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Knysna Estuary Management Plan: Situation Assessment Report

March 2022

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EXECUTIVE SUMMARY

The Knysna Estuary, an estuarine bay 1633 ha in extent, is located in the Knysna Section of the Garden Route National Park. The Knysna National Lake Area, which encompassed the Knysna Estuary, was proclaimed in 1985 under the Lake Areas Development Act. This was later repealed and the estuary and surrounds proclaimed as a Protected Environment under the National Environmental Management: Protected Areas Act.

The upper reaches of rivers flowing into the estuary are largely within the Garden Route National Park whilst the middle reaches are generally in privately owned areas supporting agriculture and forestry practices and with some indigenous vegetation. The estuary and surrounds have been modified by developments in the town of Knysna, including retaining structures, landfills, causeways, roads, factories, small-boat harbours, a waterfront complex, golf courses, and residential developments.

The climate in the region is moderate with maximum day-time temperatures in summer averaging 25.0°C, and 18.8°C in winter. South-westerly winds predominate most of the year, though warm northerly and north-easterly winds frequently occur in winter. The mean annual rainfall varies between 700 mm y^{-1} at the coast and 1161 mm y^{-1} in the Outeniqua Mountains at Buffelsnek, with average annual rainfall in the Knysna River catchment estimated at 928 mm y^{-1}. Rainfall occurs throughout the year with peaks generally experienced in February, March, May, September, November and December.

The Knysna River catchment lies within the Cape Fold Belt with long east-west orientated faults and folds. Most of the catchment lies in quartzite formation of the Table Mountain Group whilst mesozoic rock outcrops that weather into sand and mud occur in low-lying areas north of the estuary. The substratum of the estuary consists predominantly of unconsolidated sandy sediments of marine, fluvial and aeolian origin.

The Knysna River is significantly the largest river draining into the estuary. The main tributaries of the Knysna River are the Kruis, Rooiels and Gouna rivers. Smaller systems which flow into the estuary include the Salt, Bongani and Bigai rivers, and numerous drainage lines and stormwater inlets discharge surface waters directly into the estuary from surrounding lands, including much of Knysna town.

Reduced freshwater inflows into the Knysna Estuary can result in salinity periodically increasing up to 36 g kg^{-1} in the upper reaches. Such changes could be expected to have significant impacts on biota, and gradual reduction in both primary and secondary productivity. During floods, the salinity throughout the estuary can drop to almost 0 g kg^{-1}. Likely effects of flow reductions and modifications on the estuarine environment have been estimated within the reserve assessment for the estuary, with freshwater inflow guidelines presented to maintain a desired ecosystem condition.

Three different hydrographic regimes have been described in the estuary: 1. The marine embayment regime, (extending inland from the estuary mouth between 3 km during neap tides and 7.5 km during spring tides) which is well flushed by tidal flows and exhibits salinities and temperatures similar to that of the ocean; 2. The lagoon regime (extending inland from the upper reaches of the bay regime and seldom beyond White Bridge) which is flushed less rapidly and is considered a transition zone between the estuary and the marine embayment; 3. The estuary regime (extending inland from the upper reaches of the lagoon regime) which is strongly influenced by the inflow of freshwater from the Knysna River and demonstrates strong vertical stratification in salinity and water temperature.

Portions of the estuary near the mouth have, in the past, been found to be as deep as 16 m below MSL. The channel between the Knysna Heads is 120 m wide and up to 15 m deep. The main channel becomes progressively shallower along its length, and is approximately 2 m in depth at the end of the tidal reach. There are no recent bathymetric maps of the estuary. Prior to the 1990's, siltation in the estuary from external sources was considered to be virtually absent, with perceived siltation emanating from the internal movement of sediments. Siltation problems within the estuary generally occur where artificial structures such as bridges and causeways have been constructed.

The earliest water chemistry data was collected in 1952, and illustrated how salinity, pH and dissolved oxygen vary along the longitudinal axis of the estuary. Water quality assessments undertaken from 1990 to 1994, when compared with earlier datasets (1952 to 1984), demonstrated that no clear long-term changes in recorded parameters at that time. Water temperatures vary seasonally with maximum temperatures of 29°C in summer and minimum temperatures (outside of marine upwelling events) of 12°C in winter. Ocean temperatures are generally colder than estuary temperatures, with variations in water temperature occurring within the estuary due to tidal fluctuations.

Overall, the Knysna Estuary can be considered a nutrient poor (oligotrophic) system due mainly to the large volumes of nutrient poor marine waters that pass through the Heads twice daily. Changes in nutrient levels are affected by specific events such as river flooding and stormwater inflows. Localised regions of high nutrient inputs can result from stormwater and sewage plant inflows. Changes in the nutrient levels in sediments in these areas have been noted, with periodic eutrophication resulting in localised proliferation of algae, and die-back of eelgrass.

Thirty-nine phytoplankton species have been recorded in the estuary. The zooplankton community is numerically dominated by copepods, with species composition varying spatially and influenced by the hydrodynamics of the system. Macrophytes (e.g., salt marsh plants, seagrass, sedges, and reeds) act as a nutrient sink, are an important food source for estuarine biota, and provide a refuge and nursery to many fish and invertebrate species. Intertidal salt marsh plants dominate the estuary (551.9 ha) followed by submerged macrophytes, consisting mainly of Cape eelgrass *Zostera capensis* and paddleweed *Halophilla ovalis* (447.3 ha), supratidal salt marsh species (133 ha), and reeds and sedges (37.8 ha). The Knysna Estuary supports the largest and most stable remaining stands of *Cape eelgrass* in South Africa, estimated at 353 ha. Recent assessments have found the extent of eelgrass beds within the estuary to be increasing. Several anthropogenic threats to intertidal wetlands occur including trampling and sediment compaction from people traffic and unmoored boats; the uprooting of plants and sediment disturbance from the collection of benthic bait organisms such as prawns; the construction of causeways and housing developments; and siltation resulting from poor catchment management.

The invertebrate fauna in Knysna Estuary is dominated by benthic (mud dwelling) species, with relatively low faunal diversity found on the sparse rocky banks. Approximately 310 species of benthic macrofauna have been listed in the Knysna Estuary. The critically endangered false limpet *Siphonaria compressa* has been found in intertidal eelgrass meadows at Bollard Bay, while the protected pansy shell, *Echinodiscus bisperforatus* occurs and breeds on sand banks in the main channel of the estuary.

Seventy-three fish species have been recorded in the Knysna Estuary. Marine estuarine-dependent and marine estuarine-opportunistic species numerically dominate the fish community, with Sparidae and Mugilidae being the most important families. The Knysna Estuary is home to the endangered Knysna seahorse *Hippocampus capensis,* whilst the rare estuarine Dwarf goby *Pandaka silvana* is also endemic to this system.

Sixty-seven waterbird species have been recorded on the Knysna Estuary. The estuary supports globally significant abundances of African Black Oystercatcher, along with substantial numbers of waders and other shorebirds (eg. curlew sandpiper, grey plover, whimbrel and greenshank) in summer, and larger piscivorous birds (eg. cormorants, herons and egrets) in winter. Densities have been described as low, with higher abundances in summer due to the seasonal influx of Palearctic migrants. Low bird abundances have been assumed to be due to disturbance from bait collection and recreational activities, as well as low invertebrate densities. Additional pressures on estuarine birds not necessarily confined just to the estuary include dwindling availability of prey due to overfishing and shifts in distributions of prey species likely due to climate change, harassment by dogs, loss of breeding habitat, and hunting along migration routes.

Out of the 290 estuaries in South Africa, Knysna has been rated highest in terms of conservation importance and ecosystem service provision in South Africa, and supports an estimated 42% of the country's estuarine plant and vertebrate biodiversity. This rating was determined by comparing biota (plants, invertebrates, fish and birds), size, biogeographic zone, rarity of estuary type and habitat diversity across all estuaries in the country.

The current ecological status of the Knysna Estuary, as well as its desired future status were assessed during reserve determination studies, with the system currently categorised as a B (largely natural with few modifications). The biotic health of the system is not as good as the physical habitat and due to this disparity, the ecological state is given in the 2018 National Biodiversity Assessment as a B/C. The Knysna Estuary falls within a protected area and therefore should ideally be Category A (unmodified, natural) or Best Attainable State (BAS). Achievement of an A is impossible given current developments and pressures; hence, the Recommended Ecological Category is BAS which is a B.

An intermediate reserve assessment in 2006 modelled various water use and development scenarios. The massive tidal exchange significantly mitigates anthropogenic nutrient inputs. Due to the marine nature of the system, any impacts of freshwater abstraction will be felt predominantly in the upper reaches of the estuary above the Red Bridge. So, while most abstraction scenarios result in the whole estuary having an Ecological Category of a Low B, it must be recognised that the impact of the scenarios in the upper reaches will be far more severe. The system is also on a negative trajectory in terms of ecosystem health, which is driven predominantly by anthropogenic non-flow factors.

The value of ecosystem services supplied by the Knysna Estuary has been estimated at between R1,258 billion and R1,311 billion per year. The larger value is based on studies undertaken up to 2005 and both the methods used and values estimated at that time are likely outdated by now. A preliminary list of ecosystem services, which could potentially serve as a basis for more detailed studies, include i) provisioning services including freshwater from the Knysna River; fish and bait resources; direct and indirect livelihood/job provision. ii) regulatory services, which include waste dilution; storm water regulation; carbon sink in the form of seagrass beds; and iii) cultural services including aesthetic value; recreation; sense of place and cultural heritage; spiritual and social experiences; opportunities for scientific knowledge generation; environmental education.

There are various environmental pressures and threats to Knysna Estuary, including alien species, climate change, exploitation of natural resources, pollution, freshwater flow reduction, land-use change and infrastructure development. Within the Knysna Estuary, 22 alien species have been recorded covering a range of taxa. Expected impacts of climate change on South Africa's estuaries include wind regime shifts; increasing air temperature; modification of terrestrial climatic and hydrological processes; ocean acidification and estuarine pH shifts; sea level rise; increasing wave energy; increasing frequency and intensity of coastal storms; changed upwelling and biogeochemical inputs from coastal waters; and water temperature shifts . Due to the large marine influence on the Knysna Estuary, climate impacts are more likely to originate mostly from marine processes rather than terrestrial. These would include impacts of coastal storms and storm surges, sea level rise, changes in oceanographic currents and the influence of wind-induced upwelling.

Knysna is located within a national coastal corridor, as well as a national development corridor, and extensive development and transformation of the estuary's shoreline and surrounds has occurred over the years. Numerous challenges exist with aging infrastructure, significant backlogs in the upgrade of roads and storm water systems, and a strained wastewater treatment plant that contribute to increasing pollution of the Knysna Estuary.

Over-exploitation of natural resources poses the single biggest threat to estuarine fish conservation. The primary direct impact of bait harvesting is a reduction in the density of targeted species. The impact of bait collecting is further exacerbated by illegal activities including, exceeding daily bag limits, illegal sale of bait organisms, and using banned implements including garden forks and shovels.

Boating activities have a variety of potential ecological impacts including pollution (engine emissions, sound emissions, antifouling paint leaching), disturbance of birds and fish, habitat damage including aquatic vegetation, bank erosion and resuspension of sediments leading to increased turbidity.

Knysna is one of seven local municipalities that fall within the Garden Route (Eden) District Municipality and has the third highest average annual population growth rate of 1.1% and a total population of 76 150 individuals, which is projected to increase to 79 426 by 2023. The wholesale and retail trade, catering and accommodation, transport, communication, finance, real estate and business services, general government, and social and personal services provide the most jobs. The natural and scenic appeal of the Knysna Estuary is a key tourism attraction along with the regions temperate climate, well development infrastructure, and proximity to airports. Tourism is a key economic driver in the Knysna region, as well as an important source of employment. In addition, resource extraction, mainly fishing, is an essential estuarine service, providing an estimated 70.4 tons of fish per annum.

The Knysna Estuary and surrounds has a rich cultural and archaeological heritage, with Middle Stone Age deposits indicating that the region has been inhabited for tens of thousands of years by modern humans. Some of the earliest inhabitants of the southern Cape region were the Khoi (pastoralists) and San (semi-nomadic hunter-gatherers). The earliest European inhabitants of the area were a group of Portuguese sailors whose ship was wrecked in Plettenberg Bay in 1630. Harvesting of indigenous timber surrounding Knysna began in 1763, and the creation of a port in Knysna Estuary enabled faster transportation of timber to outside markets. As one of the earliest commercial harbours in the country, the first loading wharf was constructed in 1776. The harbour was de-proclaimed in 1959. Access to, and transportation of, timber in and around the Knysna Estuary, coupled with construction and processing factories, and the establishment of the town and associated residences over the last ±250 years has impacted, and likely transformed, the Knysna Estuarine system to what we see today.

Legislation specific to estuarine management includes the National Environmental Management: Integrated Coastal Management Act and the accompanying National Estuarine Management Protocol. Key legal instruments that are applicable to estuarine management comprise national, provincial and local management documents, including the Garden Route National Park Management Plan compiled in accordance with the National Environmental Management: Protected Areas Act.

While considerable research has been undertaken in Knysna Estuary, it is striking that this has centred almost entirely on estuarine biota and processes. Such knowledge provides important building blocks for understanding how the estuary functions. Bathymetric surveys of the Knysna Estuary along with assessments of the likely origin of sediments would be helpful to evaluate changes in the quantity and spatial distribution of sediments. However, to improve understanding of the dynamics of the whole system, and effectively inform management decisions, disciplinary research should be complemented with interdisciplinary (studies that draw on and integrate knowledge from across social and natural scientific disciplines) and/or transdisciplinary (studies that incorporate local and practice-based knowledge and involve non-academic stakeholders in a process of co-learning) research. A useful place to start is to better understand the range of ecosystem services (tangible and intangible) derived from the Knysna Estuary, who the beneficiaries are, how services are mobilised and appropriated, and where possible thresholds and conflicts might arise. Implementation of the reserve with disclosure of water use licences issued, levels of compliance, and how these relate to the gazetted reserve for freshwater inflows to the estuarine environment are required for effective freshwater resource management. Proposed habitat reserves should be compared to, inter alia; invertebrate macrophyte avifauna distribution and abundance within the estuary to ensure representative areas are protected.

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ACRONYMS AND ABBREVIATIONS

All references to legislation include subsequent amendments

AFF	Agriculture, Forestry and Fishing
amsl	Above mean sea level
ANA	Anaerobic Ammonium Oxidation
BAS	Best Attainable State
BOD	Biochemical Oxygen Demand
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
cpue	Catch Per Unit Effort
CWAC	Coordinated Waterbird Counts
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DM	District Municipality
DNF	Denitrification
DNRA	Dissimilatory of Reduction of Nitrate to Ammonium
EC	Ecological Category
EFZ	Estuarine Functional Zone
EHI	Estuarine Health Index
EMP	Estuary / Estuarine Management Plan(s)
GDPR	Regional Gross Domestic Product
GMSL	Global Mean Sea Level
GRNP	Garden Route National Park
HAT	Highest Astronomical Tide
ICM Act	National Environmental Management: Integrated Coastal Management Act, 2004 (Act No. 24 of 2008)
IUCN	International Union for Conservation of Nature and Natural Resources
KADA	Knysna Angling and Diving Association
LM	Local Municipality
MAR	Mean Annual Runoff
MLRA	Marine Living Resources Act, 1998 (Act No. 18 of 1998)
MSL	Mean Sea Level
NBA	National Biodiversity Assessment
NEM: PAA	National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003)
NEMP	National Estuarine Management Protocol (Published in 2013 and revised in 2021)
psu	Practical Salinity Unit
REI	River Estuarine Interface
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SAR	Situation Assessment Report
SRP	Soluble reactive phosphorus
TSS	Total Suspended Solids
WMA	Water Management Area

1. INTRODUCTION

1.1. Background

The Knysna Estuary, located on the South Coast in the warm-temperate bioregion, falls within the Knysna Municipality of the Garden Route (formerly Eden) District (Figure 1). The Knysna Estuary and surrounds were proclaimed a Lake Area in 1985 in terms of the Lake Areas Development Act (Act No 39 of 1975). This was later repealed and the area designated as a Protected Environment in terms of the National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) (NEM: PAA). The estuary is currently managed by South African National Parks (SANParks) as part of the Garden Route National Park (GRNP).

