported an average turbidity of 29 NTU for the Zinkwazi Estuary. Begg (1984a) measured water transparency (Secchi depth) rather than turbidity. Values in water clarity varied widely. Using Cyrus' (1988b) formula to convert these Secchi depths to turbidities suggested a range of <1 to 128 NTU. On average turbidities were approximately 35 NTU. Harrison (2003) reported an average turbidity of 58 NTU from the Zinkwazi surface waters in the summer of 1999. As with salinities, the ranges present in the Zinkwazi are well within the tolerances of expected fish species. Turbidities at which changes in fish assemblages from KwaZulu-Natal estuaries are most obvious are 10, 50 and 80 NTU (Cyrus & Blaber 1987a, b). In a regional context the Zinkwazi Estuary is a semi-turbid estuary (mean turbidity within the range of 10 to 50 NTU).

Dissolved oxygen concentrations in the Zinkwazi mid-depth waters in the 2012 low flow period were generally within a range typical of healthy estuarine waters. Of note however, were some elevated recordings (>9 mg/L) at the mouth of the system. These levels are indicative of high photosynthetic activity as a result of algal blooms which in turn are symptomatic of excessive nutrient inputs. In the high flow survey even higher measurements were recorded over a wider area in the system's lower reaches. The strong positive relationship between pH and dissolved oxygen concentration is compelling evidence of dissolved oxygen concentrations being closely related to algal activity in the estuary. At the same time as increasing oxygen concentrations in water, photosynthesis decreases the amount of free carbonic acid and consequently raises the pH (Skirrow 1965, Wetzel 1983).

High oxygen concentrations and algal blooms have previously been noted in the Zinkwazi (Begg 1978, 1984a). Several potential sources of nutrient input exist. These include runoff from fertilised sugarcane fields surrounding the estuary and in the greater catchment. Sewage might also play a role, either via groundwater that might be contaminated from septic tanks directly adjacent to the estuary, or as inflow from the sewage treatment plant on the south bank of the estuary. Supporting evidence for the latter comes from a history of bacteriological water quality issues in the system (Begg 1978, 1984a) and the fact that algal blooms in recent surveys have been noted in the lower reaches.

Low oxygen concentrations have also been historically problematic in the Zinkwazi Estuary. This has generally been attributed to pollution of the system by dunder, which has a high chemical and biological oxygen demand (Begg 1978, 1984a). Algal blooms can also contribute to low oxygen tensions in estuarine waters, especially at night when photosynthesis ceases. The extent to which this might be occurring in recent times is unknown. Low oxygen concentrations were evident in the bottom waters of several deep sections of the estuary in the 2012/2013 surveys. Algal decay is almost certainly contributing to this, but decay of terrestrial (allochthonous) inputs is most likely playing a more important role. Low oxygen levels are not uncommon in KwaZulu-Natal TOCEs (Begg 1984a, Harrison 2003) particularly in the deep sections of systems protected from wind and where waters are stagnant. This is often brought about by the decay of leaf litter and in especially prevalent in systems. Anthropogenic inputs often exacerbate the situation. As noted previously dissolved oxygen concentrations ≥5 mg/L are generally considered to be protective of aquatic life while concentrations below 4 mg/L can have severe effects on aquatic biota, especially if they persist (USEPA 2003). Most South African estuarine fishes are probably quite tolerant of depressed oxygen concentrations. However fish kills related to low oxygen events are becoming increasingly common in KwaZulu-Natal estuaries. Most often this appears to be related to anthropogenic inputs of nutrients or sewage.

Fish abundance and diversity in Zinkwazi Estuary is high. This has historically been the case. In a comparative study of some sixty TOCEs in KwaZulu-Natal Begg (1984b) found the Zinkwazi to support the highest number of species (fish, prawns and crabs, omitting the Mgeni Estuary which is predominantly open and was much more comprehensively sampled than all other study systems). This is attributable to the relatively large size of the estuary, mouth open and overwash frequency, salinity regime and habitat complexity. The current study and those of previous researchers (Begg 1984a, Harrison 2003) indicate that the system is functioning well as an estuarine nursery for a wide range of marine spawned fishes. Larger crustaceans (such as Penaeid swimming prawns) are also abundant and no doubt form an important food resource for larger marine migrant species, such as *Pomadasys commersonnii*, *Caranx* spp., *Rhabdosargus* spp. and *Argyrosomus japonicus*. These species are important in recreational line fisheries both in the estuary and along the adjacent coastline. Together with other fishes that occur in the Zinkwazi they are also becoming increasingly important in coastal subsistence fisheries.

Several fish species sampled are also of conservation significance. The IUCN red list (IUCN 2013) for South African brackish water fishes contains at least ten species of fish sampled in the Zinkwazi during the two surveys conducted as part of this study. An additional five IUCN listed species have been sampled previously in the system (Begg 1984a, Harrison 2003) and six others are likely to occur but have not been reported from the Zinkwazi. Most of these fishes are listed as being of Least Concern by the IUCN Red List Categories and Criteria Version 3.1 (IUCN 2012) and are in fact locally abundant. Several however, could be regarded as locally rare and/or threatened (Weerts et al. 2014) and include many of the small estuarine fishes (e.g. *Silhouettea sibayi*, *Oligolepis keiensis, Oligolepis acutipennis*, *Redigobius dewaali*).

This highlights the importance of developing a clear strategy and management plan for the Zinkwazi Estuary. The Zinkwazi is susceptible to development pressures. There is some history of water quality problems and with recent evidence of algal blooms indications are that the system is prone to future water quality degradation. This needs to be considered in management decisions pertaining to the estuary.

Avifauna

A bird list of estuary-associated species has been constructed for the Zinkwazi Estuary (K. Achtzehn) (Table 7.22). Fifty-one species have been recorded from the area. Most are piscivores or invertebrate feeders (19 and 17 respectively, with a further four species being a combination of both) with only eight species (mostly ducks and geese) feeding on vegetation (feeding guilds from dominant food source as identified by Hockey et al. (2005)).

TABLE 7.22. WATER-ASSOCIATED BIRDS PREVIOUSLY RECORDED FROM THE ZINKWAZI ESTUARY (SOURCE: K. ACHTZEHN, ZBRRA).

Genus and species	Common name		Genus and species	Common name
Actitis hypoleucos	Common sandpiper		*Egretta alba*	Great white egret
Actophilornis africanus	African jacana		*Egretta garzetta*	Little egret
Alcedo cristata	Malachite kingfisher		*Egretta intermedia*	Yellowbilled egret
Alopochen aegyptiaca	Egyptian goose		*Euplectes orix*	Red bishop
Anas sparsa	African black duck		*Fulica cristata*	Redknobbed coot
Anas undulata	Yellowbilled duck		*Gallinula sp.*	Moorhen
Anhinga rufa	Darter		*Halcyon senegaloides*	Mangrove kingfisher
Ardea cinerea	Grey heron		*Haliaeetus vocifer vocifer*	African fish eagle
Ardea goliath	Goliath heron		*Himantopus himantopus*	Blackwinged stilt
Ardea melanocephala	Blackheaded heron		*Ixobrychus minutus*	Little bittern
Ardea purpurea	Purple heron		*Megaceryle maximus*	Giant kingfisher
Ardeola ralloides	Squacco heron		*Mycteria ibis*	Yellowbilled stork
Bubulcus ibis	Cattle egret		*Nycticorax nycticorax*	Blackcrowned night heron
Burhinus vermiculatus	Water dikkop		*Pandion haliaetus*	Osprey
Butorides striata	Greenbacked heron		*Phalacrocorax africanus*	Reed cormorant
Calidris minuta	Little stint		*Phalacrocorax capensis*	Cape cormorant
Ceryle rudis	Pied kingfisher		*Phalacrocorax lucidus*	Whitebreasted cormorant
Charadrius hiaticula	Ringed plover		*Philomachus pugnax*	Ruff
Charadrius marginatus	Whitefronted plover		*Platalea alba*	African spoonbill
Charadrius tricollaris	Threebanded plover		*Plectropterus gambensis*	Spurwinged goose
Chilidonias leucopterus	Whitewinged tern		*Podica senegalensis*	African finfoot
Ciconia episcopus	Woollynecked stork		*Sarkidiornis melanotos*	Knobbilled duck
Circus ranivorus	African marsh harrier		*Sterna bergii*	Swift tern
Colymbus ruficollis	Dabchick		*Sterna caspia*	Caspian tern
Dendrocygna viduata	Whitefaced duck		*Threskiornis aethiopicus*	Sacred ibis
			Tringa stagnatalis	Marsh sandpiper

Species that contributed most to total abundance over the current sampling period in the Zinkwazi Estuary are the Egyptian goose *Alopochen aegyptiaca* (9%), the reed cormorant *Phalacrocorax lucidus* (6%) and the yellowbilled duck *Anas undulata* (5%) (Table 7.23). The estuary-associated bird community showed a shift between seasons from a community dominated by piscivores (50% of birds recorded) under high flow (summer) conditions to one in which invertebrates and plant feeders were better represented (28% and 36% of total respectively) (Figure 7.20), reflecting the influence of seasonal migratory behaviour.

Table 7.23. Water-associated birds recorded from the Zinkwazi Estuary during the course of this study (Source: ZBC). The number of individuals (n) as well as feeding guild as determined by preferred food (I=Invertebrates, F=Fish, V=Vegetation).

Genus and species	South African common name	29/01/2013	08/05/2013	30/05/2013	27/06/2013	01/08/2013	21/08/2013	Guild
		n	n	n	n	n	n	
Actitis hypoleucos	Common sandpiper	4					1	I
Actophilornis africanus	African jacana		2;2			2;4		I
Alcedo cristata	Malachite kingfisher					1		F
Alopochen aegyptiaca	Egyptian goose			2		8		V
Anas undulata	Yellowbilled duck	2			4	2;1	4;8	V
Anhinga rufa	African darter				1;1	1		F
Ardea cinerea	Grey heron	4			1			F
Ardea goliath	Goliath heron		1					F
Ceryle rudis	Pied kingfisher			1	4			F
Ciconia episcopus	Woollynecked stork			2	1	1		I
Euplectes orix	Red bishop	2						V
Gallinula chloropus	Common moorhen				1	1		V
Halcyon albiventris	Brownhooded kingfisher		2			1		I
Haliaeetus vocifer	Fish eagle				2	2;1		F
Himantopus himantopus	Blackwinged stilt			2				I
Pandion haliaetus	Osprey					1		F
Phalacrocorax africanus	Reed cormorant						1	F
P. lucidus	Whitebreasted cormorant	5					2	F
Plectropterus gambensis	Spurwinged goose			2			1	V
Podica senegalensis	African finfoot	1		1	1			I
Porphyrio martinicus	Purple gallinule					1		V
Scopus umbretta	Hamerkop					1		Frogs
Tachybaptus ruficollis	Dabchick				1	5;3;2	2	F
Vanellus senegallus	Wattled plover					1	4	I
	Total individuals	**18**	**7**	**10**	**17**	**39**	**23**	

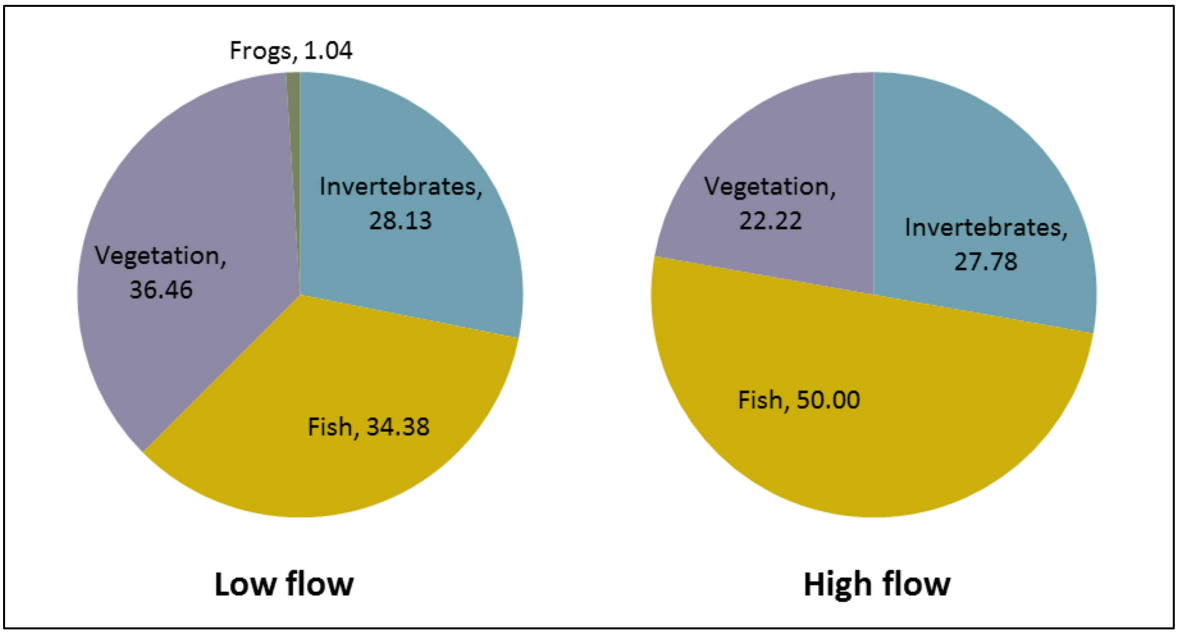


FIGURE 7.20. PERCENTAGE CONTRIBUTION OF THE FEEDING GUILDS IDENTIFIED IN HOCKEY *ET AL*. (2005) TO TOTAL BIRD ABUNDANCE IN THE ZINKWAZI ESTUARY, BY SEASON (LOW FLOW, WINTER N=96, FIVE COUNTS; HIGH FLOW, SUMMER N=18, ONE COUNT).