The high conservation importance of this estuary has been emphasised in several studies, with it ranking 3rd among South Africa's estuaries with regards to its botanical importance (Coetzee *et al.* 1997); 8th for importance for conserving fish (Maree *et al.* 2003); 19th for waterbird conservation, (Turpie 1995); and 1st for overall conservation importance, which includes criteria such as size, diversity of habitat, zonal rarity and biodiversity (Turpie *et al.* 2002).

The Knysna Estuary, categorized as an estuarine bay (Skowno *et al.* 2019), is an S-shaped stretch of water, 1633 ha in extent (Duvenhage 1983), with a channel approximately 19 km long and up to 2 km wide. It has a tidal reach of approximately 17 km (Reddering & Esterhuysen 1984). The channel between the Knysna Heads is 120 m wide and up to 15 m deep (Reddering & Esterhuysen 1987). Hills with steep slopes surround most of the estuary. The main source of freshwater in the estuary is from the Knysna River catchment. There are three islands, of which Leisure Island or Steenbok Island (82 ha), and Thesen Island or Paardeneiland (84 ha) have been connected by causeways to the mainland.

In accordance with the National Estuarine Management Protocol (NEMP), developed in line with the National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) (ICM Act), an Estuarine Management Plan (EMP) must be developed for the Knysna Estuary. This document is the Situation Assessment Report (SAR), which provides background information to inform the management planning process.

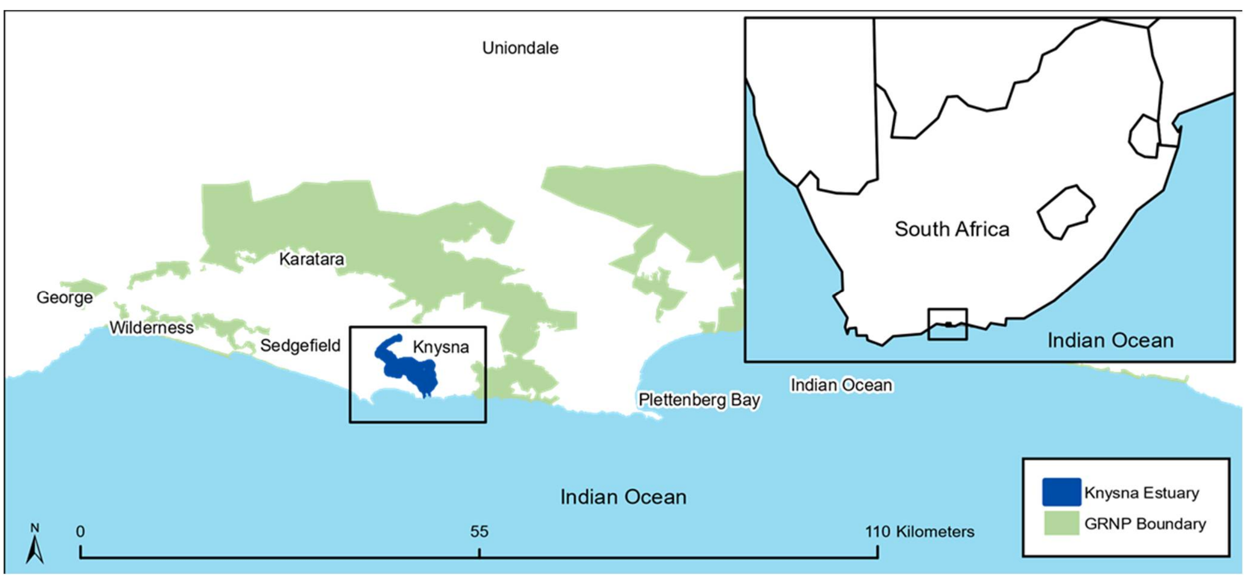

Figure 1: Location map of the Knysna Estuary.

1.2. Estuary Management Planning Process

The ICM Act was developed to facilitate the sustainable use and management of South Africa's coastline and its coastal and estuarine resources. The ICM Act mandates the Minister responsible for the Environment, in concurrence with the Minister responsible for Water, to develop a NEMP as the tool to ensure co-ordinated and efficient management of estuaries. The NEMP was promulgated in 2013 and later revised in 2021.

The development of this EMP takes cognisance of, and is written in accordance with, the National Guidelines for the Development and Implementation of Estuarine Management Plans (DEA 2015), taking note of the framework for estuarine management as well as minimum requirements as per the NEMP. A graphical representation of the framework (Figure 2) highlights that successful management of an estuary requires foremost, the setting of a "Vision" for the desired future state of the estuary, followed by the development of overarching management objectives, to achieve this state. As the Knysna Estuary falls within the GRNP, the EMP will be aligned with the objectives of GRNP Management Plan.

The geographical boundaries of the estuary has been demarcated. The estuarine functional zone (EFZ) used is that defined by the South African National Biodiversity Institute (SANBI) and the 2018 National Biodiversity Assessment (NBA) which is based on the best available information on the Knysna Estuary. The Knysna River catchment has an area of approximately 315 km^2, with a river length of approximately 64 km (Grindley 1985). Any activity that may affect the river and its tributaries (Swartkops, Steenbras, Gouna, Rooiels, Lelievlei, Witels, Palmiet, Dwars, Kruis, Outbos and Lawnwood Rivers), as well as those streams (Hornlee, Hunters Home, Ouplaas, Eastford, Westford, Brenton) and rivers (Salt, Bigai, Bongani) that enter directly into the Knysna Estuary (Grindley 1985), will form part of the EMP.

Once approved by the national Minister responsible for the Environment, implementation of the plan will be monitored from a resource, compliance as well as performance monitoring perspective. Successes, shortcomings, and the availability of new data (gleaned from both monitoring and research studies, where conducted), will be reflected upon and the EMP reviewed in the next five-to-ten-year cycle, as required. In future, revision of the EMP may be aligned with the revision period of the GRNP Management Plan, as provided for in the NEMP.

The development of an EMP is preceded by a scoping phase starting with the compilation of a SAR, this document, reflecting the current status of estuarine management in the specific estuary.

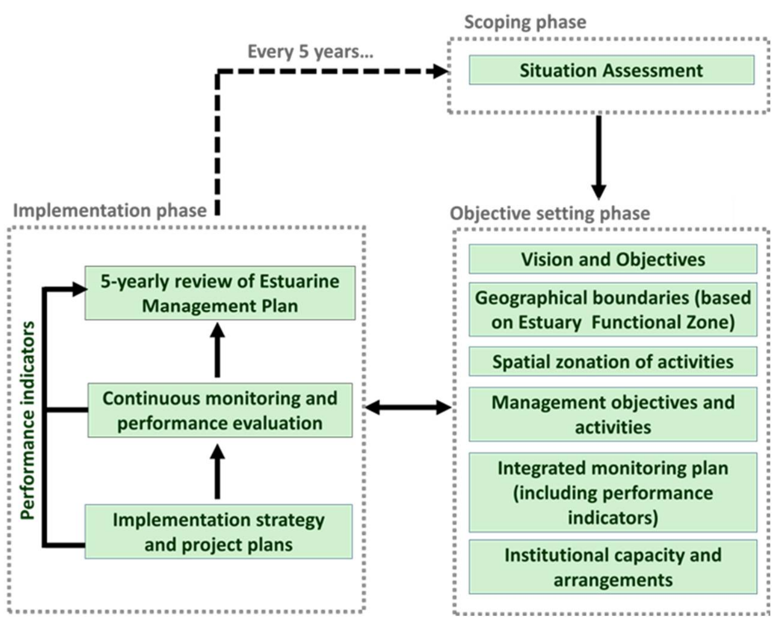

Figure 2: Framework for the development of estuarine management plans (DEA 2015).

1.3. Purpose of the Situation Assessment

The SAR gathers and interprets relevant available information that serves as the basis for the development of a vision and applicable management objectives for the estuarine system.

As per the requirements of the NEMP, this SAR:

- Describes the legislative instruments applicable as well as existing and planned management strategies relevant to the management of the estuary (section 8)
- Provides a detailed understanding of the structure, present ecological state and functioning of the estuary (sections 2, 3, 5);
- Describes the geographic socio-economic context of the system (section 6);
- Identifies the ecosystem goods and services (section 4); and
- Highlights information gaps (section 9).

2. CATCHMENT CHARACTERISTICS

2.1. Geology and Geomorphology

2.1.1. Geology

The geology of the Knysna area has been documented by Krige (1927), Miller (1975) and Dingle *et al.* (1983), and a comprehensive review given in Grindley (1985). In brief, the catchment area of the Knysna River lies within the Cape Fold Belt with long east-west orientated faults and folds. Most of the catchment lies in quartzites of the Table Mountain Group (Figure 3). Mesozoic rock outcrops that weather into sand and mud occur in low-lying areas north of the estuary. The dune complex south of the estuary (Brenton dune), is a steep (± 24°) coastal dune from the Tertiary and Pleistocene period (Reddering & Esterhuysen 1987).

2.1.1. Soils / Sediments

Three categories of soils can be distinguished in the Knysna area including (i) shallow azonal soils with imperfectly developed horizons found on all steep slopes, on recent dunes, and in wetlands, (ii), brown or grey soils forming under present day conditions, most extensive on the forested interfluves, and (iii) palaeosols including laterites and soils with Terra Rossa affinities (Tyson 1971, Butzer & Helgren 1972, Helgren & Butzer 1977).

Along the coastal belt topsoils are fine-medium sand, with A-horizons generally humus rich and of low pH. Deep depositional clays along the coastal platform create strong duplex profiles. The foothill zone exhibits gravels and sands related to ancient alluvial fans and more recent colluviation, with shallow azonal soils occurring on rocky outcrops. The A-horizons under indigenous forest tend to be thick and humus rich. Most soils in the area are found to be nutritionally deficient (Grindley 1985).

The substratum of the estuary consists predominantly of unconsolidated sandy sediments of marine, fluvial and aeolian origin (Reddering & Esterhuysen 1984, 1987). The Knysna Estuary is positioned along a rocky portion of the coastline where the longshore sediment transport capacity exceeds supply. Consequently, only small volumes of marine sediments are transported into the estuary (Chunnett 1965, Zwamborn 1980). These are distributed primarily near the mouth of the estuary. Grain size, shape and chemical composition of surface sediments in the middle reaches of the estuary indicate that they consist almost exclusively of aeolian material, which most likely originated from the Brenton dune on the southern bank of the estuary (Reddering & Esterhuysen 1987). The angularity and poorly sorted nature of sand grains in the upper reaches of the estuary indicate that these sediments are largely fluvially derived (Reddering & Esterhuysen 1987). Fluvially transported mud also occurs in the area around Thesen Island and Leisure Island where it is mixed with aeolian transported material (Reddering & Esterhuysen 1987).

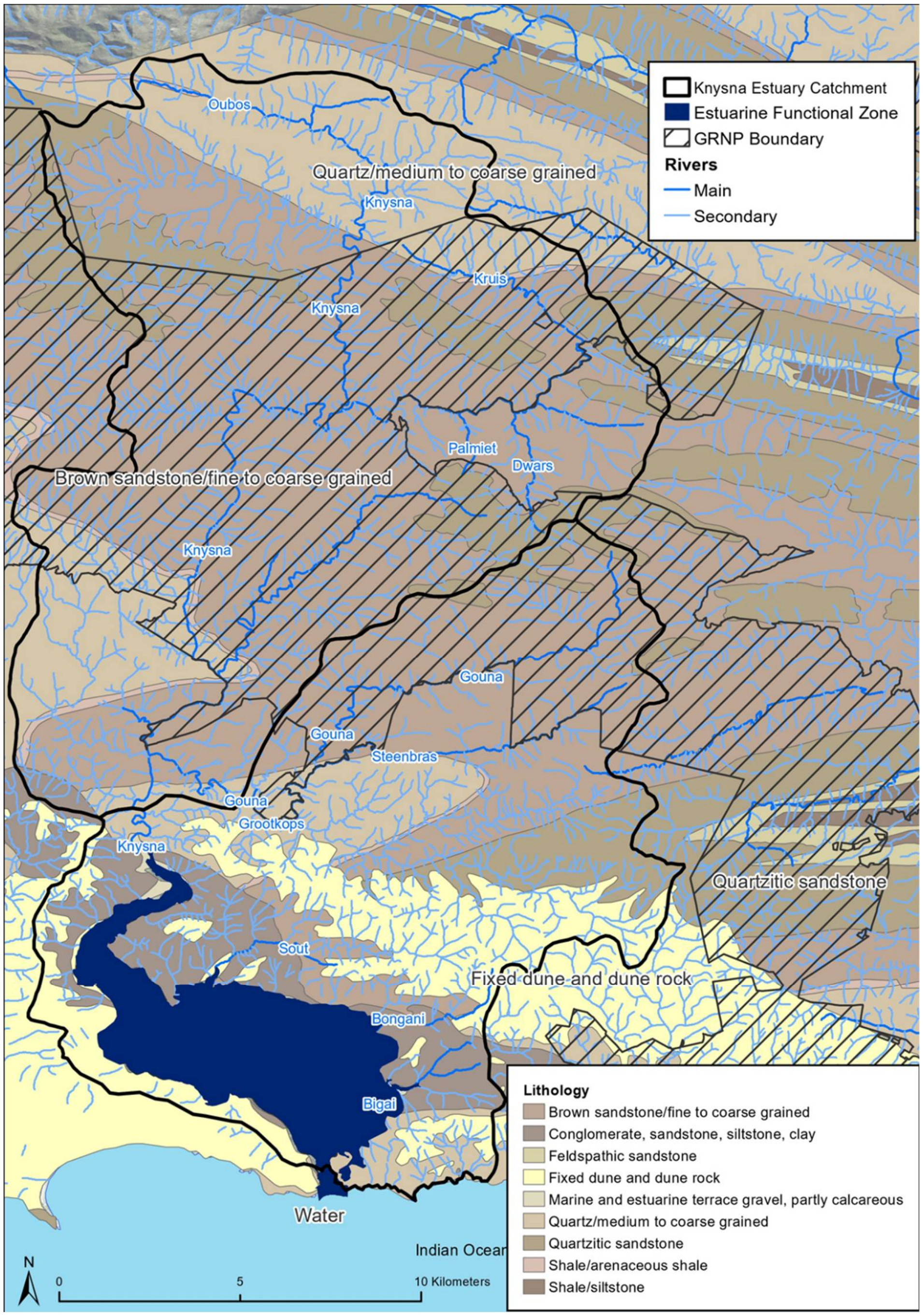

Figure 3. Geology of the Knysna Estuary catchment and GRNP boundary.

2.1.2. Topography

The Knysna Estuary is an S-shaped stretch of water, 1633 ha in extent (Duvenhage 1983), with a channel approximately 19 km long and up to 2 km wide. It has a tidal reach of approximately 17 km (Reddering & Esterhuysen 1984). Hills with steep slopes surround most of the estuary. There are three islands, of which Leisure Island or Steenbok Island (82 ha), and Thesen Island or Paardeneiland (84 ha) have been connected by causeways to the mainland. The third low-lying marshy island, called Rex Island, is situated between the Leisure and Thesen Islands. Dykes were constructed to prevent flooding of the small airstrip constructed on Rex Island, and its area has been artificially extended by reclamation of the saltmarshes.

2.2. Climate

Mean annual rainfall varies between 700 mm y^{-1} at the coast and 1161 mm y^{-1} in the Outeniqua mountains at Buffelsnek (Station 30/265), with average annual rainfall in the Knysna River catchment estimated as 928 mm y^{-1} (Pitman *et al.* 1981). Rainfall can occur throughout the year. South African Department of Planning (1970) states that the high rainfall months are usually February, March, May, September, November and December, whereas average rainfall data as given on climate-data.org indicates that the wettest months are in early summer (Figure 4). The average yearly temperature for Knysna is 16.9°C (South African Department of Planning 1970). Basic meteorological data are given in Table 1. South-westerly winds predominate most of the year, though warm northerly and north-easterly winds frequently occur in winter.

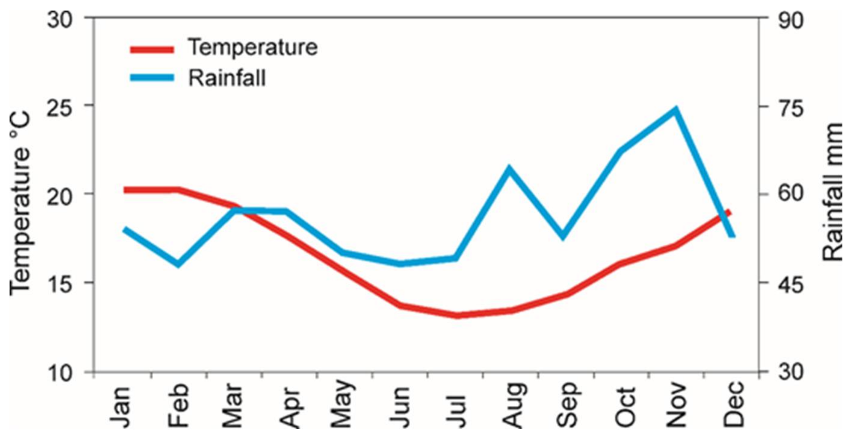

Figure 4: Mean monthly temperature and rainfall in the Knysna area (modified from climate-data.org)

Table 1: Meteorological variables in the Knysna area (modified from climate-data.org)

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature °C	20	20	19	17	15.7	14	13	14	14	16	17	19
Min. Temperature °C	17	17	16	14	12.5	10	9.8	10	11	13	14	16
Max. Temperature °C	23	24	23	21	19.6	18	17	18	18	19	20	22
Precipitation / Rainfall mm	54	48	57	57	50	48	49	64	53	67	74	53
Humidity (%)	77	78	77	76	72	70	70	71	73	75	76	67
avg Rainy days (d)	7	7	7	6	5	6	6	7	7	7	7	8
avg. Sun hours (hours)	8.8	8.3	7.9	7.7	7.7	7.5	7.4	7.8	7.9	8.3	8.8	9.1

2.3. Land-use

The upper reaches of rivers flowing to the Knysna Estuary are largely within the GRNP, whilst the middle reaches of river catchments are mostly support agriculture and forestry practices with some indigenous vegetation (fynbos and forest) interspersed in the landscape. The lower reaches of the river catchment have been extensively modified by urban development.

The shoreline and intertidal habitat of the Knysna Estuary has been substantially modified by developments. The scale and pace of development appears to have increased during the 1990s and beyond. Particularly prevalent are retaining walls with landfills, which skirt much of the northern and eastern shorelines of the estuary as well as the inhabited islands. Two bridges and three causeways have been constructed across various portions of the estuary. Several of these structures alter natural water flow and sediment movement patterns (Day 1981, Chunnett 1965). Intertidal areas have historically been reclaimed for the development of amongst others a harbour wall, roads, residential areas, factories, a runway, a refuse dumping site and a golf course. Access to the estuary is obtained via two public access slipways managed by SANParks.

Substantial developments which have occurred in the Knysna Estuary since 1990 include the construction of (i) a small-boat harbour, waterfront and two extensive housing developments on the north-eastern shoreline, (ii) a small-boat harbour on Leisure Island, (iii) conversion of the entire Thesen Island into a marina and housing estate, (iv) development of golfing estates of which one was a spectacular failure during construction resulting in environmental damage to the estuary, and (v) infilling of a substantial portion of the northern shoreline with the broadening of the N2 motorway.

3. OVERVIEW OF ECOLOGICAL FUNCTION AND STATE OF THE ESTUARY

3.1. Definition and Delineation

The ICM Act defines an estuary as "*a body of surface 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 body of surface water is open to the sea; or in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water".*

Similarly, the National Water Act, 1998 1998 (Act No. 36 of 1998) defines an estuary as "*a partially or fully enclosed water body that is open to the sea permanently or periodically, and within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land*".

The 2018 NBA: Estuarine Realm Technical Report (Van Niekerk *et al.* 2019) provides a more detailed definition of an estuary, that is, "*a partially enclosed permanent water body, either continuously or periodically open to the sea on decadal time scales, extending as far as the upper limit of tidal action, salinity penetration or back-flooding under closed mouth conditions. During floods an estuary can become a river mouth with no seawater entering the former estuarine area or, when there is little or no fluvial input, an estuary can be isolated from the sea by a sandbar and become fresh or even hypersaline*". Given this extended definition and the fact that it is not currently incorporated into or reflected in any legislation, Van Niekerk *et al.* (2019) noted the importance of updating the relevant legislation to include a broader definition of an estuary, which includes the EFZ.

Although inclusion of the EFZ in the description of an estuary is deemed important, the only legislated definition of an EFZ can be found in the 2014 Environmental Impact Assessment (EIA) Regulations, as amended, which defines the EFZ as "*the area in and around an estuary which includes the open water area, estuarine habitat (such as sand and mudflats, rock and plant communities) and the surrounding floodplain, as defined by the 5 m topographical contour (referenced from the indicative mean sea level)*". Van Niekerk *et al.* (2019) notes the shortcomings of using a 5 m topographical contour as a reference for all estuaries and instead provides for a broader definition of an EFZ as "*The open water area of an estuary together with the associated floodplain, incorporating estuarine habitat (such as sand and mudflats, salt marshes, rock and plant communities) and key physical and biological processes that are essential for estuarine ecological functioning*". The NEMP requires that a geographical description of the EFZ is provided as part of the EMP and that the definition of an EFZ as provided in the 2018 NBA (or subsequent revisions) is used.

The Knysna Estuary is classified as an estuarine bay and is located within the warm temperate biogeographic region of South Africa. An estuarine bay is described as an estuary that is permanently linked to the sea by unrestricted, deep mouths and are dominated by tidal processes, with tidal amplitudes close to those of the sea (Van Niekerk *et al.* 2019). The size of the estuary, as defined by the EFZ, is approximately 2 400 ha, extending over a length of 19 km. The area the estuary occupies, when the floodplain is included in the calculation is approximately 2 284 ha (DWS 2017). The catchment for the Knysna Estuary is approximately 419 km^2 (DWS 2017). The geographical boundaries of the Knysna Estuary, delineating the EFZ (Table 2), as well as the Knysna River are illustrated in Figure 5 and Figure 6 respectively.

Table 2: Geographical boundaries of the Knysna Estuary.

Downstream boundary	34° 4'58.05"S 23° 3'37.82"E (Estuary mouth)
Upstream boundary	33°59'54.62"S 23° 0'11.90"E
Lateral boundaries	EFZ as described in the 2018 NBA

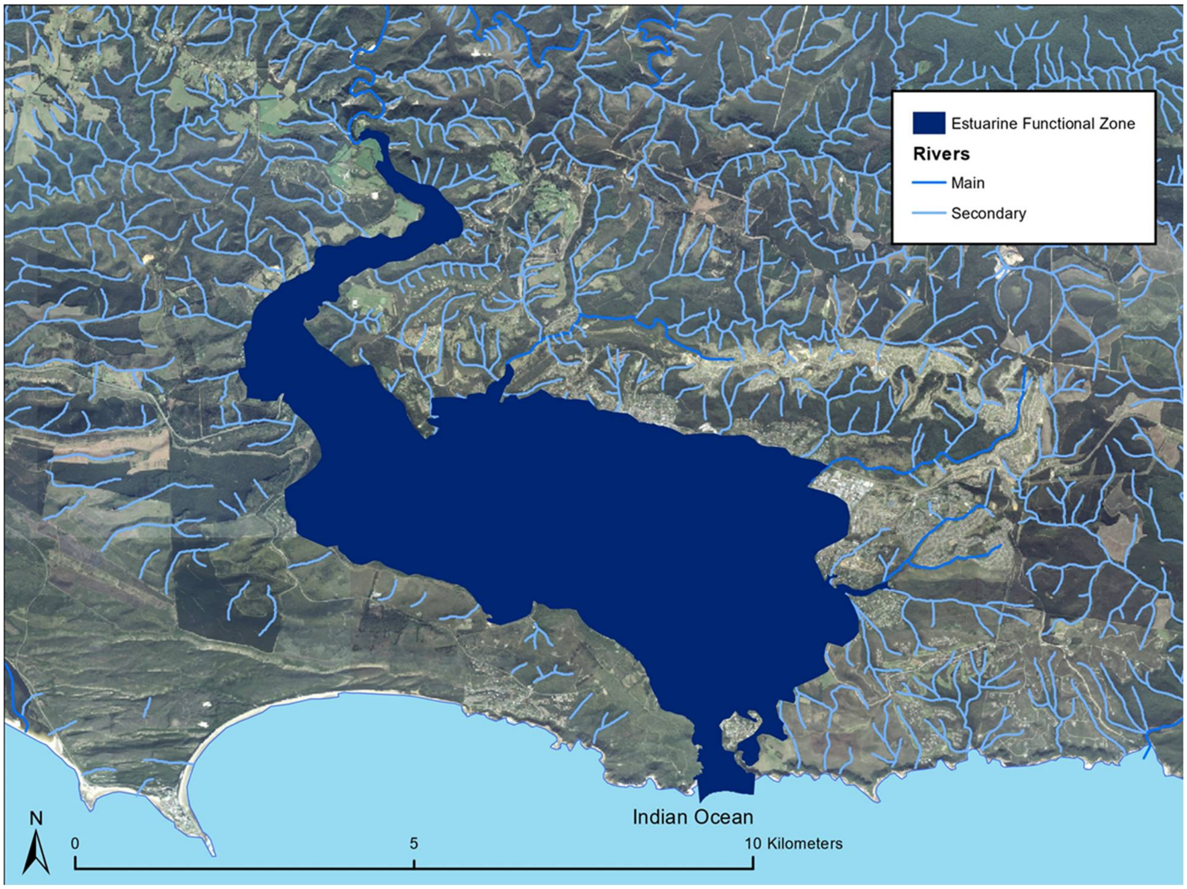

Figure 5: Geographical boundaries of the Knysna Estuary depicting the EFZ based on the 5 m amsl contour (http://bgis.sanbi.org/SpatialDataset/Detail/2689).

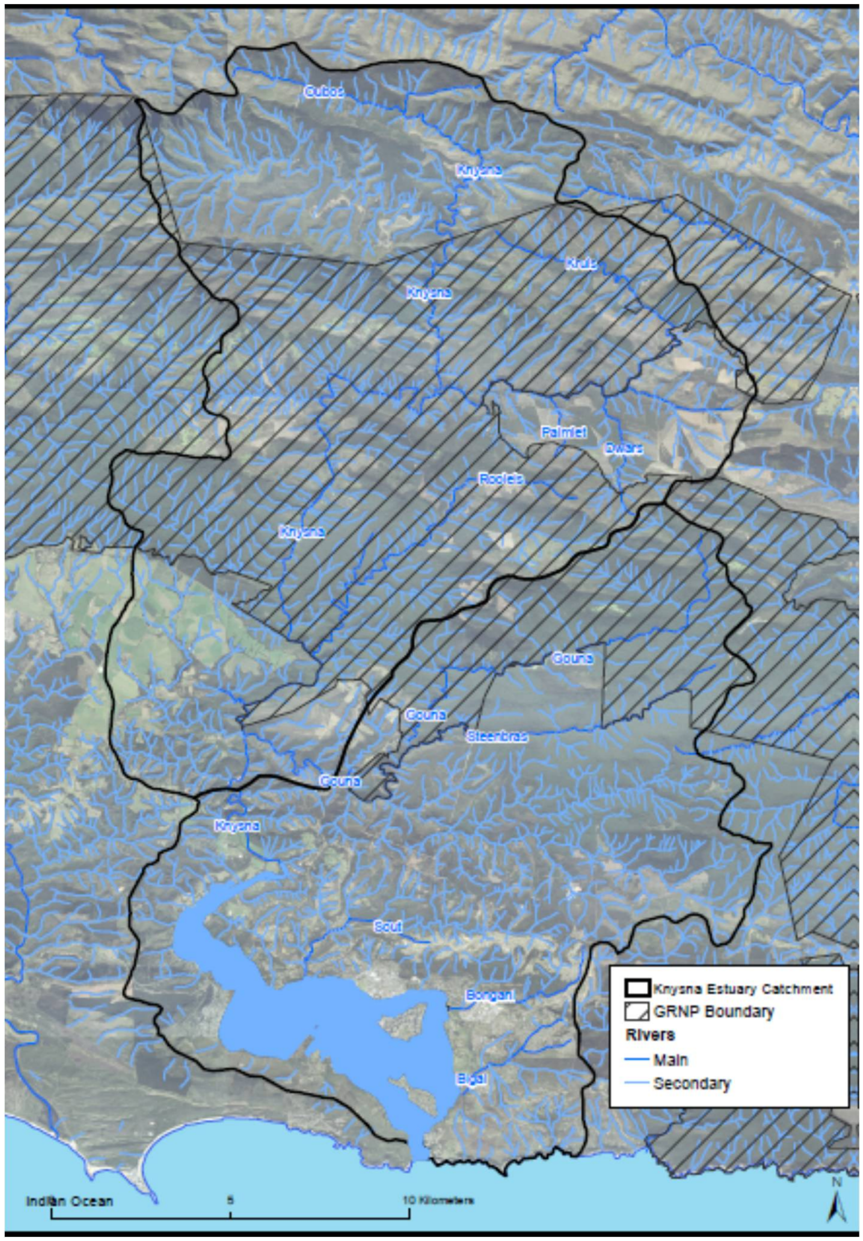

Figure 6: Geographical boundary of the Knysna Estuary and its contributing rivers as well as the Boundary of the GRNP.

3.2. Current Estuary Zonation

The Knysna Estuary is a proclaimed protected environment in terms of the NEM: PAA, with regulations for the proper administration of the Knysna protected environment promulgated in GN. No.R.1175 of 2009. The Knysna protected environment encompasses the area formerly proclaimed as the Knysna National Lake Area. The regulations state that SANParks has jurisdiction over management of activities on the water body of the estuary, the rivers that flow into the estuary (Knysna, Salt, Bigai and Bongani and their associated wetlands) as well as the sea and seashore (termed the biodiversity control area) and partial jurisdiction, shared with relevant other organs of state within a 50 m buffer area around the estuary (termed the development control area) (Figure 7). The regulations assign powers to SANParks to manage land use, access and activities as well as monitor the use of biological resources. This is most effectively achieved through zonation.