8. COASTAL VULNERABILITY

Following the March 2007 storms in KZN that resulted in significant damage to the coast, an assessment of coastal vulnerability was undertaken for the KZN coastline, the aim of which was to identify areas of coast where the physical feature potential renders it vulnerable to future damage or loss. This study resulted in the development of a Coastal Vulnerability Index (CVI) whereby small sections of the coast are ranked, based on their relative degree of vulnerability as: *risk*, *moderate risk* or *high risk*. Risk is defined as the potential to be impacted or damaged, in this case as a result of coastal erosion or extreme storm events. This section presents the results pertaining directly to the stretches of coast at, and adjacent, to the Nonoti and Zinkwazi Estuary mouths.

8.1 Methods

The CVI study used remotely-sensed data in the form of orthophotographs as base data for the assessment. Data were processed by means of Geographical Information System (GIS) methodology in order to determine input factors or value of physical coastal properties, namely beach width, dune width, percentage rocky outcrop, distance (width) of vegetation behind the back beach and distance to the 20m isobath (Palmer *et al*., 2011). *Beach width* gives an indication as to the degree to which sea run-up can occur and dissipate wave energy. *Dune width* gives an indication of coastal protection and as well as the sediment available to sustain erosion and accommodate leeward deposition of marine derived materials. The offshore *distance to the 20m isobath* relates to sub-tidal bedform and wave energy; the greater the distance the more friction is able to dissipate incoming waves. Following these factors, sites that scored high on all three properties were at greater risk than sites that did not (Table 8.1). In order to further emphasise high risk, such sites were identified and weighted by an additional factor of 4. In addition, due to the sensitive and dynamic nature of estuarine areas, cells that included estuarine mouths were also weighted by an additional factor of 4 to highlight the potential increased risk for these sections of coastline. A limitation of this assessment is that only the mouth component of estuaries was included in the assessment in terms of their interaction with the coast and the impact on them from coastal processes (DAEA and ORI 2011).

TABLE 8.1. VULNERABILITY THRESHOLDS PER PARAMETER. NUMBERS IN BRACKETS INDICATE THE ASSOCIATED VULNERABILITY SCORE PERTAINING TO THE CVI INDEX.

Physical property	Extremely low (1)	Low (2)	Moderate (3)	High (4)
Beach width	> 150m	100 - 150m	50 - 100m	< 50m
Dune width	> 150m	50m - 150m	25 - 50m	< 25m
Distance to -20m isobath	> 4km	2 - 4km	1 - 2km	< 1km
Distance of vegetation behind the back beach	> 600m	200 - 600m	100 - 200m	< 100m
Percentage outcrop	> 50%	20 - 50%	10 - 20%	< 10%

The coast was divided into 50m by 50m cells and each cell rated in terms of its degree of vulnerability based on the examination of the key indicators of physical vulnerability as outlined above (Palmer et al. 2011; DAEA and ORI 2011). Based on the scoring and subsequent weighting, each cell received a total relative vulnerability score, which reflects the vulnerability of individual cells relative to each other:

Relative CVI= a + b + c + d + e + f + g

Where a = beach width vulnerability score, b = dune width vulnerability score, c = distance to 20m isobath vulnerability score, d = percentage outcrop vulnerability score, e = distance of vegetation behind the back beach vulnerability score, f = additional weighting of highly vulnerable sites (if a, b and c = 4), g = additional weighting if the cell intersects an estuarine area.

Vulnerability scores were ranked into three categories based on CVI score distribution in order to simplify the interpretation of scores for management purposes; these being *Risk*, *Moderate Risk* and *High Risk* (Table 8.2) (DAEA and ORI 2011).

TABLE 8.2. VULNERABILITY CLASSES

	Scores	Ranking	% of coast
	9-14	Risk	30
	15-20	Moderate Risk	47
	21-32	High Risk	23

8.2 Assessment of Vulnerability: Coastal area Nonoti to Zinkwazi

Coastal Vulnerability Index (CVI) scores for the cells adjacent to the Nonoti Estuary mouth (1 km either side of the mouth) ranged from 16 to 23, with a mean of 19, resulting in this section of coast having a *Moderate Risk* rating. Similarly, CVI scores for the cells adjacent to the Zinkwazi Estuary mouth (1 km either side of the mouth) ranged from 18 to 26, with a mean of 20, resulting in this section of coast also having a *Moderate Risk* rating. In other words, both of these sites are *moderately* vulnerable or at risk to the effects of coastal erosion and storm surge events. It is recommended that the options of retreat and defence (further explained below) be explored for properties located close to the coast, and new developments should be set-back sufficiently to ensure that they are not damaged. If there is insufficient space for set-back or retreat then alternative sites for the development should be considered.

Coastal Set-back lines

In South Africa, the ICM Act calls for the determination and management of coastal set-back lines with the aim of facilitating better management of the coastal environment, ensuring sustainability of coastal resources, as well as protection of properties and infrastructure within the coastal zone. The ICM Act identifies a set-back line as a line "*seawards of which development can be prohibited or controlled*" (S 25). The KZN Department of Agriculture and Environmental Affairs (DAEA) are in the process of drafting coastal set-back lines for the province, in order to meet the objectives of the ICM Act. The set-back lines, once enforced, will control the type and location of future development along the coast. It will also serve to assist in the management of existing developments that are potentially at risk.

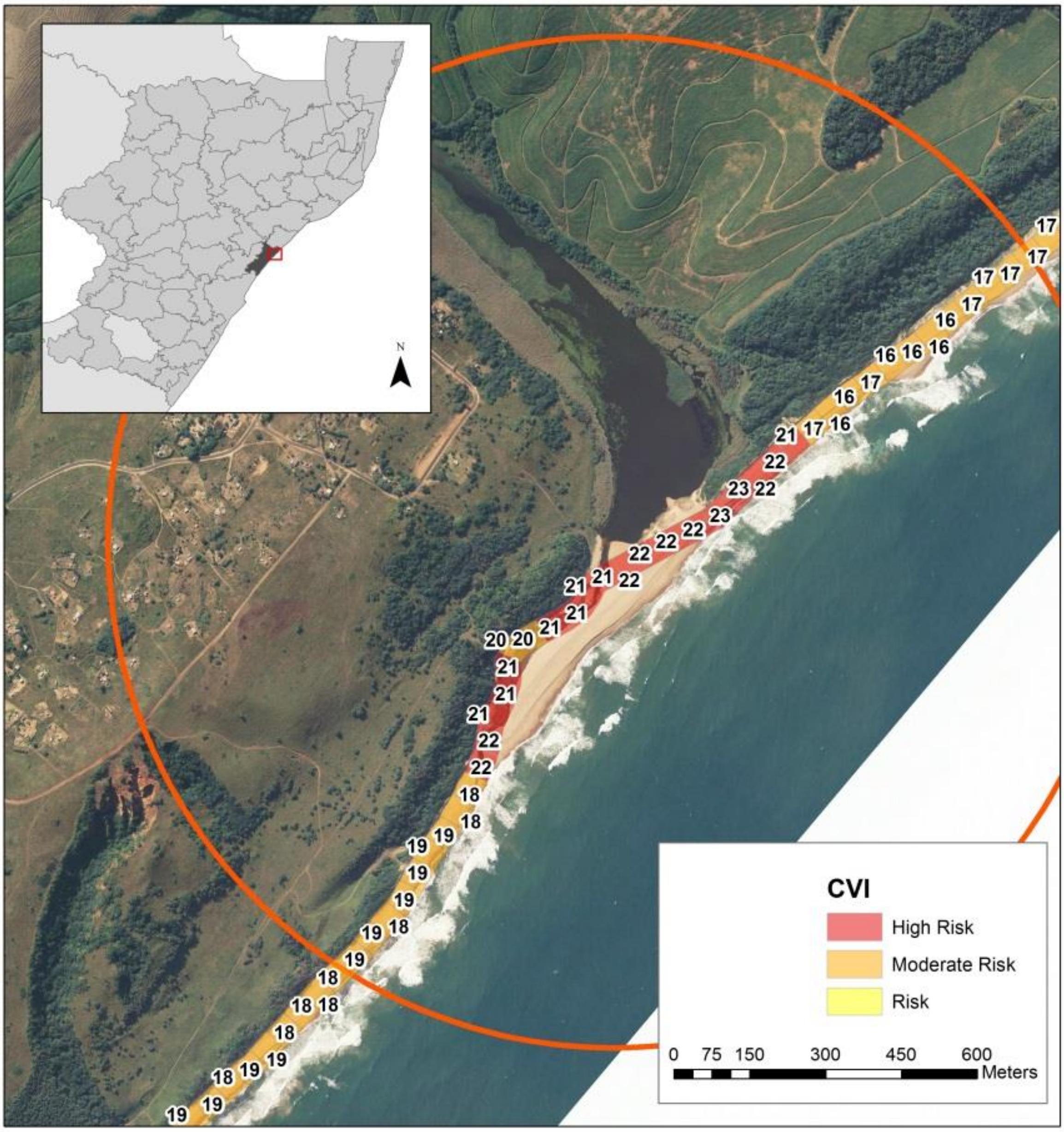


FIGURE 8.1. VULNERABILITY SCORES FOR THE NONOTI ESTUARY.

Management Alternatives

There are a number of proposed management interventions to deal with potential risk of threat to properties and infrastructure in the coastal zone (including around the Nonoti and Zinkwazi Estuaries). The interventions are separated into four categories: 1) *Retreat/Remove*, 2) *Accommodate*, 3) *Do Nothing* or 4) *Defend*.

1) Retreat/Remove

This option proposes the active removal of infrastructure that is located within a hazardous zone and therefore vulnerable to damage. The main problem with this alternative is that there is often insufficient room for retreat as much of the coast and inland areas are significantly developed. Softer Retreat options include allowing development to take place on condition that it will be abandoned if necessary, following a planned phaseout (Gilbert & Vellinga 1990). Authorities could also take a more limited role by purely ensuring that all participants in potentially vulnerable areas have full knowledge as to possible impacts of sea level rise and other uncertainties, the premise being that development would not occur if developers, lenders, and insurers are not willing to accept the risks (Gilbert & Vellinga 1990).

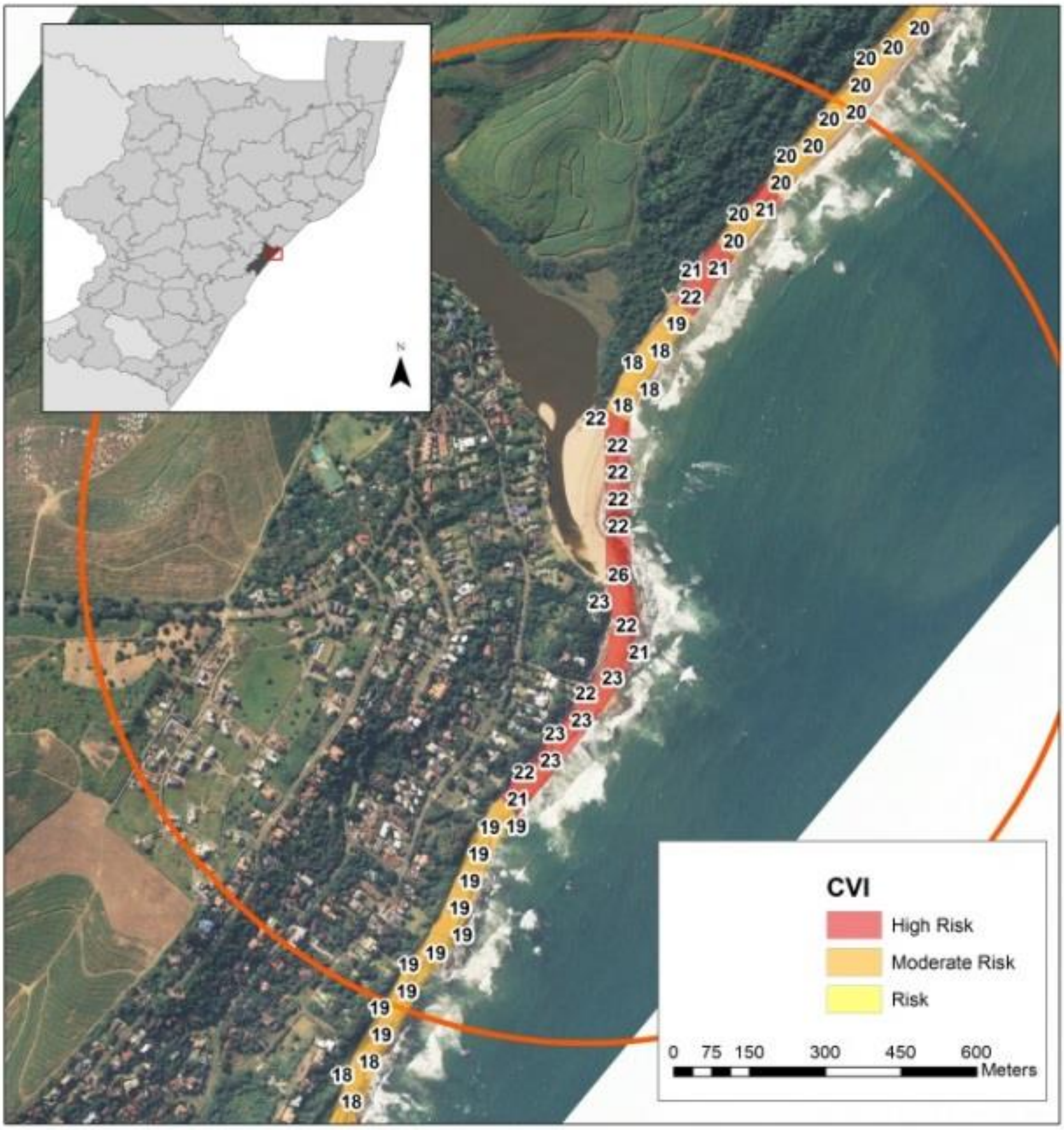


FIGURE 8.1. VULNERABILITY SCORES FOR THE ZINKWAZI ESTUARY.

2) Accommodate

Similar to Retreat, the option of *Accommodate* requires advanced planning and acceptance that some coastal functioning will be compromised. For this option, alternative planning for coastal structures is required, for example, elevating buildings on pilings for protection from floods (Gilbert & Vellinga 1990). This option speaks to the alteration of current land use practices in order to better align them with land cover that offers natural protection, for example preventing the infilling of wetlands, damming of rivers and mining of estuarine sand (Gilbert & Vellinga 1990). This option also highlights the need for storm warning and preparedness plans which would allow sufficient time to react in the event of an incident (Gilbert & Vellinga 1990).

3) Defend/Protect

Defend is the most commonly employed approach in areas that have high populations and/or important infrastructure located within the coastal zone. This is done through a range of hard or soft engineering options, applied alone or in combination depending on the conditions of the site (Gilbert & Vellinga 1990). Hard engineering options include dikes, seawalls, revetments, bulkheads and groins, which serve to protect properties from the direct effects of waves, erosion and storm surges (Gilbert & Vellinga 1990). Eroding shores would eventually reach hard defences resulting in a loss of the natural beach and ultimately erosion of the defence structure.

A number of soft engineering approaches can also be used, including beach filling or renourishment, and dune building through the use of sand bags and dune vegetation (Gilbert & Vellinga 1990). These have a less severe impact on the coastal environment as they usually consist of simulated natural features. Beach renourishment, for example, involves dredging sand from offshore and placing it on the beach (Gilbert & Vellinga 1990) as is common practice on the Durban city beachfront. Coastal ecosystems are already adapted to annual erosion/accretion cycles, resulting in the replacement of sand on the beach generally having low impact on the ecosystems (Gilbert & Vellinga 1990). Re-vegetation of coastal areas post-damage is also known to be an effective *Defend* option. Studies show that vegetation in coastal areas improves slope stability, consolidates sediment and reduces wave energy moving onshore (Prasetya 2013).

4) Do Nothing

This approach focuses on leaving infrastructure as is and allowing natural processes to take their course. The problem with this option is that public infrastructure and access roads are often in risk zones and need to be maintained in order to facilitate public access and use of the coast.

There are a number of factors that render coastal and estuarine environments vulnerable to the effects of storm surge, sea-level rise and coastal erosion. Thus it is imperative that these conditions be understood and managed in order to ensure long-term functioning of coastal and estuarine environments.

9. SUGGESTED PRESSURES AND THREATS EVALUATION

9.1 Following the Millennium Ecosystem Assessment

The Millennium Development Goals (MDG) were established by the UN in 2002, with an aim to improve the lives of the world's poorest through a number of outlined objectives, with a target for achievement by 2015. Of the eight goals established, seven are anthropocentric including for example reducing child mortality, empowering women and combating diseases such as AIDS and malaria. MDG 7 however deals specifically with the issue of environmental sustainability. A healthy environment directly affects human health, wellbeing and development, and therefore is fundamental in helping to achieve the rest of the goals.

The Millenium Ecosystem Assessment (2005), linked to the MDG recognises that natural systems are critical to supporting human life, and assesses the consequences of ecosystem change for current and future human well-being. Employing expert knowledge it measured the global state of 24 different ecosystem services and provided a synthesis of change within the last 50 years. Degradation of these services negatively impacts human well-being especially for the poor of the world, and significantly hampers achievement of the MDG. It also threatens biodiversity and the resilience of natural systems to withstand and recover from perturbations. As human population grows, there is an increasing demand for ecological services that facilitate development, for example the provision of natural resources like wood and fresh water. A key challenge is to manage natural resources in a way that allows for sustainable development and mitigation of negative impacts.

Global climate change is a topic that has become increasingly prominent in recent years. Given the overwhelming evidence for a changing climate, it is important to consider this phenomenon and its effects, as it is a factor that could not only exacerbate the effects of existing ecological pressures, but also serve to further reduce a system's resilience and ability to withstand perturbation. Among the predicted effects of climate change are an increase in frequency of extreme weather events and a rise in sea level related to thermal expansion of the oceans and melting of the polar ice caps (Nicholls & Cazenave 2010). This has direct implications for coastal areas worldwide as a change in sea level directly affects shoreline change in a way that is not uniform worldwide. The KZN nearshore marine environment is typically a high-energy, swell-dominated region (Palmer et al. 2011). In a recent study analysing shoreline change for the KZN coast, Goble and MacKay (2013) identified a historical shoreline change range of -1.97 $m.y^{-1}$ to +3.96 $m.y^{-1}$. Since erosion is the long-term trend for most of the province's coastline, projected forwards, this range equates to a necessary buffer setback line for development ranging between 99m to 394m under different time scenarios of 25 to 100 years. This is particularly exacerbated by natural factors that influence coastal vulnerability, including beach width, dune width and distance of vegetation behind the back beach (Goble & MacKay, 2013).

Healthy natural systems are ones in which ecological functions and processes are intact and have not been impeded. A system's health and ability to resist change and stress is directly affected by factors such as ecosystem intactness. Intactness is measured as the deviation of current state from a specified reference condition (Bayne et al. 2012). As this reference is usually taken as pre-modern time, intact areas therefore have no discernable human influence (Scholes & Biggs 2005). Another factor contributing to health is connectivity (biological and biogeochemical linkages) between system types or regions.

Importantly, maintaining connectivity preserves not only natural systems but also important ecological processes and functions such as nutrient cycling. An example of ecosystem connectivity in the context of estuaries is an intact riparian buffer that links the river and estuary with upland areas. Such linkages contribute to overall ecosystem health, in that animals and plants often rely on the entire region rather than their immediate location for their livelihood, for the completion of different stages of the life cycle, for movement and for feeding. In recognition of this, the Estuarine Functional Zone (EFZ) is demarcated by the 5m amsl contour which encompasses not only the subtidal and surface waters but also the estuary floodplain and fringing vegetation.

9.2 Risk assessment of pressures on Nonoti & Zinkwazi Estuaries using the DPSIR framework

One of the best ways to manage the environment such that human wellbeing is maintained is through risk assessment and reduction techniques and disaster management. Disaster Risk Reduction (DRR) in fact is central to the achievement of the MDG and includes for example land use planning and a focus on maintaining biodiversity and natural systems that increase resilience to natural disasters. On a more local scale, access to an environment that is not harmful to health or wellbeing is identified as a human right within the Constitution of South Africa, and supporting legislation such as the National Environmental Management Act (NEMA, Act 107 of 1998) has been put in place to achieve this. As a result, understanding potential consequences of an impact on the aquatic resources and associated environments and deciding on the acceptability of such consequences (keeping in mind the resource quality objectives and ecological category of RDM) is essential before development actions may be allowed to continue.

The framework of Driver, Pressure, State, Impact, Response (DPSIR), an analytical framework based on current understanding of the functioning of aquatic systems, is a suitable tool for the assessment of pressures that takes into account their root causes and examines the consequences for the aquatic system (WFD 2000) (Table 9.1).

Anthropogenic pressures that threaten estuaries arise from a number of sources, which can be grouped by economic sector including agriculture or industry. These are the drivers that directly lead to a pressure. The pressures affect the estuary's state (biological, chemical or physical), which in turn leads to specific impacts. For example, inappropriate agriculture (Driver) may result in floodplain habitat being cleared and increased erosion into the headwaters of the estuary (Pressure). This would result in a decrease in water quality, and erosion of the bank leads to loss of subtidal habitat (State). These changes could lead to the loss of sensitive or intolerant species from the estuarine community in this area, which would result in loss of biodiversity with potential impacts on trophic and community functioning (Impact). The next step in the analysis is to identify appropriate actions to mitigate the impacts, or legislation or other existing institutional guidelines that regulate the anthropogenic activity at the source of the pressure (Response).

TABLE 9.1. EXPLANATION OF THE TERMS USED IN THE DPSIR ANALYTICAL FRAMEWORK, AS ADOPTED BY THE WFD (SOURCE: WFD 2000).

	Term	Definition
D	Driver	An anthropogenic activity that may have an environmental effect (e.g. agriculture, industry).
P	Pressure	The direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry).
S	State	The condition of the water body resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics).
I	Impact	The environmental effect of the pressure (e.g. fish killed, ecosystem modified).
R	Response	The measures taken to improve the state of the water body (e.g. restricting abstraction, limiting point source discharges, developing best practice guidance for agriculture).

A desktop analysis was performed to test whether this framework would be adequate in setting some of the management objectives that are required for the Nonoti and Zinkwazi Estuaries towards setting up individual Estuarine Management Plans (EMPs). A preliminary attempt to identify some of the actual pressures, states and impacts on the Nonoti and Zinkwazi Estuaries relative to the current biophysical state of the systems is presented in Tables 9.2 - 9.3 and Figure 9.1 – 9.2. It must be iterated that this is an example of how this framework could work and only some of the outputs of such an exercise are presented. Wider stakeholder participation would be necessary to complete the exercise in full.

TABLE 9.2. EXPLANATION OF THE POTENTIAL STATES AND POSSIBLE IMPACTS IDENTIFIED IN A TEST EXERCISE ANALYSING THE POTENTIAL PRESSURES ON THE NONOTI AND ZINKWAZI ESTUARIES.