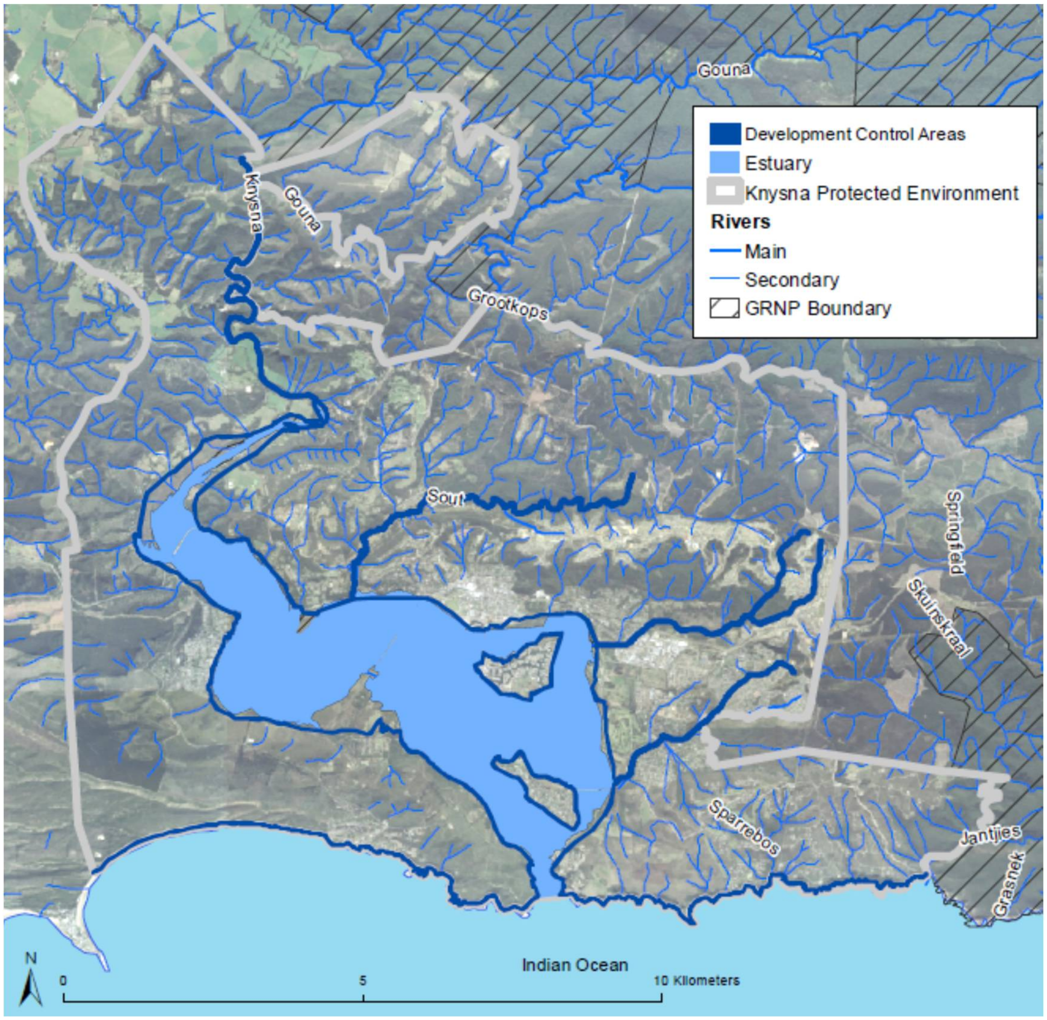

Figure 7: The Knysna protected environment, showing the biodiversity control area (water body) as well as the development control area (50 m buffer area around the water body)

The most recent zonation for the water body of the Knysna Estuary was approved in 2020 as part of the GRNP Management Plan’s zonation plan, a requirement in terms of the NEM: PAA.

Appropriate use zoning of the estuary serves to minimise conflicts between different users by separating potentially conflicting activities whilst ensuring that activities that do not negatively impact the estuary and its enjoyment by users can continue in appropriate areas. Within the current GRNP Management Plan significant changes were undertaken in terms of the zoning of the Knysna Estuary compared to previous iterations. The Knysna Estuary was largely zoned as low intensity leisure, with a high intensity leisure zone in the main channel. The current zonation identified areas of high sensitivity, such as Cape eelgrass *Zostera capensis* beds and saltmarshes, which were zoned as quiet (Figure 8).

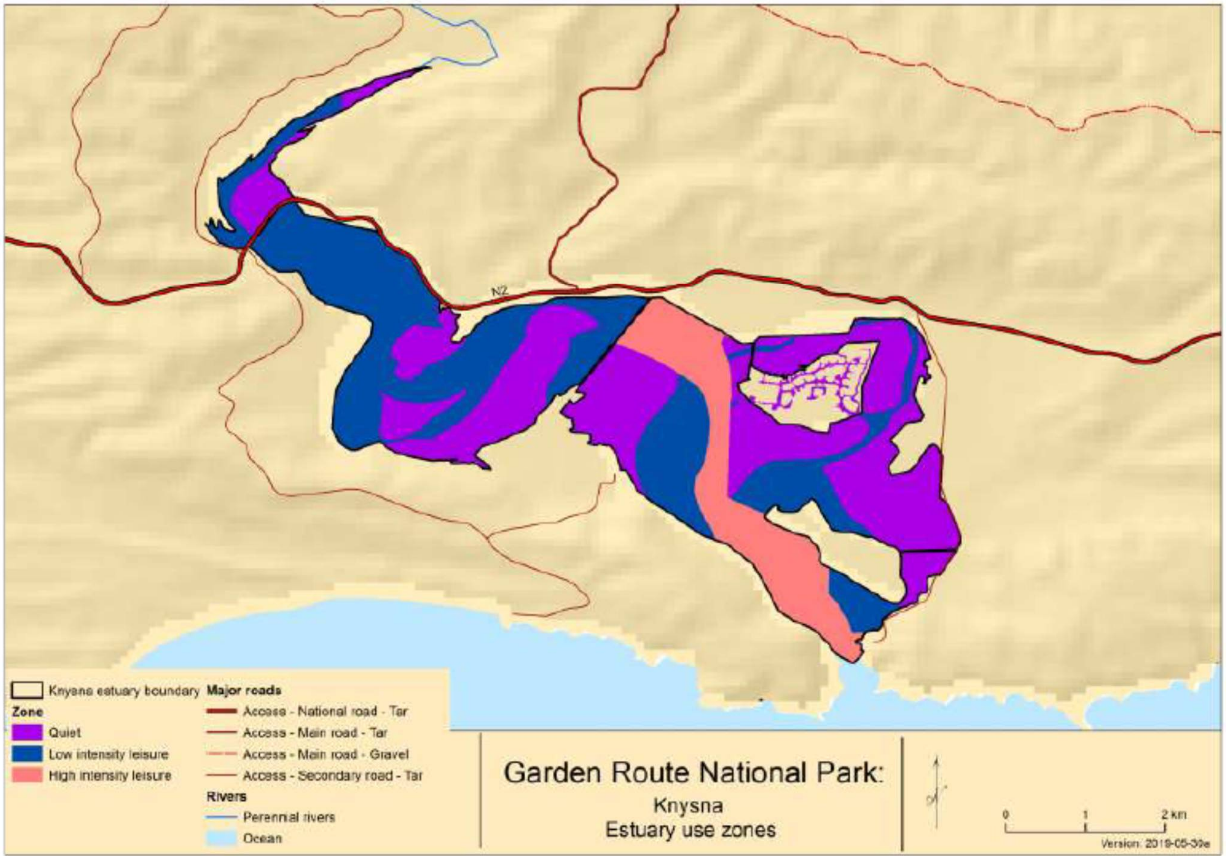

Figure 8. Use zones for the Knysna Estuary showing high sensitivity areas within the quiet zone (Source: Garden Route National Park Management Plan 2020)

To enhance visitor experience and minimise conflict between differing activities, special management overlays were applied to the use zones according to the allowable activities within each zone as described in the GRNP Management Plan (SANParks 2020) (Figure 9) and included various resource use management areas. These areas include a bait reserve, harbour, jestski and water-skiing areas, areas where no motorised vessels are allowed, no wake channels, idle speed zones, no wake areas in open water and the preferred channel.

The bait reserve is an area demarcated by pole markers and signage in which the harvesting/collecting of bait by any means at any given time is prohibited. Only angling and other boating activities as allowed in the special management overlays are permitted. This area covers the salt marshes between Thesen Island and Leisure Island (Government Gazette No. 12667 of 27 July 1990) (Figure 9). The area protects bait species as well as other estuarine fauna and flora on the intertidal mudflats and sandbanks.

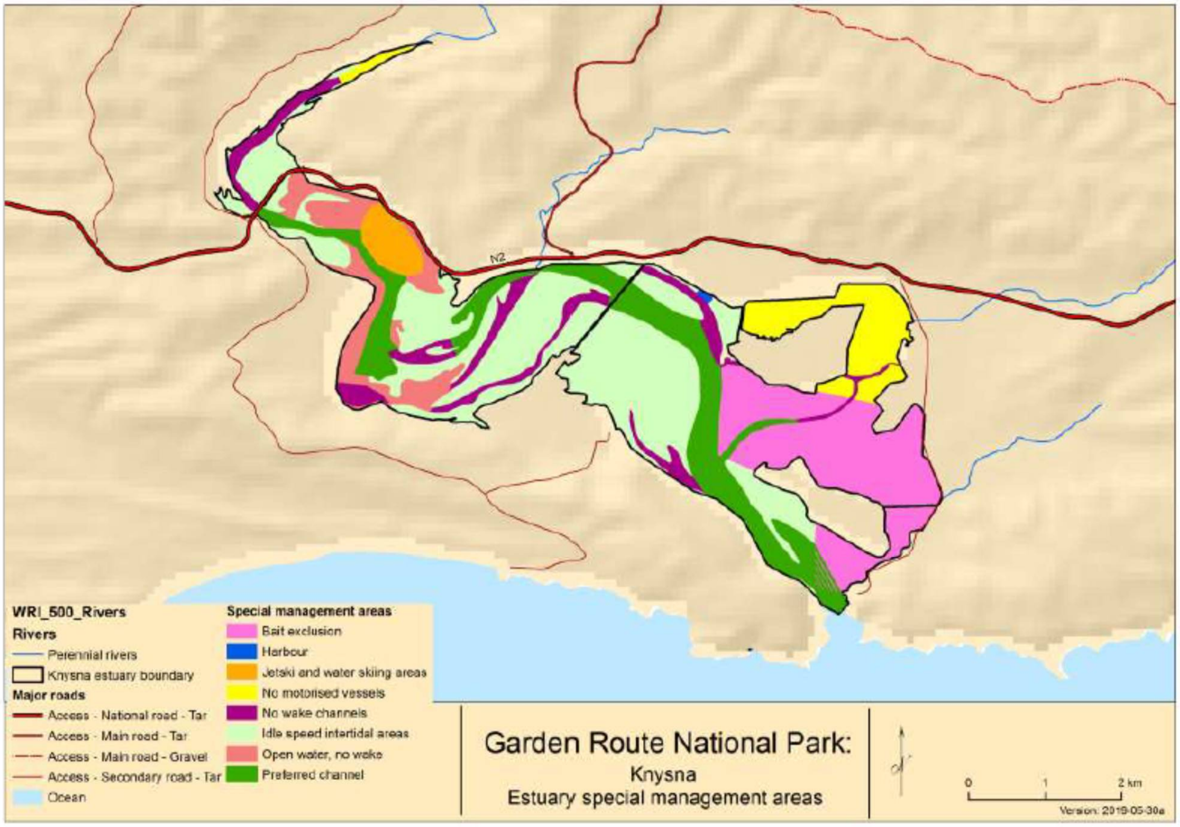

Figure 9: Special management overlays showing resource use management areas for the Knysna Estuary including the bait reserve (Source: Garden Route National Park Management Plan 2020)

The harbour area is a deep-water area demarcated by harbour walls providing sheltered floating/fixed jetty mooring facilities and slipways. Depending on access restrictions determined by the facility's management organisations, access is in some cases restricted to club's members only, alternatively facilities are accessible to the public. The jetski and water-skiing area is an area of deep water designated for safe use and manoeuvring of jet-propelled personal watercraft and water-skiing. This area is the only area designated for jet-skiing as uses in other channel / open water areas could have safety implications (i.e. on other estuary users). Additionally, restricting use to this zone reduces the risk of collision with sandbanks in shallow areas as well as potential damage to the environment caused by vessel activity in shallow waters. The areas where no motorised vessels are allowed are generally shallow and / or the use of motorised vessels can cause erosion / damage to sensitive intertidal areas, mudflats, Cape eelgrass beds and / or salt marsh vegetation due to e.g. wake of the vessel / traversing over shallow sandbanks / mudflats.

No wake channels are areas where all vessels must reduce speed in order to not create a wake which can be damaging to the environment, moored vessels or infrastructure. This overlay generally applies to shallow channels adjacent to sensitive estuarine habitat (mudflats / Cape eelgrass beds that may be subject to erosion or damage due to boating activity) or in areas where there are potential safety issues. Idle speed zones are environmentally sensitive intertidal areas, which are only accessible during high tides and are subject to vessels traversing at reduced speeds in order to not create a wake which is damaging to the environment. These areas may be subject to erosion or damage due to boating activity. Intertidal areas may be exposed during low tides, resulting in increased risk to vessels. Open water no wake areas are areas outside of the preferred channel that should not be traversed at high speeds due to risk of sediment movement and possible damage to adjacent infrastructure and vessels. Although these channels are deeper than the other no wake channels, no wake is prescribed as a safety precaution due to jetties and embankments occurring in this area.

The preferred channel is the preferred line to follow when traversing the estuary from north to south or south to north. Vessels may travel at speed, provided it is safe to do so, taking into account other water users and hazards. It consists of deeper portions of the estuary channel deemed to have lowest risk of potential environmental damage and safety risk if used in accordance with relevant regulations and safety guidelines.

In addition to the above, the GRNP Management Plan (SANParks 2020) proposes the establishment of three habitat reserves (labelled as proposed bait reserves in Figure 10). These consist of the existing bait reserve (excluding the northeast portion of the bait reserve) and additional areas that have been identified to contain key habitats, which are sensitive to disturbance. The proposed habitat reserves were spaced along the longitudinal axis of the estuary to ensure that representative habitats, coinciding with reported changes in benthic fauna (cf. section 3.4.4), were protected. These zones will ensure protection of three reaches of the estuary including sandbanks, mud flats and Cape eelgrass. Reduced accessibility was also seen as a key contributing factor for the proposed placement of these habitat reserves, facilitating enforcement and management of the sites. As establishment of habitat reserves requires legislative approval in terms of the Marine Living Resources Act, 1998 (Act No. 18 of 1998) (MLRA), this was not specifically included in the zonation but will be incorporated once these reserves have been established in terms of the relevant legislation. The habitat reserves may be subject to further refinement based on additional information collected on sensitivity and biota distribution within the estuary. Additional criteria to be considered include, *inter alia*, the conservation targets listed below as provided by Turpie & Clark (2007) for the respective habitat types in the Knysna Estuary:

- Supratidal salt marsh 30%
- Intertidal salt marsh 40%
- Reeds and sedges 20%
- Sand/mud banks 40%
- Submerged macrophytes 40%
- Channel 30%

The establishment of habitat reserves is in line with the recommended extent of protection for the Knysna Estuary by Turpie *et al.* (2012) (i.e., partial protection) and the call by Whitfield *et al.* (2020) for establishing estuarine protected areas, where the main aim of these protected areas or habitat reserves would be to conserve habitat and vegetation. A recent study by Barnes & Claassens (2020) has also shown that subtidal areas of the Knysna Estuary hosts different microbenthic assemblages than adjacent intertidal areas, and may therefore not protect harvested species (cf. section 3.4.4).

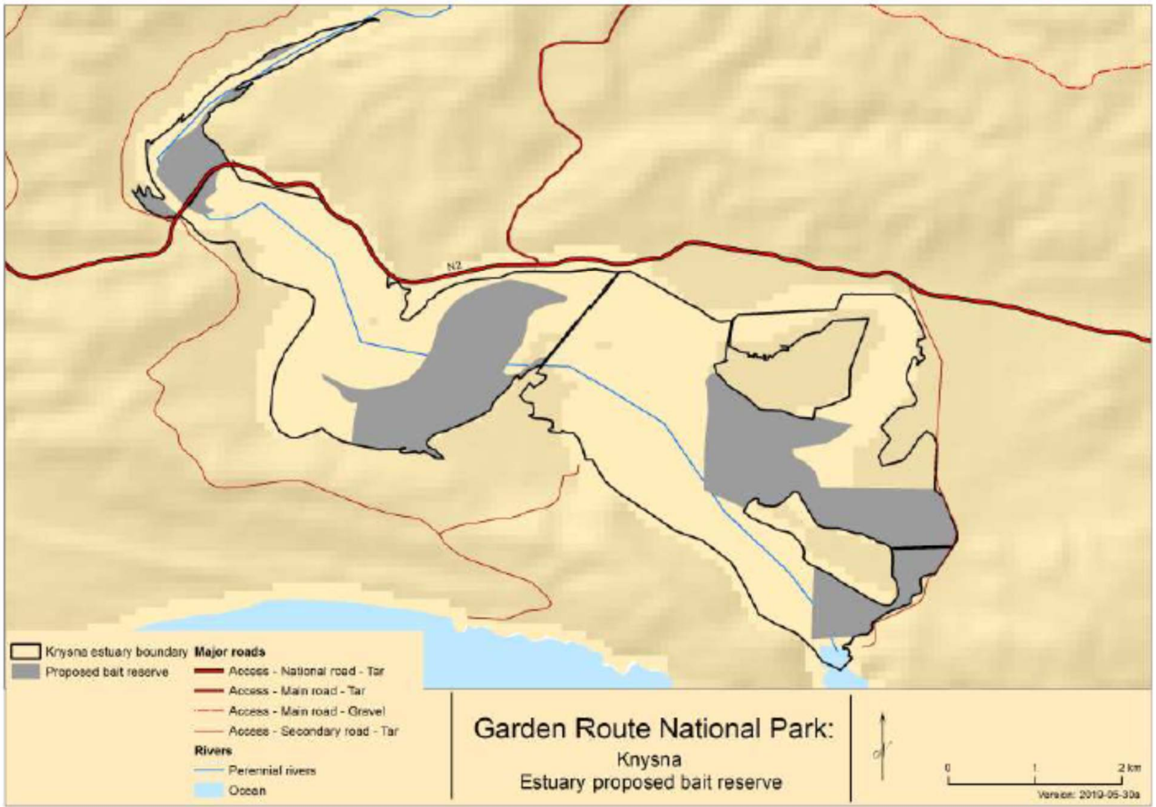

Figure 10: Proposed habitat reserves for the Knysna Estuary (Source: Garden Route National Park Management Plan 2020)

3.3. Abiotic Function

3.3.1. Hydrology

The Knysna River catchment comprises quaternary catchments K50A and K50B, which drain into the Knysna Estuary. These catchments are located in the Breede-Gouritz WMA. There are twelve sub-catchments draining into the estuary (Reddering 1994) of which the Knysna River is significantly the largest. The Knysna River is approximately 64 km long (Grindley 1985). Some confusion appears to exist regarding the size of the Knysna drainage basin which is given as 400 km^2 (Day *et al.* 1952), 526 km^2 (Noble & Hemens 1978, Day 1981) and 525 km^2 (Pitman *et al.* 1981), of which the Knysna River basin comprises 426 km^2 (Noble & Hemens 1978), 337 km^2 (Zwamborn 1980) or 315 km^2 (Reddering & Esterhuysen 1984). Presumably, the latter two areas exclude the estuary and local drainage (7 streams) which cover approximately 100 km^2 (Noble & Hemens 1978, Day 1981). The catchment at the mouth of the estuary (The Heads) is given by Knysna Municipality (2004 cited in DEA&DP 2018) as 434 km^2. In terms of human activities in the catchment requiring water usage and abstraction. The predominant land-use is forestry (i.e. 38% of the total catchment). In 2001, the area of exotic afforestation in the Knysna River catchment was estimated at approximately 17 637 ha or 38% of the total catchment. Agricultural development is confined mainly to the farms of Portland, Charlesford, Westford, Eastford, Simola and on the Gouna Commonage. Irrigated food crops are cultivated at Portland, while the predominant agricultural activity is cattle grazing. The main tributaries of the Knysna River are the Kruis, Rooiels and Gouna rivers. Smaller systems with separate inflows into the estuary are the Salt, Bongani and Bigai Stream rivers. Numerous drainage lines and stormwater inlets discharge surface waters directly into the estuary from surrounding lands, including much of Knysna town, outside of the river catchments.

Flow in the Knysna River is perennial (Reddering & Esterhuysen 1984), with mean annual runoff (MAR) estimated by Noble & Hemens (1978) as 110 x 10^6 $m^3 y^{-1}$, and by Pitman *et al.* (1981) as 133 x 10^6 $m^3 y^{-1}$. Haw (1984) however, gives MAR at Charlesford Farm as only 61 x 10^6 $m^3 y^{-1}$, and DWA (2009) give the MAR reference condition as 83.2 x 10^6 $m^3 y^{-1}$.

According to a Rapid Reserve conducted for the Knysna Estuary (Knysna Municipality 2004 cited in DEA&DP 2018), the Knysna Estuary receives varying river inflow from less than 0.5 $m^3 s^{-1}$ to >100 $m^3 s^{-1}$ during periods of high rainfall. Day *et al.* (1952) maintain that floods occur, on average, once every 10 to 12 years, at which time the estuary is heavily stained by inflowing sediments. The highest flood-level recorded in the estuary between 1965 and 1985 was mean sea level (MSL) +2.0 m (Grindley 1985). MSL is given by Grindley (1985) as 1.16 m, which would equate to a water level in the estuary of +3.16 m. Marker (2000) maintains that during a storm event on 16 June 1996 that was accompanied by extreme low pressure at spring tide, water levels at Thesen's Jetty reached the highest level on record, 0.20 m above maximum spring tide. Furthermore, surges at 15-minute intervals added between 0.10 and 0.05 m to the maximum water level. Although Marker (2000) does not give the actual recorded water height, using values of highest astronomical tide (HAT) reported by Grindley (1985) (2.29 m), water levels in the estuary would have been between 2.54 and 2.59 m above mean sea level (amsl).

There are three streamflow gauging weirs in the Knysna River catchment, K5H001 (Gouna River at Gouna commonage), K5H002 (Knysna River at Millwood Forest) and K5H003 (Knysna River at Charlesford). There are five registered dams, although others do exist. Three of these are farm dams on Portland farm and are used for irrigation. The other two are the Glebe and Akkerkloof dams with capacity of 0.180 $x10^6$ m^3 and 0.801 $x10^6$ m^3, respectively (DWA 2007b). These two dams are owned and operated by the Knysna Municipality (du Plessis *et al.* 2004 cited in DEA&DP 2018). Water supply to Knysna for urban use is 3.416 x 10^6 m^3 y^{-1} (Knysna River = 2.36, Gouna River = 0.84, Glebe Dam (Grootkops River) = 0.10; Groundwater = 0.12), and return flow from Knysna was recorded in 2003 as 1.78 x 10^6 m^3 y^{-1} in the form of treated effluent that is discharged into the estuary ((DWA, 2006a, DWA 2007b). Irrigation requirements were estimated in 2006 as 8.01 x 10^6 m^3 y^{-1} DWA (2006b) and the reduction in streamflow by affectation as 13.7 x 10^6 m^3 y^{-1} (DWA 2006c).

Haw (1984) assessed the effect of reduced freshwater inflows into Knysna Estuary on salinity, with cessation of flow resulting in salinities up to 36 psu (practical salinity units) in the upper reaches. Such changes could be expected to have significant effect on biota, with gradual reduction in both primary and secondary productivity (Haw 1984). Huizinga (1985) undertook modelling of the effects of freshwater flow reductions and flood on salinities. Reduced freshwater results in an increase in salinity in the upper reaches of the estuary, with the effects of minor floods (peak 40 $m^3 s^{-1}$) on salinity reduction visible for about 10 days, and the effects of major floods (peak 328 $m^3 s^{-1}$) visible for about 15 days, with at maximum flood the salinity throughout the estuary dropping to almost 0 mg kg^{-1} (Huizinga 1985). Likely effects of flow reductions and modifications on the estuarine environment have been estimated within the reserve assessment for the estuary (DWA 2007a) with freshwater inflows recommended to maintain desired ecosystem condition (cf. section 3.4).

Largier *et al.* (2000) described three different hydrographic regimes in the estuary created by the circulation and diffusion of river and ocean waters by variable freshwater inflows and the large tidal prism (estimated at spring tide at 19 x 10^6 m^3) and its effects on spatial and temporal variability in salinity and water temperature. These are:

- The marine embayment regime, extending inland from the estuary mouth between 3 km during neap tides and 7.5 km during spring tides. It is well flushed by tidal flows and exhibits salinities and temperatures similar to the ocean.

- The lagoon regime, extending inland from the upper reaches of the bay regime and seldom beyond White Bridge. It is flushed less rapidly, subject only to tidal diffusion effects, and exhibits long residence times. Salinities here are close to ocean salinity, but temperatures may be several degrees warmer. The lagoon is considered as a transition zone between the estuary and the marine embayment.

- The estuary regime, extending inland from the upper reaches of the lagoon regime. It is strongly influenced by the inflow of freshwater from the Knysna River and demonstrates strong vertical stratification in salinity and water temperature, and is well flushed by density-driven estuarine circulation.

The boundaries of these three regimes vary both spatially and temporally depending on the volume of freshwater inflow from the Knysna River into the estuary and the inflow of marine waters through the Heads (Largier *et al.* 2000). The lagoon regime expands as the estuary regime shrinks in response to decrease in river flow and as the bay regime shrinks in response to decrease in tidal range (Largier *et al.* 2000). During periods of high rainfall in the Knysna River catchment, the upper estuary regime may extend as far down as the marine embayment regime resulting in the temporary disappearance of the lagoon regime (Largier *et al.* 2000). Sustained river flow is required to maintain estuarine conditions above the White Bridge and enable variation in salinity in the lagoon regime. If the present retention time of some 20 days in the estuarine regime is increased to greater than 50 days as a result of decreased freshwater inputs, water quality will deteriorate (Largier *et al.* 2000).

Switzer (2003) described the Ashmead channel as a potential fourth regime in that it differed from other areas in the estuary by virtue of being very shallow (<2 m), experiences high water temperatures in summer, has a long residence time of water within the constricted channel, and a low flushing rate. This section of the estuary receives nutrient rich wastewater and storm-water runoff. In some respects, this may be a man-made regime.

3.3.2. Bathymetry

Several estimations of the maximum depth of Knysna Estuary have been made. These are 40 feet (cf. 12.2 m) (Krige 1927), 51 feet (cf. 15.5 m) (Day *et al.* 1952) and 16 m (Day 1981). Determinations of bathymetry include an aerial survey of the estuary in July 1970 which enabled the construction of a contour map, with 0.5 m vertical interval contours, from low water (-0.5 global mean sea level (GMSL)) to +5.0 GMSL. These data were combined with depth soundings carried out in the estuary in February 1971. Further depth readings were undertaken in The Heads channel on 1 October 1974. According to these studies, portions of the estuary are in excess of 16 m below MSL.

The channel between the Knysna Heads is 120 m wide and up to 15 m deep (Reddering & Esterhuysen 1987). The bar between The Heads has been chartered as between 4 and 5 m deep (Day, *et al.* 1952). The main channel follows the broad twists of the estuary, becoming progressively shallower, being approximately 2 m deep at the end of the tidal reach. Wide inter- and subtidal sandbanks line the channel over most of its length. There are no recent bathymetric maps of the estuary.

3.3.3. Sediment dynamics

Sediment loads originating from the catchment are in the order of 100-150 t km^{-2} y^{-1} (Rooseboom 1978). Despite this Chunnett (1965) suggested that, at the time of writing, over the past 100 years siltation into the estuary from external sources had been virtually absent, with perceived siltation being the internal movement of material. Grindley (1985) suggested that siltation problems generally occur where artificial structures have been erected. For example, CSIR (1989) concluded that there has been an increase in the rate of sedimentation in the Green Hole area as a result of the construction of the Leisure Island causeway and George Rex Drive. Reddering (1994) found little evidence of sediment influx, and confirmed the overall low sediment input into the estuary at that time. Significant inflows of sediments into the estuary have, however, been recorded in more recent years, with catchment exposure by property developers causing significant sediment inflows from the Salt River catchment in 1996 and 1997 (Marker 2000), and again in August 2006 from the Bigai system.

Allanson *et al.* (2000a) considers the greatest threat to the Knysna Estuary to be the pulses of stream flows rich in suspended solids that appear with increasing frequency. The arrested development of the estuary is due, in large part, to the relative (to other systems) low supply of fluvial sediments from the Knysna River during the Holocene (Reddering 1994). The significance of this immaturity is that major river floods are unlikely to scour accumulated sediments from the estuary (Allanson *et al.* 2000a) making it important to maintain a low sediment supply rate to the estuary (Reddering 1994). Continued inflows of fine cohesive sediments from accelerated catchment erosion will lead to irreversible changes in benthic habitats (Monteiro *et al.* 2000).

Marker (2000) provides accounts of the erosion of estuarine banks on Leisure Isle and in the Belvedere region, as well as sediment movement on the Pansy Bank sandspit in the 1990s, and inflow of sediments, particularly via the Salt River in 1996. It was concluded that storm conditions do not necessarily cause erosion of the beach sand, with erosion being predominantly influenced by wind strength and tide height. The Brenton shore is most affected by strong easterly winds especially when accompanied by rain, since seepage at the base of the clay cliffs causes slumping and sand removal. Another factor affecting erosion is recreational usage of the main channel. Boat wash generates considerable wave action that affects the erodible geology of the adjacent cliffs and the lower beach from mid to high tide (Marker 2000). The effect of land-derived sediments on benthic invertebrates has been addressed by Marker & Maree (2004) who observed that if medium-to-fine deposits did not exceed a depth of 0.03m the invertebrate fauna survived and recovered within 2 years. Burial to a depth of 0.20 m on a marine bank affected the fauna so that only 42% of the original numbers were present after two years. Where 0.4-0.5 m of land sediment accumulated only 6.7% of the pre-flood fauna was evident. In such circumstances, the sandprawn *Kraussillichirus kraussii* was the only prawn able to persist.