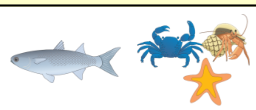
Description of States	**State 1: Physical alteration and habitat destruction**	Loss of diversity (fauna and flora) and associated loss of resilience. Modifications to bank and channel affect water flow and habitat availability.
	State 2: Flow modification	Mouth opening frequency is reduced, loss of connectivity and recruitment from the marine environment. Loss of volume and therefore loss of habitat. Reduced scouring of river and estuary beds, no turnover and clean out.
	State 3: Reduction in water and sediment quality	Increased nutrients, increased toxicants, reduced flushing, increased water residence, eutrophication.
	State 4: Exploitation of resources (living and non-living)	Artificial removal of abiotic components affects habitat characteristics and availability. Loss of biota has trophic and community implications.
	State 5: Other	Litter reduces aesthetic and recreational value of resource.
Description of Impacts		Impact 1: Changes and impacts to biological community.
		Impact 2: Loss of amenity and impact to recreation water quality and aesthetic.

Table 9.3. Test exercise to analyse pressures with the potential to affect the Zinkwazi and Nonoti Estuaries, according to the DPSIR format (WFD 2000). A description of states and impacts is given in Table 9.2.

DRIVER		PRESSURES	RESPONSE
Industry	**Catchment**	Water use and release of effluent from sugar mills (Nonoti only)	Refer to existing institutional standards incl: river water treatment and quality guidelines, monitoring programmes and water use licencing
	Adjacent catchments	Thukela catchment, especially Isithebe Industrial Estate, Mandeni, Tribal Trust Land	
Agriculture	**Commercial**	Loss of flood plain, loss of riparian (filtration), freshwater abstraction, pollution (runoff), loss of diversity, loss of flood buffer	Introduce concept of stewardship, appropriate buffer zones, refer to relevant legislation and guidelines
	Non-commercial	Similar to above but sometimes less controlled and effects are direct. Livestock especially impact bank stability as well as water quality (bacteriological and nutrient loading)	Tribal authority, concept of stewardship
Infra-structure	**Roads, bridges, rail**	Loss of bank habitat, runoff from roads (dust and rubber), flow modifications (bridge pylons)	Ensure appropriate EIA undertaken during building process, and all necessary mitigation performed
Settlements	**Formal**	Loss of flood plain, loss of riparian (filtration), freshwater abstraction, flow reduction, pollution (runoff), loss of diversity	Town planning and management to ensure appropriate development
	Informal	Same as above but on a smaller scale, less controlled	Tribal authority
Resource exploitation	**Coastal forest and grassland vegetation**	Loss of habitat, loss of floral/faunal diversity, increased run off, erosion and wind spray (salt)	Concept of stewardship, use of protected aeas or closed seasons, adherence to species-specific bag limits and minimum sizes, monitoring and compliance checks
	Fringing vegetation	Loss of estuarine habitat, loss of functional buffer, flow attenuation	
	Estuarine biota incl. fish, crabs and prawns	Loss of estuarine biological resources. Trophic and community impacts within estuarine and coastal marine communities	
Wastewater	**Industrial**	Treated industrial waste water (via catchment)	Refer to standards/ guidelines re treatment and dispersal of wastewater
	Domestic (treated)	Treated domestic waste water (direct run off and via catchment)	
	Domestic (septic tank)	Untreated domestic waste water (direct run off)	

Impacts and consequences	**Socio-economic consequences**	Degraded state reduces delivery of environmental goods and services, as well as reducing subsistence, aesthetic and recreational uses.		
		Decrease in human health and well-being, especially for rural community.		
		Economic value of resource and associated property decreases.		
	Environmental impacts	Loss of floral and faunal diversity leads to decreased resilience and increased susceptibility to disturbance.		
		Organic and inorganic pollutants reduce water and sediment quality and decrease nursery function.		
		Increased water abstraction reduces freshwater inflow, affects mouth dynamics and decreases connectivity with the nearshore marine environment.		
		Loss of critical habitat and biodiversity, with implications for trophic and community functioning.		
		Loss of flood buffer and estuary goods and services such as water filtration.		
Direct causes and underlying sectors	**Sectors**	**AGRICULTURE.** Clearing of catchment, floodplain and riparian vegetation. Fertilizer and pesticides runoff. Monoculture. Freshwater abstraction. Bank destabilization and water nutrient enrichment.	**INDUSTRY.** Effluent from Darnall Mill. Changes to freshwater quantity, quality and timing of flow because of water use.	**URBANISATION.** Clearing of land for proposed Nonoti development. Increased pressure on resources, especially fresh water. Increased waste generation. Growing poor rural community reliant on estuary's resources.

Figure 9.1. Summary of preliminary assessment of risks and threats to the current ecology and associated socio-economics of the Nonoti Estuary.

<table>
<tr><td rowspan="9">Impacts and consequences</td><td rowspan="3">Socio-economic consequences</td><td colspan="3">Degraded state reduces delivery of environmental goods and services, as well as reducing subsistence, aesthetic and recreational uses.</td></tr>
<tr><td colspan="3">Decrease in human health and well-being, especially for rural community.</td></tr>
<tr><td colspan="3">Economic value of resource and associated property decreases.</td></tr>
<tr><td rowspan="6">Environmental impacts</td><td colspan="3">Loss of floral and faunal diversity leads to decreased resilience and increased susceptibility to disturbance.</td></tr>
<tr><td colspan="3">Organic and inorganic pollutants reduce water and sediment quality and decrease nursery function.</td></tr>
<tr><td colspan="3">Increased water abstraction reduces freshwater inflow, affects mouth dynamics and decreases connectivity with the nearshore marine environment.</td></tr>
<tr><td colspan="3">Loss of flood buffer and processes such as filtration.</td></tr>
<tr><td colspan="3">Increased sediment load reduces estuarine water area and allows encroachment of reeds.</td></tr>
<tr><td colspan="3">Loss of critical habitat and biodiversity, with implications for trophic and community functioning.</td></tr>
<tr><td>Direct causes and underlying sectors</td><td>Sectors</td><td>AGRICULTURE. Clearing of catchment, floodplain and riparian vegetation. Fertilizer and pesticides runoff. Monoculture. Freshwater abstraction. Bank destabilization and water nutrient enrichment.</td><td>URBANISATION. High income resort town, identified by the KwaDukuza Municipality as an opportunity for urban expansion. Increased pressure on resources including freshwater. Increased waste generation. Loss of habitat.</td><td>INDUSTRY. Little to no industrial activities in the Zinkwazi catchment. Heavy industrial activities in the adjacent Thukela catchment reduce Thukela water quality, but the biggest impact from this for the Zinkwazi Estuary is probably litter deposition.</td></tr>
</table>

FIGURE 9.2. SUMMARY OF PRELIMINARY ASSESSMENT OF RISKS AND THREATS TO THE CURRENT ECOLOGY AND ASSOCIATED SOCIO-ECONOMICS OF THE ZINKWAZI ESTUARY.

9.3 Generic pressures and threats to KZN estuarine health and function

Generally there is a strong relationship between the size of a catchment's human population and the degree of modification of an estuary (Turner et al. 2004). The issues facing our estuaries can be combined under a number of common themes. The following pertain especially to the Nonoti and Zinkwazi estuaries:

Water Flow

South Africa a naturally semi-arid country with a pressing freshwater demand to meet domestic, industrial and agricultural needs for a population of 50.6 million. In this water stressed situation, the amount and natural timing of river water reaching estuarine and marine environments has been altered through the construction of dams and direct extraction. Changes to water flow before it reaches the coast affects the way an estuarine ecosystem functions and therefore the services it provides.

Water Quality

Pollution from a host of human activities in the catchment causes harmful concentrations of chemicals, nutrients, herbicides, pesticides and litter in our estuaries. One of the consequences of human settlement on the coast is that waste water treatment effluent flows directly into estuaries have increased causing oxygen depletion often leading to fish kills, algal blooms and a host of human health problems (UNEP 2009). In part, estuaries are productive ecosystems because they receive nutrients from the surrounding catchment. When the quantity of pollutant exceeds the filtration capacity of estuaries, they can be some of the most polluted ecosystems (USEPA 1993).

Poor Agricultural Practices

Natural vegetation and forests retain integrity of soils and stream bank structure. Removal of which for crops, grazing or housing on steep slopes in particular leads to soil erosion and mud deposition into rivers and estuaries. Coupled with reduction in flow which ordinarily would flush this accumulation, habitats are lost from a reduced estuary depth.

Estuary Mouth Breaching

Most often, mouth manipulation is required when inappropriate development has taken place inside the estuarine functional zone (Van Niekerk & Turpie 2012). Artificial breaching of an estuary results in a sudden and catastrophic lowering of water levels for aquatic plants and non-motile animals which will disrupt natural functioning in the system. Non-managed breaching at an unsuitable time of year can be one of the most destructive effects on a system that may require some time for ecological balance to be restored.

Harvesting of Resources

Illegal or irresponsible harvesting of resources through the destruction of habitat and/or overfishing can lead to loss of critical habitat and species, sometimes indirectly influencing the wellbeing and health of non-target species.

Developments & Hard Structures

Irresponsible planning, design and placement of buildings, concreted embankments, jetties and bridges change water flow, cause erosion, loss of habitat and pollution in estuaries. All have dramatic consequences to the natural functioning and management of estuaries.

Habitat Destruction

The physical removal of sand for building or construction in or upstream from estuaries has often permanent and negative consequences on the ecology of the system. In a survey, one third of 64 estuaries in KZN surveyed supported sand mining operations (Demetriades 2007). The provision of sand through the estuarine system to the coast and marine environment is now understood to be critical. Removal of mangroves, submerged aquatic vegetation or coastal forest can alter the manner in which an estuary flows and limits the shelter that is available for particular species that use these habitats.

Future Challenges

A new recognised pressure covered in the most recent National Biodiversity Assessment (Van Niekerk & Turpie 2012) deals with climate change challenges. The majority of pressures faced by KZN estuaries are known and understood to a certain extent. Yet those that are anticipated with a different climate regime (e.g. warmer temperatures, sea level rise and intensification of the hydrologic cycle) are going to increase existing pressures on estuaries as well as give rise to new problems. The USEPA program for Climate Ready Estuaries (CRE) (USEPA 2013) warns that management strategies and practices will require growth as climate changes. It may not be sufficient to restore or sustain reference or even present conditions. Sustainability might require innovative thinking around creating and maintaining new environments too.

Invasive Species

Biodiversity can be lost through destruction of habitats, overexploitation and biological activity such as pollution and invasive species, a growing and important potential threat in South Africa. Marine introduced species have been found in all marine and estuarine habitats surveyed to date in South Africa, inclusive of the open coast. (Mead et al. 2011) Taxa with the largest numbers of introduced species are the Crustacea (33 species), Mollusca (22 species), Ascidiacea (sea squirts - 18 species), and Cnidaria (16 species). Invertebrate biodiversity loss upsets the balance of ecosystems, which is why it is important to safeguard its sustainability.

Exotic species that successfully invade new habitats form large populations relatively quickly with exceptional densities compared to that of the naturally occurring species. This obviously then creates a competitive advantage over the indigenous species, altering community structure through competition leading to massive changes in the structure and functioning of the natural ecosystem, impacting on genetic variability and causing the extinction of indigenous species (Levy 2004, Karateyev et al. 2009). The invasive success of any one species is ultimately determined by both the life history traits of the invading species and the abiotic factors occurring in the new habitat of the invader (Williamson & Fitter 1996).

Of relevance here and a finding of this biophysical baseline survey is that the Nonoti and Zinkwazi estuaries are both subject to an infestation of the invasive gastropod *Tarebia granifera*. *Tarebia granifera* is an Asian mollusc species that is both parthenogenetic and ovovoviparious in nature and together with the long lifespans and slow intrinsic growth rates, allows this species to be an incredibly successful invader. Being able to reproduce parthenogenticially allows this mollusc to colonise water bodies quickly where high densities form extensive mats in a variety of habitats, on both natural and artificial substrata (Appleton et al. 2009). Furthermore, female *T.granifera* are able to reproduce individually without the presence of males (Chaniotis et al. 1980).

Tarebia granifera has a natural range from Madagascar, through India to Hawaii, including countries in Southeast Asia, the Philippines, Japan and the Society Islands. This species has been transported across the globe via the aquarium trade and is now widely distributed across the world. The appearance of *T.granifera* was first reported in South Africa in 1999 in northern KwaZulu-Natal (Appleton et al. 2009), and was most probably introduced several years earlier via the aquarium trade which receives supplies from Hong Kong and Singapore (Appleton 2003). Since then T. granifera has spread rapidly and is now colonising estuaries within KwaZulu-Natal. Thus *T.granifera* is capable of colonising freshwater, brack and considerably saline environments (Appleton et al. 2009).

The two main concerns associated with the proliferation of *T.granifera* in KZN estuaries, include firstly the changes to the ecology through competitive exclusion of native snail and other invertebrate populations (Pointier 2001, Wolmarans & de Kock 2006, Tolley-Jordan & Owen 2008). Depending on the invading environment, the full spectrum of benthic riverine and estuarine infauna and epifauna could be affected by the intense competition for space and resources inflicted by the high population densities of *T.granifera* (Appleton et al. 2009). Furthermore, other indigenous molluscs at the southern limit of their distribution in Africa may be displaced by *T.granifera* (Appleton et al. 2009).

While numerous chemical molluscicides and other substances have been used in attempts to eliminate the intermediary molluscan hosts of various parasites, few have been successful or practically sustainable (Morgan et al. 2001, Ellis-Tabanor & Hyslop 2005). With the paucity of data regarding the biology and ecology of *T.granifera* in South Africa, the efficacy of this species to carry other parasites harmful to humans, and aquatic fauna, remains unknown. Due to the parthenogenetic reproductive nature of *T.granifera*, the invasive process is irreversible and there are no known control measures for this species (Pointier 2001, Appleton 2003). *Tarebia granifera* is able to tolerate poor water quality conditions (Chaniotis et al. 1980). However, shallow, permanent and stable habitats that are well oxygenated, and which support emergent macrophyte communities, provide ideal living conditions for these snails. These are the features of estuarine margins, therefore under these favourable conditions *T.granifera* can displace the majority of other snails and will quickly become the most dominant species within the system.

10. CONCLUSIONS & RECOMMENDATIONS

The baseline assessments of the Nonoti and Zinkwazi Estuaries showed that both are subject to varied, direct and indirect impacts as demonstrated by the ecological and biophysical conditions of both systems. However, the initiative taken by the Zinkwazi Beach Ratepayers and Residents Association and the Lower Tugela Biodiversity Protection Project to oversee studies and engage in private sector partnerships for estuarine protection and management demonstrates that there is excellent opportunity to remediate this state.

Based on the natural capital of these systems under investigation the following can be said:

- The Nonoti is in a poor ecological state. Alien invasive vegetation is the proximal cause of this, although it is highly likely that a consistent nutrient input to the system is contributing to the infestation. In addition, much of the natural vegetation buffer in the estuarine functional zone has been disturbed or removed. The immediate consequences are that the system has possibly limited or even lost the capacity to filter and buffer against this
- There is limited opportunity for fish conservation in the system. However, conservation worthy species have been found to occur in relative abundance in this estuary
- The system has potentially high aesthetic value, particularly if the little remaining naturally occurring macrophytes (e.g. *Nymphaea*) and riparian forest remains (e.g. *Barringtonia, Hibiscus*)
- The potential for 'green' tourism is high, particularly as avifauna continue to roost and feed along the system
- The Zinkwazi Estuary is biologically diverse and relatively rich in terms of the estuarine invertebrate and vertebrate fauna it supports
- The estuary offers high potential for recreation with respect to angling and fish conservation
- The Zinkwazi Estuary has high intrinsic value as an aesthetically pleasing subtropical TOCE
- Avifauna are prolific in and around the system, which too indicates a consistent and rich food supply for a range of functional feeding groups
- However, there is still high potential for spread of invasive flora and fauna due to poor water quality at times and artificial mouth manipulation, upsetting the natural balance and function of this estuary

It is recommended that this study and the peripheral information provided is now sufficient to commence the basic assessment for an Estuary Management Plans (EMP) for the Nonoti and Zinkwazi Estuaries, to fall in line with water resource custodianship and protection. The urgency in conducting Estuary Management Plans became apparent during the development of the new Integrated Coastal Management Bill. Estuaries and the management thereof now form an integral part of the new Integrated Coastal Management Bill which outlines a National Estuarine Management Protocol. The protocol identifies the need for the development of EMPs, as these would help to align and coordinate estuaries management at a local level. The broad components of which are:

1. Situation Assessment and Evaluation
2. The setting of a Vision and Strategic objectives
3. The evaluation of Management Strategies to achieve the vision and objectives
4. The preparation of an Estuary Zoning Plan (EZP) and the establishment of Operational Specifications

5. The identification of Management Action Plans (MAPs)
6. The Implementation of the MAPs and
7. Monitoring

11. REFERENCES

Adams JB, Knoop WT and Bate GC. 1992. The distribution of estuarine macrophytes in relation to freshwater. Botanica Marina 35: 215-226.

Adams JB and Bate GC. 1999. Growth and photosynthetic performance of *Phragmites australis* in estuarine waters: a field and experimental evaluation. Aquatic Botany 64: 359-367.

Adams JB, Bate GC and O'Callaghan M. 1999. Primary producers. In: Allanson BR and Baird D. (eds). Estuaries of South Africa. Cambridge University Press, Cambridge, pp 91-117.

Adams JB, Snow GC and Veldkornet DA. 2012. Estuarine Habitat. In: Van Niekerk L and Turpie JK. (eds). South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch, pp 50-59.

Alongi DM. 1998. Coastal Ecosystem Processes. CRC Press, Florida.

Appleton CC. 2003. Alien and invasive fresh water Gastropoda in South Africa. African Journal of Aquatic Science 28(1): 69-81.

Appleton CC, Forbes AT and Demetriades NT. 2009. The occurrence, bionomics and potential impacts of the invasive freshwater snail *Tarebia granifera* (Lamarck, 1822) (Gastropoda: Thiaridae) in South Africa. Zoologische Medelingen Leiden 83:525-536.

Attrill MJ, Rundle SD and Thomas RM. 1996. The influence of drought-induced low freshwater flow on an upper-estuarine macroinvertebrate community. Water Research, 30:261-268.

ASCLME 2010. Coastal Livelihoods in the Republic of South Africa. South Africa Annex XI Coastal Livelihoods Assessment (CLA). EcoAfrica publishers.

Baird D and Ulanowicz RE. 1993. Comparative study on the trophic structure, cycling and ecosystem properties of four tidal estuaries. Marine Ecology Progress Series 99:221-237.

Bate GC, Whitfield AK, Adams JB, Huizinga P and Wooldridge TH. 2002. The importance of the river-estuary interface (REI) zone in estuaries. Water SA 28: 271-280.

Bayne EM, Capmbell J and Haché S. 2012. Is a picture worth a thousand sepcies? Evaluating human perception of biodiversity intactness using images of cumulative effects. Ecological Indicators 20: 9-16.

Beckley LE. 1983. The ichthyofauna associated with *Zostera capensis* Setchell in the Swartkops Estuary, South Africa. South African Journal of Zoology 18: 15-24.

Beesley PL, Ross GJB and Glasby CJ. 2000. Polychaetes and allies: The southern synthesis. Fauna of Australia. Vol. 4A Polychaeta, Myzostomida, Pogonophora, Echiura, Sipuncula. CSIRO Publishing, Melbourne.

Begg G. 1978. The estuaries of Natal. Natal town and regional planning report 41: 657 pp.

Begg GW. 1984a. The estuaries of Natal. Part 2, Natal Town and Regional Planning Report 55: 631 pp.

Begg GW. 1984b. The comparative ecology of Natal's smaller estuaries. Natal Town and Regional Planning Report 62: 182 pp.

Bell KNI, Cowley PD and Whitfield AK. 2001. Seasonality in frequency of marine access to an intermittently open estuary: Implications for recruitment strategies. Estuarine, Coastal and Shelf Science 52: 327-337.

Biggs R and Scholes RJ. 2002. Land-cover changes in South Africa 1911-1993. South African Journal of Science 98: 420-424.

Blaber SJM. 1978. Fishes of the Kosi system. Lammergeyer 24: 28-41.

Blaber SJM. 1980. The Functioning of Estuaries in southern Africa. International Symposium on habitats and their influences on Wildlife. Endangered Wildlife Trust, Pretoria, pp 26-34.

Blaber SJM. 1981. The zoogeographical affinities of estuarine fishes in south-east Africa. South African Journal of Science 77: 305-307.

Blaber SJM. 1997. Fish and fisheries of tropical estuaries (Fish and Fisheries Series 22). Chapman and Hall, London, 367 pp.

Blaber SJM, Kure NF, Jackson S and Cyrus DP. 1983. The benthos of South Lake, St Lucia following a period of stable salinities. South African Journal of Zoology 18: 311–319.

Boesch DF, Wass ML and Virnstein RW. 1976. The Dynamics of Estuarine Benthic Communities. In: Wiley M. (ed). Estuarine Processes. Academic Press Inc., New York.

Bond J, Green AN, Cooper JAG and Humphries MS. 2013. Seasonal and episodic variability in the morphodynamics of an ephemeral inlet, Zinkwazi Estuary, South Africa. Journal of Coastal Research 65: 446-451.

Bortone SA. 2005. The quest for the "perfect" estuarine indicator: An introduction. In: Bortone SA. (ed.). Estuarine Indicators, CRC Press, Florida, 531 pp.

Bosman C, Uken R, Leuci R, Smith AM and Sinclair D. 2007. Shelf sediments off the Thukela River mouth: complex interaction between fluvial and oceanographic processes. South African Journal of Science 103: 490-492.

Branch M and Branch GM. 1985. The living shores of South Africa. C. Struik Ltd., Cape Town.

Branch GM and Grindley JR. 1979. Ecology of southern African estuaries. Part XI. Mngazana: A mangrove estuary in Transkei. South African Journal of Zoology 14: 149-170.

Branch GM, May J, Roberts B, Russell E and Clark BM. 2002. Case studies on the socio-economic characteristics and lifestyles of subsistence and informal fishers in South Africa. South African Journal of Marine Science 24: 439-462.

Braus J. 1999. Windows on the wild: Biodiversity Basics. World Wildlife Fund, Tustin, Acorn Naturalists, 477p.

Brown AC and Jarman N. 1978. Coastal marine habitats. In: Wiener MJA. (ed). Biogeography and Ecology of Southern Africa. W. Junk, The Hague, pp 1239–1277.

Burke K and Gunnell Y. 2008. The African Erosion Surface: A Continental-scale Synthesis of Geomorphology, Tectonics, and Environmental Change Over the Past 180 Million Years. Geological Society of America, 66 pp.

Bursey ML and Wooldridge TH. 2003. Physical factors regulating macrobenthic community structure on a South African estuarine flood-tidal delta. African Journal of Marine Science 25:263-274.

Chaniotis BN, Butler JM, Ferguson FF and Jobin WR. 1980. Presence of males in Puerto Rican *Thiara* (*Tarebia*) *granifera* (Gastropoda: Thiaridae), a snail thought to be parthenogenetic. Caribbean Journal of Science 16: 95-97.

Clark JR. 1996. Coastal Zone Management Handbook. Lewis Publishers, New York, 694 pp.

Clarke KR and Warwick RM. 2001. Changes in marine communities: an approach to statistical analysis and interpretation. PRIMER-E Ltd, Plymouth.

Cockcroft AC, Sauer WHH, Branch GM, Clark BM, Dye AH and Russel E. 2002. Assessment of resource availability and suitability for subsistence fishers in South Africa, with a review of resource management procedures. South African Journal of Marine Science 24: 489–501.

Collins T, Meyer C, Loubser J, van Weele G and Maree G. 2012. Environmental Management Framework for iLembe District Municipality, 237pp.

Conservation International. 2013. Sugar, GreenChoice producer initiative. Conservation International. At:http://www.conservation.org/global/ci_south_africa/our-initiatives/food-security-land-reform/greenchoice/pages/sugar.aspx [14 August 2013].

Cooper JAG. 1990. Ephemeral stream-mouth bars at flood-breach river mouths: comparison with ebb-tidal deltas at barrier inlet. Marine Geology 95: 57-70.

Cooper JAG, Ramm AEL and Harrison TD. 1994. The Estuarine Health Index: A new approach to scientific information transfer. Ocean and Coastal Management 25:103-141.

Cooper JAG, Harrison TD, Ramm AEL and Singh RA. 1993. Refinement, enhancement and application of the Estuarine Health Index to Natal's estuaries, Tugela-Mtamvuna. Report prepared for Department of Environment Affairs, No. EFP.05.930402.