3.3.4. Water quality

The earliest comprehensive recorded data about the chemistry of the Knysna Estuary is given in Day *et al.* (1952) who demonstrated that salinity, pH and dissolved oxygen vary along the longitudinal axis of the estuary. Ranges of the water quality parameters water temperature, salinity, dissolved oxygen, pH and secchi disk depth in Knysna Estuary from 1990 to 1994 are given in Russell (1996) and compared with earlier data as given by Day *et al.* (1952), Day (1967, 1981), Grindley & Eagle (1978) and Haw (1984). It was concluded that no clear long-term changes in recorded water quality parameters were evident. Allanson *et al.* (2000a) found there to be a qualitative improvement in chemical water quality when compared to data reported by Grindley & Eagle (1978), thought to be due to an improvement in flow around Thesen Island and an upgrading of the sewage purification works at that time.

3.3.5. Water temperature

Water temperatures demonstrate a strong seasonal pattern with maximum temperatures (up to 29°C) recorded during summer and minimum values during winter (12°C) (Grindley 1985). Schumann (2000) used temperature variability to demonstrate the hydrodynamics of the estuary, particularly in terms of ocean-estuary exchanges. Ocean temperatures were generally found to be colder than estuary temperatures, with variations in water temperature as a result of tidal fluctuations clearly evident. The temperature regime within the estuary may, however, be modified by the intrusion of colder marine water derived from coastal upwelling, as demonstrated in February 1998 where a temperature drop of over 13°C occurred in about 2 hours.

3.3.6. Salinity

Salinities within the upper reaches of the estuary range from freshwater during floods to hypersaline (> 35 psu) during periods of drought (Grindley 1985). A longitudinal gradient in salinity is evident, with marine waters dominating in the lower and middle reaches of the estuary and freshwater in the upper reaches (Russell 1996, Allanson *et al.* 2000a, Largier *et al.* 2000). Vertical stratification can occur, particularly in the upper reaches during periods of strong river flow (Largier *et al.* 2000).

3.3.7. pH

Several authors have published measured pH values, including Le Roi Le Riche and Hey (1947), Day *et al.* (1952), Gridley & Eagle (1978), Grindley & Snow (1983), Russell (1996), Allanson *et al.* 2000a and Knysna Municipality (2004 cited in DEA&DP 2018). The general trend observed by all are higher pH (8.1-8.5) near the estuary mouth due to the dominance of marine waters, and lower pH (< 7) in the upper regions due to the inflow of river water containing humic acids, and longitudinal gradients in-between, the nature of which are variable dependent on the extent of either river or marine inflows and mixing.

3.3.8. Dissolved oxygen

Relatively few data exist on dissolved oxygen concentrations. Russell (1996) found dissolved oxygen to range from 3.1 to 10.2 mg l^{-1} with mean concentrations decreasing longitudinally up the estuary. Low dissolved oxygen concentration (<5 mg l^{-1}) are periodically recorded throughout the estuary (Russell 1996).

Grindley and Eagle (1978) recorded ranges of 6 to 10 mg l^{-1} at Thesen Island. Low oxygen levels in the estuary are likely to be a result of natural biochemical oxygen demand (BOD) of the water column enriched by humates (Allanson *et al.* 2000a). Knysna Municipality (2004 cited in DEA&DP 2018) observed that dissolved oxygen is sustained at near saturation i.e., 82-97% throughout the system. Lowered water temperatures resulting from upwelling events can result in increases in dissolved oxygen levels (Schumann 2000). Allanson *et al.* (2000a) has also suggested that a significant source of oxygen rich water could be the shallow Ashmead channel where nutrient rich effluent from the Knysna waste water treatment works and stormwater inflows leads to phytoplankton growth and Cape eelgrass meadows in intertidal areas.

3.3.9. Turbidity

Knysna Estuary is generally a clear water system. A secchi disk depth of 7.21 m has been recorded in the estuary mouth (Russell 1996), though mean values are in the order of 2.2 m in the embayment, and dropping to an average of 1.2-1.3 m in the upper estuarine reaches (Russell 1996, Allanson *et al.* 2000a). Water clarity does demonstrate a strong spatial pattern with the highest water clarity generally occurring within the embayment and lowest in the upper reaches of the estuary (Grindley 1985, Russell 1996). This pattern can be ascribed to the hydrology of the estuary. Transparency can also vary with season, with early summer (October – November) normally being a rainy period in the region, and with associated increased river and stream inflows increasing suspended solids and reducing clarity (Allanson *et al.* 2000a). An increase in urbanisation and exposure of easily erodible sediments by poor land management does cause an increase in total suspended solids (TSS) concentrations in floodwaters and reduced clarity (Russell 1996). Catchment exposure by property developers caused significant sediment inflows from the Salt River catchment in 1996 and 1997 (Marker 2000), and again in August 2006 from the Bigai system. Continued inflows of fine cohesive sediments from accelerated catchment erosion will lead to irreversible changes in benthic habitats (Monteiro *et al.* 2000).

3.3.10. Nutrients

Overall, the Knysna Estuary can be considered as a nutrient poor (oligotrophic) system largely due to the large volumes of nutrient poor marine waters that pass through the Heads twice daily (Allanson *et al.* 2000a). Dissolved phosphorous values have in the past been found to be relatively low (Korringa 1956) and remain relatively constant throughout the estuary (Day 1981), likely due to the buffering action of sediments. Nutrient levels change with salinity (Allanson *et al.* 2000a), with levels typically decreasing with increasing salinity. The hydrographic structure of the estuary does not affect nutrient levels (Allanson *et al.* 2000a). Changes in nutrient levels are, instead more affected by specific events such as river flooding and stormwater inflows.

Localised regions of high nutrient inputs are derived from stormwater and sewage plant inflows although the contribution of these sources to the total nutrient budget within the system is generally considered low (Allanson *et al.* 2000a). However, changes in the sediment nutrient levels in these areas have been noted, while periodic eutrophication has knock-on effects in terms algal proliferations and dieback of Cape eelgrass beds (Human *et al.* 2016). Inflow of freshwater from the Knysna River contributes to increased nutrient loads within the system. The observed pattern appears to relate to agricultural activities within the catchment area, which contribute to increased nutrient loads within the Knysna River (Allanson *et al.* 2000a). A study by Switzer (2003) has shown that the Knysna River contributes considerable quantities of nitrogen to the estuary during spring storms when inorganic and organic fertilizers (urea) are used by dairy and beef farmers in the river catchment. Intertidal wetlands aid in controlling the trophic status of the estuary.

3.4. Biotic Function

3.4.1. Microalgae

Relatively few studies have been undertaken of phytoplankton in Knysna Estuary. Korringa (1956) identified thirty-nine phytoplankton species in the estuary, and preliminary species lists of some diatoms (Grindley 1985) and dinoflagellates (Grindley 1976, Grindley & Eagle 1978) have been published. Day (1981) suggested the clarity of the water indicated that phytoplankton biomass is generally low. This is borne out by assessments of phytoplanktonic chlorophyll-a concentrations (Allanson *et al.* 2000a) with a mean of $2.16 \pm 1.40\ \mu g\ l^{-1}$ recorded in surveys in the late 1990s.

Assessments of the spatial distribution in phytoplanktonic biomass have indicated non-significant spatial differences within the estuary (Grindley 1985, Allanson *et al.* 2000a, Calvo-Ugarteburu 1998). Wind generated coastal upwelling in the marine environment appears to play an important role in determining the phytoplankton biomass within the Knysna Estuary. Cold, nutrient rich water penetrating into the estuary is associated with a dramatic increase in the total phytoplankton biomass within the estuary with levels of up to 18.4 $\mu g\ l^{-1}$ being recorded (Allanson *et al.* 2000a). The freshwater inflow from the Knysna River is also associated with increases in the phytoplankton biomass as riverine inflow represents the most importance source of macronutrients necessary to sustain the growth of the phytoplankton. These results highlight the importance of catchment management strategies in maintaining the health of the Knysna Estuary.

3.4.2. Zooplankton

Grindley (1985) gives a comprehensive description of the zooplankton community within the estuary. Zooplankton community structure varies spatially reflecting the hydrodynamics of the system. Neritic (oceanic) species dominate in the lower and middle reaches of the estuary while true estuarine species predominate only in the upper reaches (Grindley 1985). The zooplankton community throughout the estuary is numerically dominated by copepods. Among the copepods, species of the genera *Oithona, Paracalanus, Oncaece* and *Pseudodiaptomus* dominate in the lower and middle reaches while in the upper reaches the estuarine copepods in the genus *Psuedodiaptomus* and *Acartia* are most numerous. In addition to the copepods, several additional neritic species of chaetognath, mysid and gelatinous zooplankton have also been recorded within the system.

3.4.3. Macrophytes

Macrophytes refer to vascular aquatic plants (e.g., salt marsh plants, seagrass, sedges, reeds, and mangroves) associated with water bodies including estuaries and can be either submerged, emerged or floating (Whitfield 2017). They create an essential structural habitat providing a refuge and nursery to many fish and invertebrate species. Macrophytes are an important component of the estuarine ecosystem since they contribute to primary productivity and are an important food source. They also act as a nutrient sink, are an important source of detritus and are responsible for the cycling and transference of nutrients through growth and decay. Macrophyte stands are important foraging grounds for both fish (Le Quesne 2000) and birds (Martin *et al.* 2000) due to the high abundance and biomass of invertebrates and nekton they can support.

As an estuarine bay, the Knysna Estuary has a deep mouth that is permanently open to the sea with a tidal regime similar to that of the ocean. Reduced riverine inflows have produced a typically saline system in the lower and middle areas while the upper reaches experience limited freshwater mixing. These conditions support 2 381 ha of macrophytes – placing the Knysna Estuary as the third largest vegetated estuary in the country (Adams *et al.* 2019). Intertidal salt marsh plants dominate the estuary (551.9 ha) followed by submerged macrophytes, mainly Cape eelgrass and paddle weed (also called saltweed, spoon grass or dugong grass) *Halophila ovalis* (447.3 ha), supratidal salt marsh species (133 ha), and reeds and sedges (37.8 ha) (Adams *et al.* 2016). Areas within the Knysna Estuary supporting macrophytes can be divided into three distinct zones.

<u>Subtidal</u>

Submerged macrophytes are plants that occur in soft sediment intertidal and subtidal zones and can tolerate complete and partial tidal submersion as well as varying salinity levels. The dominant plant on shelving mudbanks below the mid-tide level is Cape eelgrass (Grindley 1985). Despite occurring in intertidal patches in sheltered estuaries along most of the coastline, cover is highly variable and Cape eelgrass populations have generally been declining and completely lost in some estuaries receiving an International Union for Conservation of Nature and Natural Resources (IUCN) Red List status of “Vulnerable" because of its restricted range and declining population trend (Short *et al.* 2010). In Knysna, the distribution and abundance of aquatic plants is dynamic though in the mid-1970s the mean dry biomass of Cape eelgrass was recorded as 67.5 g m^{-2} at Ashmead, and 238.4 g m^{-2} north of Leisure Island (Grindley 1976). In places, paddle weed was found to grow in association with Cape eelgrass.

In the upper reaches of the estuary, from Westford (Red) Bridge upstream, tassel pondweed (also called beaked tasselweed, ditch grass, or widgeon grass) *Ruppia cirrhosa* becomes common, eventually largely replacing Cape eelgrass at the Old Drift (Grindley 1985).

In 2009, the invasive red seaweed, the red sea plume *Asparagopsis taxiformis* was recorded for the first time in the small-boat harbour at Leisure Island and in the canals of the Thesen Island marina (Bolton *et al.* 2011). In 2013, Schmidt (2013) estimated the area cover of Cape eelgrass in Knysna Estuary to be approximately 238 ha. A remotely operated underwater vehicle was used to remap subtidal estuarine habitats in 2018 (Wasserman *et al.* 2020) enabling description of the area cover of dominant subtidal macrophyte species (Figure 11). The area covered comprised approximately 74% of vegetated areas (631.9 ha) and <1% sponges and soft corals (2.6 ha) (Wasserman *et al.* 2020). In the vegetated areas, submerged macrophytes and macroalgae commonly occurred together. Cape eelgrass was the dominant macrophyte but was often found among macroalgae and sparse small patches of paddle weed. The area supporting Cape eelgrass was found to be approximately 130 ha greater than in previous surveys. The green seaweed *Caulerpa filiformis*, dominates in macroalgal stands, though the invasive red sea plume was widespread throughout.

The Knysna Estuary supports the largest and most stable remaining stands of Cape eelgrass in South Africa, (Adams 2016) estimated at 353 ha and displaying an increasing population trend (Adams *et al.* 2019). They contribute to the highly productive system supporting a large associated biodiversity (Barnes and Barnes 2014), including providing habitat for critically endangered species such as the pulmonate limpet *Siphonaria compressa* and Knysna seahorse *Hippocampus capensis*, the only globally documented fully estuarine seahorse and found exclusively in the Knysna, Keurbooms and Swartvlei estuaries (Lockyear *et al.* 2006). Seagrass habitats in Knysna are highly dynamic and biomass is often lost after flood events or from disturbance and trampling as a result of boating and bait collecting activities. Competition with macroalgae as a consequence of eutrophication from increasing nutrient runoff is also predicted to be problematic for Cape eelgrass (Adams *et al.* 2019). Loss of seagrass habitats implies a loss in primary productivity and has been linked to declines in fish production (Nordlund *et al.* 2018, Unsworth *et al.* 2019).

Submerged macrophytes are valuable indicators of estuarine health because of their early response to changes in the environment. Deterioration in water quality in the estuary that has led to macroalgal blooms has contributed to the loss of Cape eelgrass particularly in the Ashmead Channel (Human *et al.* 2016), and measures to reduce wastewater discharge and improve water quality levels in the estuary is essential. Sea level rise because of climate change is predicated to increase salinity levels in estuaries likely causing the expansion of Cape eelgrass into upper estuarine areas, however rising intensity and frequency of storm events and rainfall might see an escalation in seagrass loss. Maintaining a healthy and functional seagrass ecosystem is therefore important to ensure the resilience of populations to persist and recover from such events.