Cowley PD, Whitfield AK and Bell KNI. 2001. The surf zone ichthyoplankton adjacent to an intermittently open estuary, with evidence of recruitment during marine overwash events. Estuarine, Coastal and Shelf Science 52: 339-348.

CSIRO. 2000. Huon Estuary Study: Environmental Research for Integrated Catchment Management and Aquaculture. Project No. 96/284, Final Report to the Fisheries Research and Development Corporation. 285 pp.

Cyrus DP. 1988a. Turbidity and other physical factors in Natal estuarine systems. Part 1: Selected estuaries. Journal of the Limnological Society of Southern Africa 14: 60-71.

Cyrus DP. 1988b. Turbidity and other physical factors in Natal estuarine systems. Part 2: Estuarine lakes. Journal of the Limnological Society of Southern Africa 14: 72-81.

Cyrus DP and Blaber SJM. 1987a. The influence of turbidity on juvenile marine fishes in estuaries. Part 1: Field observations at Lake St Lucia on the southeastern coast of Africa. Journal of Experimental Marine Biology and Ecology 109: 53-70.

Cyrus DP and Blaber SJM. 1987b. The influence of turbidity on juvenile marine fishes in estuaries. Part 2: Laboratory studies, comparisons with field data and conclusions. Journal of Experimental Marine Biology and Ecology 109: 71-91.

Cyrus DP and Blaber SJM. 1987c. The influence of turbidity on juvenile marine fishes in the estuaries of Natal, South Africa. Continental Shelf Research 7: 1411-1416.

Cyrus D, Jerling H, MacKay F and Vivier L. 2011. Lake St Lucia, Africa's largest estuarine lake in crisis: Combined effects of mouth closure, low levels and hypersalinity. South African Journal of Science 107: 1-13.

Daily G, Matson P and Vitousek P. 1997. Ecosystem services supplied by soil. In: Daily G. (ed). Nature's Services: Societal dependence on natural ecosystems. Island Press, Washington DC, pp 124-125.

Day JH. 1980. What is an estuary? South African Journal of Science 76: 198.

Day JH. 1981. Estuarine ecology with particular reference to southern Africa. Balkema, Cape Town, 411 pp.

Day JH, Blaber SJM and Wallace JH. 1981. Estuarine fishes. In: Day JH. (ed). Estuarine ecology with particular reference to southern Africa. Balkema, Cape Town, pp 197-221.

Day, JW, Hal, CAS, Kemp WM and Yáñez-Arancibia A. 1989. Estuarine Ecology. John Wiley & Sons Inc., Toronto, 558 pp.

de Freitas AJ. 1986. Selection of nursery areas by six southeast African Penaeidae. Estuarine, Coastal and Shelf Science 23: 901–908.

Demetriades N. 2007. An inventory of sandmining operations in KwaZulu-Natal: Mtamvuna to Thukela. Investigational Report for Coastwatch, WESSA, KZN, 31 pp.

Department of Agriculture and Environmental Affairs (DAEA) and Oceanographic Research Institute (ORI). 2011. KwaZulu-Natal Coastal Vulnerability Assessment, background to CVI determination. Department of Agriculture and Environmental Affairs, Cedara.

Department of Environmental Affairs and Tourism (DEAT). 2006. South Africa Environmental Outlook. A Report on the State of the Environment. Department of Environmental Affairs and Tourism, Pretoria.

Department of Water Affairs and Forestry (DWAF). 1999. Resource directed measures for protection of water resources. Volume 2: Integrated manual, Version 1.0. Pretoria, South Africa.

Department of Water Affairs (DWA). 2010. Resource Directed Measures for protection of water resources: Methods for the Determination of the Ecological Reserve for Estuaries. Water Resource Protection and Assessment Policy Implementation Process: Version 3, Pretoria.

Department of Water Affairs (DWA). 2011. IEM Series training manual: 2nd Edition, Pretoria.

De Villiers CJ, Hodgson AN and Forbes AT. 1999. Studies on estuarine macroinvertebrates. In: Allanson BR and Baird D. (eds). Estuaries of South Africa. Cambridge University Press, Cambridge, pp 167-207.

Di Gregorio A. 2005. Land cover classification system, classification concepts and user manual, Food and Agriculture Organization of the United Nations, Rome.

Dolbeth M, Cardoso PG, Ferreira SM, Verdelhos T, Raffaelli D and Pardal MA. 2007. Anthropogenic and natural disturbance effects on a macrobenthic estuarine community over a 10-year period. Marine Pollution Bulletin 54: 576-585.

Dollar ESJ, Brown CA, Turpie JK, Joubert AR, Nicolson CR and Manyaka S. 2006. The development of the Water Resource Classification System (WRCS). Vol 1: Overview and 7-step classification procedure. CSIR and Department of Water Affairs and Forestry, Pretoria.

Eagle RA. 1975. Natural fluctuations in a soft bottom benthic community. Journal of the Marine Biological Association of the United Kingdom 55:865-878.

Edwards R. 2012. Proposed Nonoti Beach Tourism Development in the KwaDukuza Local Municipality, KwaZulu-Natal: Draft Scoping Report. Report No. DC29/0022/2011, SiVest, 34 pp.

Elliott M, Whitfield AK, Potter IC, Blaber SJ, Cyrus DP, Nordlie FG and Harrison TD. 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish and Fisheries 8: 241–268.

Ellis-Tabanor M and Hyslop E. 1995. Effect of sublethal concentrations of endosufan on growth and fecundity of two species of snails. Bulletin of Environmental Contamination and Toxicology 74: 1173-1178.

EMATEK CSIR. 1995. Coastal Dynamics in KwaZulu-Natal. Town and Regional Planning Supplementary Report: Volume 41. 62 pp

European Union. 2000. Parlimentary and council directive 92/43/EEC of 21st May 1992 on the Conservation of natural habitats and world fauna and flora. Official Journal L206, European Commission, Brussels.

Fichera CR, Modica G and Pollino M. 2012. Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics, European Journal of Remote Sensing 45: 1-18.

Flint RW and Kalke RD. 1986. Niche characterization of dominant estuarine benthic species. Estuarine, Coastal and Shelf Science 22:657-674.

Forbes AT and Cyrus DP. 1993. Biological effects of salinity gradient reversals in a southeast African estuarine lake, Netherlands Journal of Aquatic Ecology 27: 483-488.

Forbes NT and Forbes AT. 2011. Nonoti Estuary: Background, history, present status and assessment of proposed Nonoti Estate. Marine and Estuarine Research Report prepared for Mr S. Wiggill and Sustainable Development Projects: Version 2. 32 pp.

Forbes AT, Niedinger S and Demetriades NT. 1994. Recruitment and utilisation of nursery grounds by penaeid prawn postlarvae in Natal, South Africa. In: Dyer KR and Orth RJ. (eds). Changes in Fluxes in Estuaries: Implications from Science to Management. Olsen & Olsen, Fredensborg, pp. 379–384.

Franco A, Franzoi P, Malavasi S, Riccato F, Torricelli P and Mainardi D. 2006. Use of shallow water habitats by fish assemblages in a Mediterranean coastal lagoon. Estuarine, Coastal and Shelf Science 66: 67-83.

Froneman PW. 2002. Response of the plankton to three different hydrological phases of the temporarily open/closed Kasouga Estuary, South Africa. Estuarine, Coastal and Shelf Science 55: 535-546.

Gangai I and Ramachandran S. 2010. The role of spatial planning in coastal management—A case study of Tuticorin coast (India). Land Use Policy 27: 518-534.

Gilbert J and Vellinga P. 1990. Coastal Zone Management. Intergovernmental Panel on Climate Change, The Hague.

Giri CP. 2012. Remote sensing of Land Use and Land Cover, Principals and Applications. CRC Press, Taylor and Francis Group, Boca Raton.

Goble BJ and Mackay CF. 2013. Developing risk set-back lines for coastal protection using shoreline change and climate variability factors. Proceedings 12th International Coastal Symposium (Plymouth, England). Journal of Coastal Research Special Issue 65: 2125-2130.

Goldewijk KK. 2001. Estimating Global Land Use Change over the Past 300 years: the HYDE Database. Global Biogeochemistry Cycles 15: 417–433.

Gordon N, Adams JB and Bate GC. 2008. Epiphytes of the St. Lucia Estuary and their response to water level and salinity changes during a severe drought. Aquatic Botany 88: 66-76.

Graham DJ and Midgley NG. 2000. Graphical representation of particle shape using triangular diagrams: An Excel spreadsheet method. Earth Surface Processes and Landforms 25: 1473-1477.

Gray JS. 1981. The Ecology of Marine Sediments: An introduction to the structure and function of benthic communities. Cambridge University Press, Cambridge.

Gründlingh M.L. and Pearce A.F. (1990). Frontal features of the Agulhas Current in the Natal Bight. South African Geographical Journal 72: 11–14.

Haedrich RL. 1983. Estuarine fishes. In: Ketchum BH. (ed). Ecosystems of the world 26: Estuaries and enclosed seas. Elsevier Scientific Publishing Company, Amsterdam, pp 183-207.

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EM, Perry MT, Seliq ER, Spalding M, Steneck R and Watson R. 2008. A global map of human impact on marine ecosystems. Science 319: 948–952.

Hanekom N and Baird D. 1984. Fish community structures in *Zostera* and non-*Zostera* regions in the Kromme Estuary, St Francis Bay. South African Journal of Zoology 19: 295-301.

Harrison TD. 2002. Preliminary assessment of the biogeography of fishes in South African estuaries, Marine and Freshwater Research 53: 479-490.

Harrison TD. 2003. Biogeography and community structure of fishes in South African estuaries. PhD thesis, Rhodes University, 229 pp.

Harrison TD and Whitfield AK. 2006. Estuarine typology and the structuring of fish communities in South Africa, Environmental Biology of Fishes 75: 269-293.

Harrison T D and Whitfield AK. 2008. Geographical and typological changes in fish guilds of South African estuaries. Journal of Fish Biology 73: 2542-2570.

Hockey PAR, Dean WRJ and Ryan PG. 2005. Roberts - Birds of Southern Africa: VII Edition. The Trustees of the John Voelcker Bird Book Fund, Cape Town, 1296 pp.

Houghton RA. 1994. The Worldwide Extent of Land-use Change. BioScience 44: 305-313.

Humphries P, Potter IC and Loneragan NR. 1992. The fish community in the shallows of a temperate Australian estuary: Relationships with the aquatic macrophyte *Ruppia megacarpa* and environmental variables. Estuarine, Coastal and Shelf Science 34: 325-346.

iLembe District Municipality. 2012. iLembe District Municipality: 5 Year 2012/2017 IDP. iLembe District Municipality, South Africa.

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, 32 pp.

IUCN. 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. Downloaded on 19 December 2013.

Karatayev AY, Burlakova LE, Karatayev VA and Padilla DK. 2009. Introduction, distribution, spread, and impacts of exotic freshwater gastropods in Texas. Hydrobiologia 619: 181-194.

Kemp JOG and Froneman PW. 2004. Recruitment of ichthyoplankton and macrozooplankton during overtopping events into a temporarily open/closed southern African estuary. Estuarine, Coastal and Shelf Science 61: 529-537.

Kennish MJ. 1986. Ecology of Estuaries. Vol. 1: Physical and Chemical Aspects. CRC Press Inc, Florida, 405 pp.

Kennish MJ. 1994. Marine Biology. In: Kennish MJ. (ed). Practical Handbook of Marine Science: 2nd Edition. CRC Press Inc, Florida.

King L. 1972. The Natal Monocline, explaining the origin and scenery of Natal, South Africa. Geology Department, University of Natal, Durban.

KwaDukuza Municipality. 2009. KwaDukuza SDF and LUMS, Spatial Development Framework. KwaDukuza Municipality, South Africa.

KwaDukuza Municipality. 2012. KwaDukuza Municipality Integrated Development Plan 2012/17. KwaDukuza Municipality, South Africa.

Kyle R. 1989. A mass mortality of fish at Kosi Bay. Lammergeyer 40: 39.

Kyle R. 1995. Wise use of wetlands by rural indigenous people. The Kosi Bay Nature Reserve: A case study. In Cowan GI. (ed). Wetlands of South Africa. Department of Environmental Affairs and Tourism, Pretoria, pp 273-291.

Laffoley D d'A. 2008. Towards Networks of Marine Protected Areas. The MPA Plan of Action for IUCN's World Commission on Protected Areas. IUCN WCPA, Gland, Switzerland, 28 pp.

Lamberth SJ and Turpie JK. 2003. The Role of Estuaries in South African Fisheries: Economic Importance and Management Implications. African Journal of Marine Science 25: 131-157.

Lamberth SJ, Drapeau L and Branch GM. 2009. The effects of altered freshwater inflows on catch rates of non-estuarine-dependent fish in a multispecies nearshore linefishery. Estuarine, Coastal and Shelf Science 84: 527–538.

Lambin E F, Turner BL, Geist HJ, Agbola SC, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C and Xu J. 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11: 261-269.

Levy K. 2004. Neglected consequences: Role of introduced aquatic species in the spread of infectious diseases. EcoHealth 1: 296-305.

Long BG and Poiner IR. 1994. Infaunal benthic community structure and function in the Gulf of Carpentaria, Northern Australia. Australian Journal of Marine and Freshwater Research 45:293-316.

Lopoukhine, N. 2008. Protected areas – For Life's sake. Protected Areas in Today's World: Their Values and Benefits for the Welfare of the Planet. Secretariat of the Convention on Biological Diversity, Technical Series no. 36, pp 1-3.

Lubowski RN, Plantinga AJ and Stavins RN. 2003. Determinants of land use change in the United States 1982-1997. Discussion Paper 03–47, Resources for the Future, Washington D.C.

Ludwig JA and Reynolds JF. 1988. Statistical Ecology: A primer on Methods and Computing. John Wiley & Sons Inc., Toronto, 337 pp.

Lynch SD. 2004. Development of a raster database of annual, monthly and daily rainfall for Southern Africa. WRC Report 1156/1/04. Water Research Commission, Pretoria, 78 pp.

MacKay CF. 1996. The benthos of the Siyaya estuary: species composition, density and distribution. Unpublished MSc Thesis, University of Zululand, 230 pp.

MacKay CF and Cyrus DP. 2001. Is freshwater quality adequately defined by physico-chemical components? Results from two drought-affected estuaries on the east coast of South Africa. Marine and Freshwater Research 52:267-281.

Margalef R. 1961. Information theory in ecology. General Systems 3:36-71. In: Kastoro W, Aswandy I, Al Hakim I, De Wilde PAWJ. and Everaarts JM. 1989. Soft-bottom benthic community in the Estuarine waters of East Java. Netherlands Journal of Sea Research 23:463-472.

Martínez ML, Intralawan A, Vázquez G, Pérez-maqueo O, Sutton P and Landgrove R. 2006. The coasts of our world: Ecological, economic and social importance. Ecological Economics 63: 254-272.

Matoti A, Boyd A and de Villiers P. 2008. C.A.P.E. Estuaries Programme Newsletter Volume 1, 2 pp.

McCormick S, Cooper JAG and Mason TR. 1992. Fluvial sediment yield to the Natal coast: a review. Southern African Journal of Aquatic Sciences 18: 74-88.

McLusky DS. 1974. Ecology of Estuaries. Heinemann Educational Books Ltd., London, 144 pp.

McLusky DS. 1981. The estuarine ecosystem. Blackie & Son Limited, Glasgow, 150pp.

McLusky DS and Elliott M. 2004. The Estuarine Ecosystem: ecology, threats and management. Oxford University Press, Oxford.

Mead A, Carlton JT, Griffiths CL and Rius M. 2011. Introduced and cryptogenic marine and estuarine species of South Africa. Journal of Natural History 45: 2463-2524.

Methods for the Improvement of Vulnerability Assessment in Europe (MOVE). 2010. D5: Generic conceptual framework for vulnerability measurement. European Commission DG Environment Seventh Framework Programme Cooperation: Theme 6 – Environment (including Climate Change), WP 2 "Building the new framework and the guidelines", 27 pp.

Metzeling L. 1993. Benthic macroinvertebrate community structure in streams of different salinities. Australian Journal of Marine and Freshwater Research 44: 335-351.

Miranda NAF, Perissinotto R and Appleton CC. 2011. Population structure of an invasive parthenogenetic gastropod in coastal lakes and estuaries of northern KwaZulu-Natal, South Africa. PlosOne 6: 1-8.

Moes H. and Rossou, M. 2008. Considerations for the utilization of wave power around South Africa. Workshop on Ocean Energy, Centre for Renewable and Sustainable Energy Studies, Stellenbosch.

Morant PD and Quinn NW. 1999. Influence of man and management of South African estuaries. In: Allanson BR and Baird D. (eds). Estuaries of South Africa. Cambridge University Press, Cambridge, pp 289-320.

Morgan JA, Dejong RJ, Snyder SD, Mkoji GM and Loker ES. 2001. *Schistosoma mansoni* and *Biomphalaria*: past history and future trends. Parasitology 123(7): 211-228.

Moss A, Cox M, Scheltinga D and Rissik D. 2006. Integrated estuary assessment framework. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Technical Report 69, 93 pp.

Nagelkerken I, Blaber SJM, Bouillon S, Green P, Haywood M, Kirton LG, Meynecke JO, Pawlik J, Penrose HM, Sasekumar A and Somerfield PJ. 2008. The habitat function of mangroves for terrestrial and marine fauna: A review. Aquatic Botany 89: 155-185.

Ngubane J, Pupuma F, Kiepel J, Diab R, Garland G, Harris J, Mann B, Tomalin B, Taylor R, Elliot B and Sink K. 1997. Preliminary characterisation and assessment of the South African coast: Hibiscus Coast Region. Coastal Zone Policy Programme, 1st Draft.

Nicholls RJ and Cazenave A. 2010. Sea-level rise and its impact on coastal zones. Science 18: 1517-1520

Odum EP. 1971. Fundamentals of ecology. WB Saunders Company, Philadelphia, 574 pp.

Palmer BJ, Van der Elst R, Mackay F, Mather AA, Smith AM, Bundy SC, Thackeray Z, Leuci R and Parak O. 2011. Preliminary coastal vulnerability assessment for KwaZulu-Natal, South Africa, Journal of Coastal Research SI64: 1390-1395.

Papadopoulos I, Wooldridge T and Newman BK. 2002. Larval life history strategies of sub-tropical, southern African, estuarine brachyuran crabs and implications for tidal inlet management. Wetlands Ecology and Management 10: 249-256.

Paterson AW and Whitfield AK. 2000. The ichthyofauna associated with an intertidal creek and adjacent eelgrass beds in the Kariega Estuary, South Africa. Environmental Biology of Fishes 58: 145-156.

Perissinotto R, Nozais C and Kibirige I. 2002. Spatio-temporal dynamics of phytoplankton and microphytobenthos in a South African temporarily-open Estuary. Estuarine, Coastal and Shelf Science 55: 47-58.

Perissinotto R, Blair A, Connell A, Demetriades N, Forbes AT, Harrison TD, Iyer K, Joubert M, Kibirige I, Mundree S, Simpson H, Stretch D, Thomas S, Thwala X, and Zietsman I. 2004. Contributions to information requirements for the implementation of resource directed measures for estuaries.

Volume 2: Responses of the biological communities to flow variation and mouth state in two KwaZulu-Natal temporarily open/closed estuaries. WRC Report No. 1247/2/04. Water Research Commission, Pretoria.

Perissinotto R, Stretch DD, Whitfield AK, Adams JB, Forbes AT and Demetriades NT. 2010. Temporarily open/closed Estuaries in South Africa. Nova Science Publishers Inc., New York.

Pielou EC. (1986). The Measurement of diversity in different types of biological collection. Journal of Theoretical Biology, 13:131-144. In: Kastoro W, Aswandy I, Al Hakim I, De Wilde PAWJ. and Everaarts JM. 1989. Soft-bottom benthic community in the Estuarine waters of East Java. Netherlands Journal of Sea Research 23:463-472.

Pointier JP. 2001. Invading freshwater snails and biological control in Martinique Island, French West Indies. Memorias do Instituto Oswald Crus, Rio de Janeiro, 96: 67-74.

Prasetya G. 2013. Chapter 4: Protection From Coastal Erosion, thematic paper: The role of coastal forests and trees in protecting against coastal erosion. FAO Corporate Document Repository. At: http://www.fao.org/docrep/010/ag127e/AG127E09.htm [22 August 2013].

Potter IC, Beckley LE, Whitfield AK and Lennanton CJ. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate western Australia and southern Africa. Environmental Biology of Fishes 28: 143-178.

Preston-Whyte R and Oelofse C. 2007. Managing Coastal Tourism Resorts, A Global Perspective. In: Agarwal A and Shaw G. (eds.). Multilingual Matters, London, pp 187-203.

Rajkaran A, Adams J and Taylor RH. 2009. Historic and recent (2006) state of mangroves in small estuaries from Mlalazi to Mtamvuna in KwaZulu-Natal, South Africa. Southern Forests: a Journal of Forest Science 71: 287-296.

Reavell PE and Cyrus DP. 1989. Preliminary Observations on the Macrocrustacea of Coastal Lakes in the vicinity of Richards Bay, Zululand, South Africa. Southern African Journal of Aquatic Sciences 15:103-128.

Romine BM, Fletcher CH, Frazer LN, Genz AS, Barbee MM and Lim S. 2009. Historical Shoreline Change, Southeast Oahu, Hawaii: Applying Polynomial Models to Calculate Shoreline Change Rates. Journal of Coastal Research 25: 1236-1253.

Rooseboom A. 1975. Sediment produksiekaart vir Suid- Afrika. Department of Water Affairs and Environmental Conservation Technical Report 61: 1-13.

Roussouw, J. 1989. Design waves for the South African coastline. Unpublished PhD Thesis, University of Stellenbosch, 169 pp.

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV and Woolmer G. 2002. The human footprint and the last of the wild. Bioscience 52: 891–904.

Schlacher TA and Wooldridge TH. 1996. Ecological responses to reductions in freshwater supply and quality in South Africa’s estuaries: lessons for management and conservation. Journal of Coastal Conservation 2: 115–130.

Scholes RJ and Biggs R. 2005. A biodiversity intactness index. Nature 434: 45-49

Schulze RE and Lynch SD. 2007. Annual Precipitation. In: Schulze RE. (ed.). South African Atlas of Climatology and Agrohydrology. WRC Report 1489/1/06, Section 6.2. Water Research Commission, Pretoria.

Schumacher BA. 2002. Methods for the determination of total organic carbon (TOC) in soils and sediments. Technical Document, USEPA.

Shannon CE and Weaver W. 1963. The Mathematical Theory of Communication. University Illinois Press, Urbane. 117pp. In: Kastoro W, Aswandy I, Al Hakim I, De Wilde PAWJ. and Everaarts JM. 1989. Soft-bottom benthic community in the Estuarine waters of East Java. Netherlands Journal of Sea Research 23:463-472.

Singels A, Ferrer S, Leslie GW, Mcfarlane SA, Sithole P and Van Der Laan M. 2011. Review of South African sugarcane production in the 2010/2011 season from an agricultural perspective. Proceedings of the South African Sugar Technological Association 84: 66-83.

Skelton PH. 1993. A complete guide to the freshwater fishes of southern Africa. Southern Book Publishers, Halfway House, 388 pp.

Skirrow G. 1965. The dissolved gases: Carbon dioxide. In: Riley JP and Skirrow G. (eds). Chemical oceanography. Academic Press, London, pp 312-316.

Smith MM and Heemstra PC. 1991. Smith's Sea Fishes: 1st Edition. Southern Book Publishers, Johannesburg, 1048 pp.

Smith A, Mather A., Guastella L, Cooper JAG, Ramsay PJ, and Theron A. 2010. Contrasting styles of swell-driven coastal erosion: examples from KwaZulu-Natal, South Africa. Geological Magazine 147: 940-953.

South African Sugarcane Research Institute. Unknown. Sustainable Sugarcane Initiative, Using an eco-agricultural approach to Watershed management. South African Sugarcane Research Institute and Mondi Wetlands Programme, South Africa.

Stow CA. 2011. Spatial and temporal variations in macrozoobenthic communities in KwaZulu-Natal temporarily open/closed estuaries. Unpublished MSc thesis, University of KwaZulu-Natal, 257pp.

Taljaard S and Van Niekerk L. 2007. Proposed generic framework for estuarine management plans. C.A.P.E. Generic Estuary Management Plan, Version 1, 43 pp.

Taljaard S, Van Niekerk L and Joubert W. 2009. Extension of a qualitative model on nutrient cycling and transformation to include microtidal estuaries on wave-dominated coasts: Southern hemisphere perspective. Estuarine, Coastal and Shelf Science 85: 407–421.