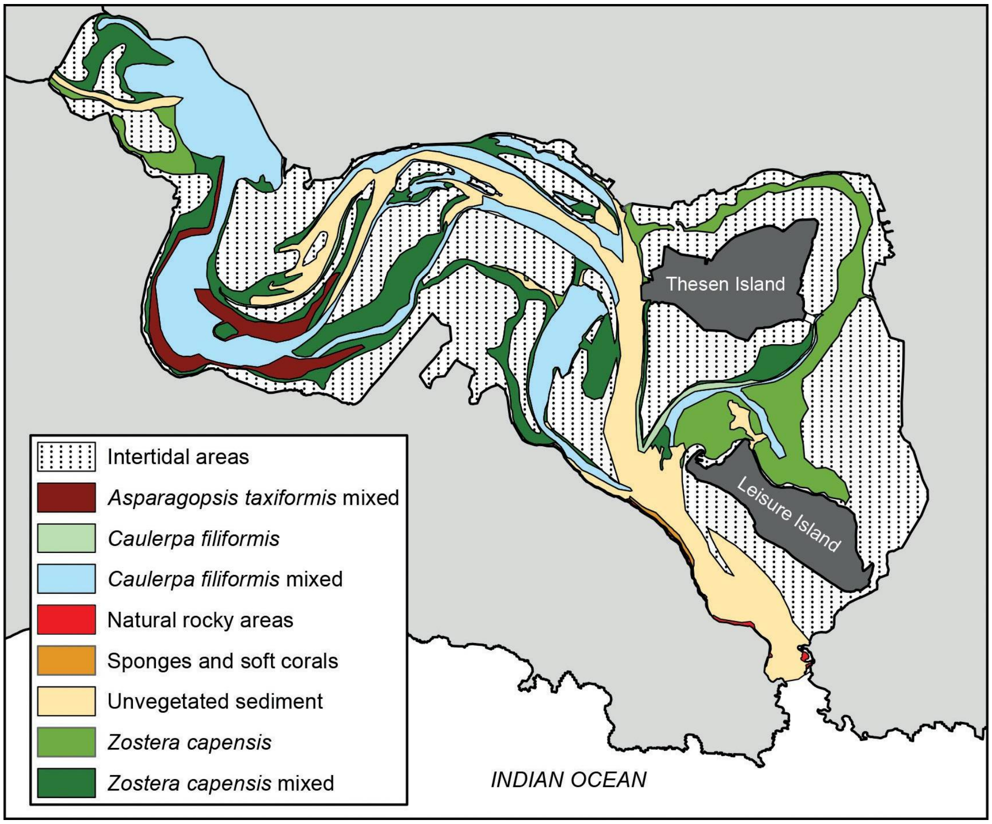

Figure 11. Distribution of macrophytes in Knysna Estuary (Wasserman *et al.* 2020)

<u>Intertidal</u>

An outstanding biological feature of Knysna Estuary is the extensive intertidal saltmarshes. There are large differences in the literature about the area covered by intertidal wetlands, no doubt due, in part, to differing interpretations on what constitutes an intertidal saltmarsh. Salt marsh species comprise a range of vascular plants that display distinct zonation patterns along salinity and tidal gradients, and have adapted tolerance levels to extreme conditions of desiccation, salinity and tidal flooding (Adams *et al.* 2016). Maree (2000) mapped wetland vegetation in the Knysna system and estimated the intertidal wetlands, extending landward of the mid-tide level, to cover an area of 1 000 ha. Van Niekerk *et al.* (2019) give the extent of intertidal saltmarsh in Knysna Estuary as ± 552 ha, which is the third largest in South Africa. This is likely because of the estuary's sizeable tidal volume and moderately sloped banks. Fifty-four plants species have been collected in Knysna saltmarshes, of which 27 occur exclusively in this habitat (Maree 2000). Species recorded in 2020 include *Bassia diffusa*, *Plantago crassifolia*, *Salicornia* spp., cord grass *Spartina maritima*, *Sporobolus virginicus*, and *Triglochin* spp. (Raw *et al.* 2020). Cord grass is abundant at the mid-tide level, with ranges in dry biomass on the eastern shores of the estuary estimated at 1614 to 6465 g m^{-2}, and along with Cape eelgrass in the subtidal zone and the dune slack rush (salt marsh rush, sea rush, jointed rush, matting rush) *Juncus kraussii* in the supratidal zone, is a major source of detritus in the estuary. These habitats protect estuarine banks from erosion by stabilizing sediment. In addition, they serve an important ecological role by filtering sediments from pollutants and other organic/inorganic constituents creating nutrient rich zones of high productivity (Adams *et al.* 2019).

A number of anthropogenic threats to intertidal wetlands have been identified including the formation of pathways, collection of bait, unmoored boats, the construction of causeways and housing developments which interfere with the natural tidal movement over the marshes, storm water outflows and siltation resulting from poor catchment management strategies in the Knysna River (Maree 2000, Adams 2020). Salt marshes have, in the past, been reclaimed for the development of amongst others a harbour wall, roads, residential areas, factories, a runway, refuse dumping site and a golf course. The last thirty years have also seen significant developments within the estuary and its catchment (cf section 2.3 Land Use). These developments have resulted in significant losses (30.5%) of intertidal saltmarshes in the estuary functional zone (Van Niekerk *et al.* 2019). Research by Human *et al.* (2016) highlighted the adverse indirect impacts of poor water quality on intertidal wetlands in the Knysna Estuary. High nutrient loads emanating from the poorly-oxygenated sediment and discharges of effluent from the local waste water treatment works resulted in proliferation of the floating macroalgae, the sea lettuce *Ulva lactuca*. This had a significant impact on the intertidal vegetation, specifically the Cape eelgrass beds in the Ashmead channel, where a noteworthy die-off was observed.

An emerging threat to intertidal wetlands is increased inundation and loss due to future sea level rises. These habitats can respond by increasing their relative elevation, or by migrating into adjacent areas. Raw *et al.* (2020) provided the first report on surface elevation changes for salt marshes in the Knysna Estuary, and predicted the responses of these habitats to sea-level rise. Salt marsh habitats cover was estimated in this study as 667 ha (including both intertidal and supratidal stands) between the estuary mouth and the N2 (white) bridge. The long-term (1960–2017) relative sea-level rise (RSLR) was estimated as 2.19 mm y^{-1}. Comparisons of surface elevation between 2009 and 2018 at seven sites in the Knysna Estuary showed that only two were keeping pace with sea-level rise. Modelling in a focus area near Thesen Island predicted up to 40% loss of upper intertidal salt marsh by 2100, because developments in the adjacent areas prevent habitat migration. Artificial structures are present along 20.7 km of the perimeter of the estuary preventing landward migration of saltmarshes and resulting in coastal squeeze. Several areas within the estuary functional zone currently supporting saltmarsh vegetation have been zoned for development. These areas consist of erven and farms and cover an area of 60.4 ha below the N2 bridge and 81 ha above (Raw *et al.* 2020). Development on these lands would result in further saltmarsh loss and exacerbate coastal squeeze. It was concluded that protecting areas for salt marsh migration should be a conservation priority.

<u>Supratidal</u>

The supratidal saltmarshes are only inundated during high water spring tides. The vegetation of this region is dominated by a variety of species, including *Juncus, Sarcocornia, Triglocin, Chenolea, Limonium* and *Plantago* species (Grindley 1985). The dune slack rush occurs near the high spring-tide level, and covers extensive areas of mudbanks in the upper reaches of the estuary (Grindley 1976). Ranges in dry biomass of saltmarsh plant species in communities on the eastern shores of the estuary are given in Grindley (1976), Grindley & Eagle (1978) and Grindley & Snow (1983) as:

Plantago carnosa = 1943 to 2456 g m^{-2}
Limonium scabrum = 388 to 1059 g m^{-2}
Chenolea diffusa = 630 to 2096 g m^{-2}
Sarcocornia decumbens = 397 to 958 g m^{-2}
Triglochin bulbosa/striata = 854 to 4603 g m^{-2}
Spartina spp. = 1614 to 6465 g m^{-2}

Supratidal saltmarshes are a major source of detritus in the estuary (Grindley 1976) thus contributing significantly to the food chain. Supratidal saltmarsh covers an area of approximately 133 ha (Van Niekerk *et al.* 2019). It is the zone most impacted by developments with 64.5% estimated to have already been lost (Adams 2020) due to reclamations for developments such as housing estates, roads, an airstrip and recreational facilities.

3.4.4. Invertebrates (benthic macrofauna)

The Knysna Estuary is populated mainly by mud dwelling species, with relatively poor faunal diversity found on the sparse rocky banks within the estuary (Day 1967). Day (1981) listed approximately 310 species of benthic macrofauna in the estuary. This included the mudprawn *Upogebia africana*, bloodworm *Arenicola loveni*, *Solen corneus*, bivalves such as the horse mussel *Atrina squamifera*, gastropods including *Assiminea globulus, Hydrobia sp.* and the tick shell *Nassarius kraussianus* as well as amphipods and isopods, with some commonly found in the saltmarsh vegetation including the estuarine crab *Sesarma catenata, Cleistostoma spp.* and other crabs (Grindley 1985). Day *et al.* (1952) demonstrated that the diversity of aquatic invertebrates and typical seashore species progressively declines up the estuary, with marine species absent at Charlesford Rapids (the head of the estuary). Estuarine species are widespread in the estuary, whereas "brack-water species" favouring oligohaline conditions can be found at Charlesford Rapids (Day *et al.* 1952). The faunistic divisions of the macrobenthos in the estuary appear largely to correspond to physical and chemical changes along the length of the system (Day *et al.* 1952).

Similar studies to those of Day *et al.* (1952) were undertaken in 1997 (Allanson *et al.* 2000b). No significant difference between species richness (total number of species or taxa) of transects were reported for the two periods. A significant increase was however recorded in species diversity (number of species and equitability or evenness of individuals among species) (Shannon-Weiner Index) in quantitatively sampled sediments in the Cape eelgrass zone, which was thought to be due to intermittent increases in fluvial derived suspensoids in the water column (Allanson *et al.* 2000b). It has been suggested that an increase in silts and clays (<60 *µm*) after settling has altered the quality of intertidal sediments, making them more suitable for increases in both the number of individuals of resident taxa as well as new taxa, thus affecting species diversity (Allanson *et al.* 2000b).

Day (1967) found that marsh crabs *Sesarma* spp, talitrid amphipods *Parorchestia* spp as well as the sandprawn were all common at the head of the estuary. Species diversity is higher on the extensive flats of the upper channel, with the sandflat crab *Cleistostoma edwardsii*, tick shells, mudprawns, pencil bait *Solen capensis,* lesser heart-clams *Dosinia hepatica,* littoral tellins *Salmacoma litoralis* and species of polychaete worms (e.g. the estuarine nereid *Ceratonereis erythraeensis*) commonly found there. These species extend into the lagoon regime of the estuary, where some species extend laterally between the low and high water marks, likely due to the more evenly sloping shore of this section of the estuary. Towards the mouth tidal currents increase in the main channel and intertidal banks are broad and sandier than upstream. Species such as southern periwinkles *Afrolittorina knysnaensis,* shore crabs *Cyclograpsus punctatus* and bloodworm are found in this section of the estuary. Day (1967) also noted that benthic carnivorous invertebrates such as *Glycera convolute, Gorgonorhynchus* sp., *Thais dubia* and *Natica genuana (Tectonatica tecta)* could also be found in the system.

Claassens *et al.* (2020) summarise the work done in the preceding decade on the distribution, abundance, diversity and species composition of the Knysna Estuary's macrobenthos. Among these, work undertaken by Barnes (2013, 2016, 2018b, 2019a, 2019b), Barnes & Ellwood (2012), Barnes & Barnes (2014) and Barnes & Hendy (2015) showed, *inter alia*, that estuarine fauna changed along the long axis of the estuary (from mouth to the head, similar to the findings of Day *et al.* 1952) (with seven statistically different faunal assemblages) as well as along the perpendicular gradient of tidal height and shelter (from the main channels to the fringing blocks of saltmarsh).

Barnes (2018b) found that three species (*'Hydrobia' knysnaensis, 'Assiminea' capensis* and *Halmyrapseudes cooperi*) comprised >70%, often >90% of the seagrass macrofauna (Barnes 2018b). Of these, the endemic mudsnail *'H.' knysnaensis* has been the focus of detailed studies (see Barnes 2004). An interesting observation noted in these studies was that the number of species present per unit area was constant, despite differing species composition of samples. This was attributed to species being distributed at random, likely due to being maintained at below carrying capacity as a result of predation (Barnes 2021a). Barnes (2018a) also noted that the dieback of Cape eelgrass due to a macroalgal bloom in the estuary (cf. section 3.4.3) resulted in a change from epifaunal assemblages to infaunal polychaete assemblages, similar to natural areas of bare sand, provided that no sediment hypoxia exists.

Barnes & Claassens (2020) compared the biodiversity between subtidal and intertidal zones and concluded that each zone supports its own characteristic assemblages of macrofauna. As a result, subtidal areas may not necessarily be refuge areas for intertidally dominant fauna subjected to harvesting pressure. Barnes & Barnes (2014) also noted that faunal abundance was lower in seagrass than in adjacent unvegetated areas, unlike other studies in similar habitats elsewhere in South Africa, additionally, seagrass assemblages were more similar to adjacent bare sand than seagrass assemblages elsewhere. In a later study, Barnes (2019) notes that fauna associated with seagrass in the Knysna Estuary displays patchiness at any given site, though this patchiness does not vary statistically along the long (mouth to the head) axis of the estuary, regardless of assemblage abundance, location or species composition. This patchiness appears to be a characteristic of dwarf-eelgrass assemblages, as it was also noted in similar systems in subtropical Queensland and in cool-temperate England (Barnes 2019, 2021b).

A relatively recent addition to the macro-benthic fauna is the presence of *Diopatra aciculata*, a polychaete worm, native to Australia, and commonly known as the moonshine worm. The taxon was not detected during surveys of the macrobenthos conducted in Knysna in the 1940s (Day 1967) and 1990s (Allanson *et al.* 2000b), and was first reported as a harvested bait species in the mid-2000s by Napier *et al.* (2009). Its appearance in Knysna Estuary is therefore likely to have occurred within the last three decades. van Rensburg *et al.* (2020) provides an updated detailed morphological description of the moonshine worm in South Africa and also investigated the species' distribution and population size in the Knysna Estuary. Despite its relatively recent introduction the species is now found throughout the system below the White bridge in both subtidal and intertidal areas. Abundance is patchy with areas of high (median densities of 3–8 worms m^{-2}, e.g., Bollard Bay) and low densities (median densities of 0 worms m^{-2}, e.g., Thesen Island North) identified (van Rensburg *et al.* 2020). Based on the mean density per sample (3.47 worms m^{-2}) and conservative estimate of the total area that could be occupied by the moonshine worm, the estimated population size in the Knysna Estuary is between 20 and 24 million worms (van Rensburg *et al.* 2020). The species is used as bait by recreational and subsistence fishers although in the mid-1990s Hodgson *et al.* (2000b) found that the only polychaete harvested by few recreational fishermen was the bloodworm. A decade later, Napier *et al.* (2009) found that while bloodworm was still harvested, more fishermen, including subsistence fishermen, were also collecting other polychaete species, with moonshine worms (identified as *Diopatra* sp.) being the third most frequently collected species. Another 10 years later and Simon *et al.* (2019) found that moonshine worm was the most preferred (albeit not the most collected) bait polychaete among subsistence and recreational fishermen in the estuary. Van Rensburg *et al.* (2020) caution that given the size of individual worms and the population estimate, the moonshine worm can be expected to have significant ecological impacts in the estuary and further research is required.

The mudprawn is an abundant, widespread and dominant component of the benthic macro-invertebrate community (Hodgson *et al.* 2000a). Mudprawns occupy 62% of the available intertidal zone, with density (74-76 m^{-2}) and biomass (26-27 g m^{-2} dry weight) usually greatest in the *Spartina* and lower Cape eelgrass zones and only small individuals recorded in the upper reaches of the estuary (Hodgson *et al.* 2000a). In 1995 the Bait Reserve was found to have a low density and biomass of mudprawns, (11.7 m^{-2}; 3.9 g m^{-2}) whereas a relatively inaccessible mudbank (Oyster Bank) in the middle reaches of the estuary had a much larger population (176 m^{-2}; 6.5 g m^{-2}) (Hodgson *et al.* 2000a). This difference could be a result of more favourable habitat at the Oyster Bank (e.g., less variable temperature and salinity) and/or the inaccessibility of the site to bait collectors (Hodgson *et al.* 2000a).