Teal JM. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43: 614-624.

Ter Morshuizen LD, Whitfield AK and Paterson AW. 1996. Influence of freshwater flow regime on fish assemblages in the Great Fish River and Estuary. South African Journal of Aquatic Science 22: 52-61.

Teske PR and Wooldridge TH. 2001. A comparison of the macrobenthic faunas of permanently open and temporarily open/closed South African estuaries. Hydrobiologia 464: 227-243.

Teske PR and Wooldridge TH. 2003. What limits the distribution of subtidal macrobenthos in permanently open and temporarily open/closed South African estuaries? Salinity vs. sediment particle size. Estuarine, Coastal and Shelf Science 57: 225-238.

Teske PR and Wooldridge TH. 2004. Affinities of some common estuarine macroinvertebrates to salinity and sediment type: empirical data from Eastern Cape estuaries, South Africa. African Zoology 39: 183-192.

Thompson MW, van den Berg HM, Newby TS and Hoare D. 2001. Guideline Procedures for National Land-Cover Mapping and Change Monitoring. Council for Scientific and Industrial Research (CSIR) and Agricultural Research Council (ARC), Pretoria.

Tinley K.L. 1985. Coastal dunes of South Africa. South African National Scientific Programmes Report 109, 304 pp.

Tolley-Jordan LR and Owen JM. 2008. Habitat influences snail community structure and trematode infection levels in a spring-fed river, Texas, USA. Hydrobiologia 600: 29-40.

Traynor CH. 2008. *Juncus kraussii* harvesting in Umlalazi Nature Reserve, KwaZulu-Natal, South Africa: socio-economic aspects and sustainability. African Journal of Aquatic Science 33: 27-36.

Turner L, Tracey D, Tilden J and Dennison WC. 2004. Where River meets Sea: exploring Australia's estuaries. Cooperative Research Centre for Coastal Zone Estuary and Waterway Management, Brisbane, Australia, 278 pp.

Turpie J. 1999. Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystems. Appendix E4, Version 1, Draft 3. DWAF, 15 pp.

Turpie J. 2012. The Estuary Health Index: A standardised metric for use in estuary management and the determination of ecological water requirements. WRC Report No. 1930/1/12. Water Research Commission, Pretoria, 84 pp.

Turpie JK, Adams JB, Joubert A, Harrison TD, Colloty BM, Maree RC, Whitfield AK, Wooldridge TH, Lamberth SJ, Taljaard S and Van Niekerk L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA 28: 191-206.

Turpie JK and Clark B. 2007. The health status, conservation importance and economic value of temperate South African estuaries and development of a regional conservation plan. C.A.P.E. Regional Estuarine Management Programme.

Turpie JK, Wilson G and Van Niekerk L. 2012. National Biodiversity Assessment 2011: National Estuary Biodiversity Plan for South Africa. Anchor Environmental Consultants, Cape Town. Report produced for the Council for Scientific and Industrial Research and the South African National Biodiversity Institute.

UNEP/Nairobi Convention Secretariat, CSIR & WIOMSA. 2009. Regional synthesis report on the status of pollution in the Western Indian Ocean Region. UNEP, Nairobi, Kenya, 134 pp.

U.S. Environmental Protection Agency (USEPA). 1993. Volunteer Estuary Monitoring: A Methods Manual. EPA 842-B-93-004. Washington DC, 176 pp. At: http://www.epa.gov/owow/estuaries/monitor/.

USEPA. 2003. Ambient water quality criteria for dissolved oxygen, water clarity and Chlorophyll a for the Chesapeake Bay and its tidal tributaries. EPA 903-R-03-002. Washington DC.

USEPA 2013. USEPA program for Climate Ready Estuaries (CRE). At: http://water.epa.gov/type/oceb/cre [19 September 2013].

Van Ballegooyen RC, Taljaard S, van Niekerk L, Lamberth SJ, Theron AK and Weerts SP. 2007. Freshwater flow dependency in South African marine ecosystems: a proposed assessment framework and initial assessment of South African marine ecosystems. WRC Report No. KV 191/07. Water Research Commission, Pretoria.

Van de Bund WJ and Groenendijk D. 1994. Seasonal dynamics and burrowing of littoral chironomid larvae in relation to competition and predation. Archives Für Hydrobiologie 132: 213-225.

Van Niekerk L and Turpie JK. 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch, 225 pp.

Van Niekerk L, Lamberth S, Cowley P, Huizinga P, Hutchings K, Mann B, Petersen C and Taljaard S. 2012. Key pressures on estuaries. In: Van Niekerk L and Turpie JK. (eds.). South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch, pp 66-85.

Van Niekerk L, Petersen C, April V, Daniels F, Maherry A, Malebu T. 2012. The estuarine functional zone. In: Van Niekerk L and Turpie JK. (eds.). South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch, pp 28-36.

Van Niekerk L, Adams JB, Bate GC, Forbes AT, Forbes NT, Huizinga P, Lamberth SJ, MacKay CF, Petersen C, Taljaard S, Weerts SP, Whitfield AK and Wooldridge TH. 2013. Country-wide assessment of estuary health: An approach for integrating pressures and ecosystem response in a data limited environment. Estuarine, Coastal and Shelf Science *in press* 1-13 pp.

Vitousek PM. 1994. Beyond Global Warming. Ecology 75: 1861-1876.

Vorwerk PD, Whitfield AK, Cowley PD and Paterson AW. 2003. The influence of selected environmental variables on fish assemblage structure in a range of southeast African estuaries. Environmental Biology of Fishes 66: 237-247.

Wallace JH and van der Elst RP. 1975. The estuarine fishes of the east coast of South Africa. IV: Occurrence of juveniles in estuaries. V: Ecology, estuarine dependence and status. Investigational Report of the Oceanographic Research Institute, Durban 42: 1-63.

Wallace JH, Kok HM, Beckley LE, Bennett B, Blaber SJM and Whitfield AK. 1984. South African estuaries and their importance to fishes. South African Journal of Science 80: 203-207.

Wallace JH. 1975. The estuarine fishes of the east coast of South Africa. I: Species composition and length distribution in the estuarine and marine environments. II: Seasonal abundance and migrations. Investigational Report of the Oceanographic Research Institute, Durban 40: 1-72.

Water Framework Directive (Directive 2000/60/EC). 2000. Guidance Document 3: IMPRESS. At: http://www.wise-rtd.info/en/info/wfd-cis-guidance-documents. [11 October 2013]

Water Framework Directive (Directive 2000/60/EC) 2000. Directive of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

Weerts SP. 2011. The influence of mouth condition in temporary open closed estuaries on populations of estuarine fishes with different recruitment strategies. 14th SAMSS/49th ECSA International Conference, Rhodes University, Grahamstown, South Africa, Book of Abstracts, pp 116.

Weerts SP and Cyrus DP. 2002. Occurrence of young and small-sized fishes in different habitats within a subtropical South African estuary and adjacent harbour. Marine and Freshwater Research 53: 447-456.

Weerts SP, Cilliers G and Cyrus DP. 2003. Estuarine macrocrustacea of Richards Bay Harbour, South Africa, with particular reference to the penaeid prawns. African Zoology 38: 285-296.

Weerts SP, MacKay CF and Cyrus DP. 2014. The potential for a fish ladder to mitigate against the loss of marine–estuarine–freshwater connectivity in a subtropical coastal lake. Water SA 14 *in press*.

Wetzel RG. 1983. Limnology. CBS College Publishing, Philadelphia, 767 pp.

Whitfield AK. 1983. Factors influencing the utilization of southern African estuaries by fishes. South African Journal of Science 79: 362-365.

Whitfield AK. 1986. Fish community structure response to major habitat changes within the littoral zone of an estuarine coastal lake. Environmental Biology of Fishes 17: 41-51.

Whitfield AK. 1990. Life-history styles of fishes in South African estuaries. Environmental Biology of Fishes 28: 295–308.

Whitfield AK. 1992. A characterization of southern African estuarine systems. Southern African Journal of Aquatic Sciences 18: 89-103.

Whitfield AK. 1994a. An estuary-association classification for the fishes of southern Africa. South African Journal of Science 90: 411-417.

Whitfield AK. 1994b. A review of ichthyofaunal biodiversity in southern African estuarine systems. In: Teugels G, Guégan JF and Albaret JJ. (eds). Biological diversity of African fresh- and brackish water fishes. Annales du Musée Royal de l'Afrique Central no. 275, Tervuren. pp 149-163.

Whitfield AK. 1994c. Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. Marine Ecology Progress Series 105: 257-267.

Whitfield AK. 1994d. Fish species diversity in southern African estuarine systems: an evolutionary perspective. Environmental Biology of Fishes 40: 37-48.

Whitfield AK. 1995. Available scientific information on individual South African estuarine systems. WRC Report No. 577/1/95. Water Research Commission, Pretoria, 204 pp.

Whitfield AK. 1998. Biology and ecology of fishes in Southern African Estuaries. Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa. No. 2, 223 pp.

Whitfield AK. 1999. Ichthyofaunal assemblages in estuaries: A South African case study. Reviews in Fish Biology and Fisheries 9: 151-186.

Whitfield AK. 2000. Available scientific information on individual South African estuarine systems. WRC Report No. 577/3/00. Water Research Commission, Pretoria, 217 pp.

Whitfield AK and Bate GC. 2007. A review of information on temporarily open/closed estuaries in the warm and cool temperate biogeographic regions of South Africa, with particular emphasis on the influence of river flow on these systems. WRC Report No 1581/1/07. Water Research Commission, Pretoria, 232 pp.

Whitfield AK and Bok AH. 1998. Estuarine fishes. In: Lubke R and de Moor I. (eds.). Field guide to the Eastern and Southern Cape coasts. University of Cape Town Press, Rondebosch, pp 205-215.

Whitfield AK and Lubke RA. 1998. Estuarine and coastal lake ecology. In: Lubke R and de Moor I. (eds.). Field guide to the Eastern and Southern Cape coasts. University of Cape Town Press, Rondebosch, pp 216-231.

Whitfield AK and Marais JFK. 1999. The ichthyofauna. In: Allanson BR and Baird D. (eds). Estuaries of South Africa. Cambridge University Press, Cambridge, pp 209-233.

Whitfield AK, Blaber SJM and Cyrus DP. 1981. Salinity ranges of some southern African fish species occurring in estuaries. South African Journal of Zoology 16: 151-155.

Whitfield AK and Wooldridge TH. 1994. Changes in fresh-water supplies to southern African estuaries: some theoretical and practical considerations. In: Dyer KR and Orth RJ. (eds.). Changes in fluxes in estuaries: implications from science to management. Olsen & Olsen, Fredensburg, pp 41-50.

Whitfield AK, Adams JB, Bate GC, Bezuidenhout K, Bornman TG, Cowley PD, Froneman PW, Gama PT, James NC, Mackenzie B, Riddin T, Snow GC, Strydom NA, Taljaard S, Terorde AI, Theron AK, Turpie JK, Van Niekerk L, Vorwerk PD and Wooldridge TH. 2008. A multidisciplinary study of a small, temporarily open/closed South African estuary, with particular emphasis on the influence of mouth state on the ecology of the system. African Journal of Marine Science 30:453-473.

Williams LRR and Kapustka LA. 2000. Ecosystem vulnerability: a complex interface with technical components. Environmental Toxicology and Chemistry 19: 1055 –1058.

Williamson MH and Fitter A. 1996. The characters of successful invaders. Biological Conservation 78: 163-170.

Wilson E. 1992. The diversity of life. Harvard University Press, New York, 424 pp.

Wolff WJ. 1983. Chapter 3: Estuarine Benthos. In: Ketchum BH. (ed.). Ecosystems of the World 26: Estuaries and Enclosed Seas. Elsevier Scientific Publishing Company, New York, pp 151-182.

Wolmarans CT and De Kock KN. 2006. The current status of freshwater molluscs in the Kruger National Park. Koedoe 49: 39-44.

Wooldridge TH. 1994. The effect of periodic inlet closure on recruitment in the estuarine mudprawn, *Ubogebia africana*. In: Dyer KR and Orth RJ. (eds.). Changes in fluxes in estuaries: implications from science to management. Olsen & Olsen, Fredensburg, pp 329-333.

Wyda JC, Deegan LA, Hughes JE and Weaver MJ. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay. Estuaries 25:86-100.