The critically endangered false/pulmonate limpet *S. compressa*, originally described by Allanson in 1958 from the Langebaan Lagoon, has been recorded in intertidal Cape eelgrass meadows at Bollard Bay, Leisure Isle (Allanson & Herbert 2005). This represents only the second known site of occurrence of this species. The rarity of *S. compressa* and its endangered status seem dictated by its extremely narrow and temporally changeable habitat range (Angel *et al.* 2006). The Knysna population is considered to be viable (Allanson & Herbert 2005). Any changes to the Cape eelgrass habitat may influence its distribution and abundance, and if the species is lost from the system, it is highly unlikely that it would occur there again as the only other population is found on the west coast (Langebaan Lagoon) (Claassens *et al.* 2020). Allanson & Msizi (2010) and Allanson & Fearon (2012) found that growth to maturity was rapid and consequently generation time was short for *S. compressa* based on *ex situ* study of juveniles reared in a laboratory. Increased spawning of *S. compressa* was noted in summer, with spawn, measuring less than 5 mm in diameter, only deposited on Cape eelgrass*,* leaves in the wild and often hidden under layers of leaves (Allanson & Msizi 2010).

The pansy shell, *Echinodiscus bisperforatus* occurs and breeds on sand banks in the main channel adjacent to Leisure Isle (Grindley 1985). The species is listed under the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) Threatened or Protected Marine Species Regulations, 2017 (GN. No. R. 477 of 2017) as a protected species and hence may not be collected by recreational MLRA permit holders (see GN. No. R 476 of 2017 for full list of restrictions). In an unpublished report, Hanekom & Russell (1991) estimated that the Knysna Estuary was host to ±16 000 individuals, making it one of the largest populations in the southern Cape.

One species of piddock is also found along a narrow stretch of the estuary. This species is believed to be an alien species from Europe, *Pholas dactylus* (Branch *et al.* 2016) although the genetics and species classification of this species is currently under investigation. This small, apparently isolated population is currently being investigated.

Although not typical of an estuarine environment, Day (1967) noted that marine species such as the eightshell barnacle *Octomeris angulosa*, limpets *Patella* spp and periwinkles *Oxystele* and *Turbo* spp can be found at the rocky shores near the mouth of the estuary, but that this environment is poorer in species than similar exposed marine reefs.

3.4.5. Fish

Diversity

Numerous fish species are found within estuaries but their habitat utilisation patterns vary widely. Depending on their origin and spawning habits, the fishes associated with southern African estuaries may be divided into four broad categories, i.e., marine, estuarine, diadromous and freshwater (Whitfield 2019). Each of these categories comprises multiple guilds (Table 3).

Table 3: South African classification of fish utilizing estuaries (Whitfield 2019).

Category	Description of Category
A	Marine straggler
B	Marine estuarine-opportunist
C	Marine estuarine-dependent
D	Solely estuarine
E	Marine & estuarine
F	Estuarine & freshwater
G	Estuarine migrant
H	Catadromous
I	Freshwater straggler
J	Freshwater estuarine-opportunist

Due to the overall size, variety of habitats available, and the deep, wide permanently open mouth, there are a high number of fish species found within the Knysna Estuary (Grindley 1985). Relating to the recruitment of early juveniles from the sea into the estuary, seasonal spring and summer increases in juvenile fish abundance has been documented in the Knysna Estuary by Whitfield & Kok (1992). Their work highlighted the importance of the Knysna Estuary regionally as a predictable nursery area due to the permanent open mouth status. Furthermore, the system is noted for having a high proportion of marine stragglers when compared with other estuaries in the area, due to the strong marine influence (James & Harrison 2009). Grindley (1976) is often cited as providing a complete species list, in excess of 200 species. However, the Grindley (1976) species list was based, in part, from verified sightings or catches along with expert opinion of what could occur based on species distributions. For example, spotted gully shark *Triakis megalopterus* is included in the list but with the provision of “could enter Heads”. As such, the list should be used with caution and seen as a potential species list rather than documented occurrence.

In a later report, Grindley (1985) provides a list of common fish found in the estuary, which consists of 60 different fish species from 38 families. Very few system wide fish community assessments have been undertaken and published on the Knysna Estuary since Grindley (1985), and those that have been undertaken have recorded far fewer species (see Table 3.9.2). Using both seine and gill nets (James and Harrison 2009) recorded 33 species from 18 families. Mugilidae and Sparidae were the most important families with seven species each, followed by Gobiidae with five species. Seven species were estuarine dependents, seventeen were inshore marine species whose juveniles utilise estuaries, and seven were marine species that are not dependent on estuaries. Estuarine-dependent marine species comprised 51.1% of the catch numerically and 91.9% by mass. Solely estuarine species comprised 47.9% numerically and 1.9% by mass, while marine stragglers comprised 0.9% numerically and 6.1% by mass.

Over a six-year period a seine net dataset by the Department responsible for fisheries (Department of Forestry, Fisheries and the Environment – DFFE) covering 26 samples sites (covering lower, middle and upper reaches) recorded 50 species from 30 families (Meiklejohn 2020). Marine estuarine-dependent (18 species) and marine estuarine-opportunistic species (12 species) dominated with Sparidae and Mugilidae being the most important families with nine and six species respectively. Working with the DFFE dataset Claassens *et al.* (2020) showed no discernible trend in either fish abundance or diversity over the data collection period. A summary of the species recorded in the Knysna Estuary by the different surveys covering a period from 1985 to 2020 is provided in Appendix 1. A total of 41 families and 73 species are represented.

<u>Habitat usage</u>
Le Quesne (2000) investigated the usage by fish of intertidal marshes dominated by dune slack rush in the upper reaches of the Knysna Estuary. Twenty-five, predominantly euryhaline marine species were recorded, which were dominated numerically by juvenile (<30 mm) Mugilidae, Cape silverside *Atherina breviceps* and South African mullet *Chelon richardsonii*, and in terms of biomass by South African mullet, white steenbras *Lithognathus lithognathus*, spotted grunter *Pomadasys commersonnii* and Cape stumpnose *Rhabdosargus holubi*.

Intertidal marshes are argued to provide areas of refuge from predators and feeding opportunities, with the nine most dominant taxa actively feeding in marsh areas. In 2016, Pollard *et al.* (2017) compared the occurrence of sparids and mugilids in Cape eelgrass and nearby bare sediment areas using previously unpublished results from monthly seine netting conducted in the lower, middle and upper reaches of the estuary between July 1978 and December 1980. They tested the hypothesis that mugilids are dominant in unvegetated areas of the Knysna Estuary littoral whereas sparids predominate within Cape eelgrass beds located in the same zone. The results indicated that the family Mugilidae is better represented at unvegetated sites when compared to members of the family Sparidae, with the exception of white steenbras, but that the dominant three sparids and dominant two mugilids were most abundant in sparse Cape eelgrass beds that included both bare and vegetated areas within this habitat type.

Using the 2007 to 2012 DFFE dataset, Meiklejohn (2020) undertook a spatial analysis of estuarine habitats and associated fish assemblages in order to: 1) map the distribution of various categories of estuarine fishes, 2) map the abundance and size distribution of key species, and 3) to identify potential nursery hotspots. His results indicated that marine stragglers (category A) were more abundant in the lagoon section, marine estuarine-opportunists (category B) were widespread but more dominant in the marine bay, marine estuarine-dependent (category C) were more abundant in the lower estuary, solely estuarine (category D) in the marine bay, marine and estuarine (category E) were more abundant in lagoon and marine bay, estuarine and freshwater (category F) in the marine bay and freshwater estuarine-opportunists (category J) were most abundant in the upper estuary (Figure 12). No species falling within the estuarine migrant or catadromous guilds were sampled. Interestingly when looking at selected individual species there were distinct populations of large and small individuals indicating potential habitat separation at different life-stages.

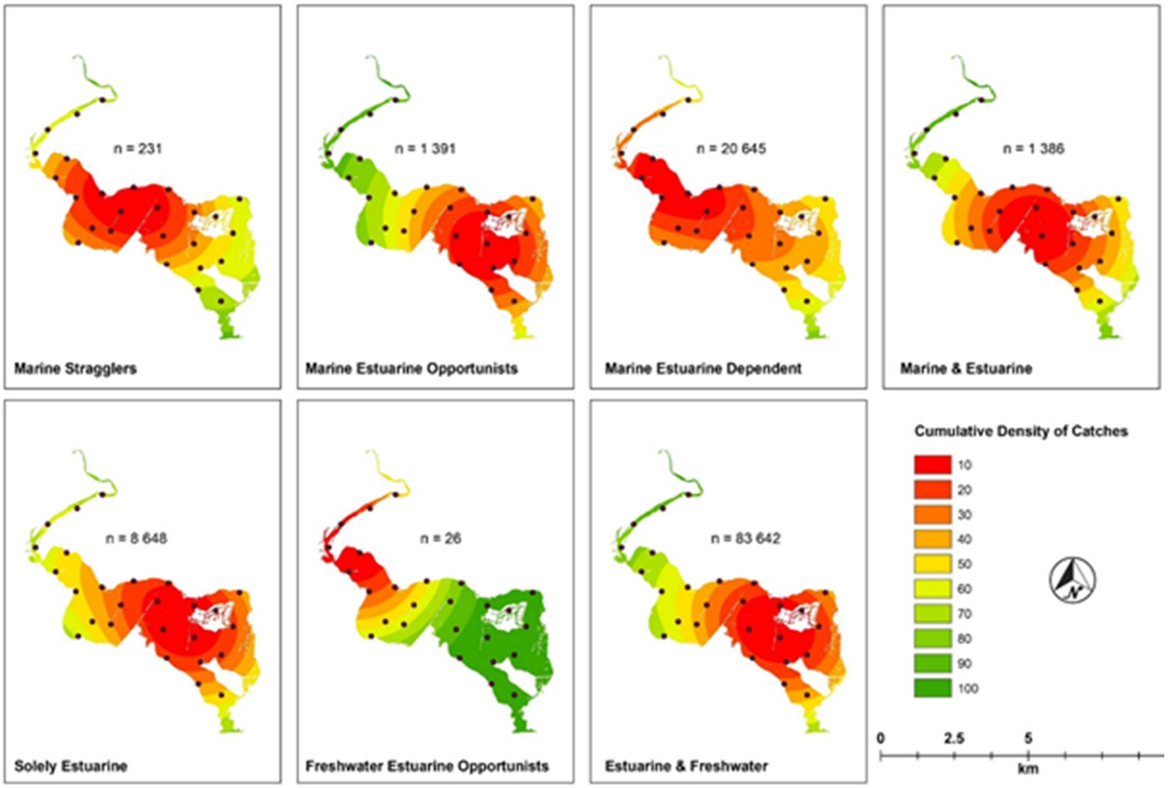

Figure 12: Density of catches (2007 – 2012) within the Knysna Estuary based on estuarine guild (Whitfield 2019). Figure taken from Meiklejohn 2020.

The Knysna Estuary also acts a thermal refuge area for various species during coastal upwelling events (Grindley 1985). Occurring primarily in spring and summer, these upwelling events, driven by easterly winds, can cause a rapid drop in water temperatures. Various species including white musselcracker *Sparodon durbanensis* and various elasmobranch species temporarily migrate into the estuary to escape the cold water.

Species of special concern and rare species

What is thought to be a new species of goby from the Knysna River *Gobius maxillaris* sp. n. was described by Davies (1948), however, since this time no further specimens of this species have been recorded in the Knysna Estuary, or any other estuary. A rare estuarine goby, dwarf goby *Pandaka silvana*, is endemic to Knysna Estuary (Penrith & Penrith 1972).

3.4.6. The Knysna seahorse

The Knysna seahorse is endemic to South Africa and is the only fully estuarine seahorse species (Bell *et al.* 2003). Found in only three estuaries, they have a restricted distribution and, partly due to this localised distribution, is the first seahorse species listed as Endangered on the IUCN Red List of Threatened Species (Hilton-Taylor 2000). The Knysna seahorse is also listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Given the endangered status of the Knysna seahorse and the CITES listing, harvesting of the species is prohibited, and it is not known to form part of international trade (Foster 2004, Lourie *et al.* 2004), although Chang *et al.* (2013) found one Knysna seahorse when sampling seahorses at a traditional Chinese medicine market in Taiwan. The origin of the individual could, however, not be ascertained.

Of the three estuaries that host the Knysna seahorse, the Knysna Estuary supports the largest, most stable population (Mkare *et al.* 2021). Threats to Knysna seahorse habitat include habitat degradation and reduced water quality associated with urban expansion within the EFZ and catchments of the rivers that feed into the estuary.

Boat usage on the estuary is high, which may impact Knysna seahorse habitat (Lockyear *et al.* 2006) whilst significant changes in visibility, feeding and courtship noted by Claassens & Hodgson (2018a, b) during the summer holiday period suggest that boat noise has an adverse impact on seahorse behaviour.

Studies using molecular techniques have focused on efforts to resolve taxonomic uncertainties around and the phylogenic placement of the Knysna seahorse within the genus *Hippocampus*; which has placed the species within the yellow seahorse *H. kuda* complex containing mostly south-east Asian species (Teske 2003, BOLD 2016). This placement in the yellow seahorse complex has led to Lourie *et al.* (2016) questioning the validity of the Knysna seahorse as a separate species; although they maintain its status as a species in their global review. Population genetic studies were conducted to determine if the populations in the three known estuaries can be considered as distinct management units; with results suggesting that there is some interaction and sharing of genetic information between the three populations, possibly a result of the Knysna population acting as a seeding area for the other two populations, though this may be less common for the Swartvlei population than the Keurbooms population (Toefy 2000, Teske *et al.* 2003). Additionally, spread of the species between these estuaries is believed to have occurred relatively recently (<450 years ago), with systems showing relatively stable (Swartvlei Estuary) or increasing (Knysna and Keurbooms Estuaries) effective population sizes over this period. The Endangered status of the species is therefore more likely as a result of its small home range rather than decreasing population size (Mkare *et al.* 2021).

Knysna seahorses are believed to be diurnal (Lockyear *et al.* 1997), with no apparent depth restrictions except that they are more common in shallower water (Toefy 2000). The Knysna seahorse is commonly found attached to Cape eelgrass (Bell *et al.* 2003; Teske *et al.* 2007), *C. filiformis*, *Codium extricatum*, paddle weed or spiral tasselweed *Ruppia cirrhosa* (Teske *et al.* 2007). More recent studies have shown that artificial structures may also play an important role as holdfasts for the Knysna seahorse (Claassens 2016, Claassens & Hodgson 2018b, Claassens *et al.* 2018, Claassens & Harasti 2020). Population assessments of the Knysna seahorse have been undertaken by Bell *et al.* (2003) and Lockyear *et al.* (2006) finding average densities of 0.0008 and 0.01 seahorses m^{-2} respectively.

Preliminary studies suggest that the Knysna seahorse reaches sexual maturity within its first year (approximately 6.5 cm standard length (SL)) (Whitfield 1995). Breeding occurs in the warmer spring and summer months, and males in a breeding condition show enhanced colouration, including an orange fringe to the dorsal fin (Grange & Cretchley 1995). In a study on the breeding habits of captive Knysna seahorses, Lockyear *et al.* (1997) hypothesised that temperature was the principal environmental factor governing reproduction in the Knysna Estuary, although the authors note that additional studies at temperatures below that found in the Knysna Estuary (22°C) need to be conducted to confirmed this hypothesis.

3.4.7. Birds

Following a study by Martin *et al.* (2000) who reported a total of 67 species of waterbirds in the Knysna Estuary over a five-year period (1993-1998), no subsequent studies have been published relating to birds in the Knysna area. However, bird abundances are regularly monitored through Coordinated Waterbird Counts (CWAC), with surveys carried out biennially (summer and winter) throughout the estuary by local birders. Waterbird densities in the estuary were described as low, with higher abundances reported in summer than winter dominated by Palearctic migrants (Martin *et al.* 2000). These counts have shown that the estuary supports globally significant abundances of African black oystercatcher *Haematopus moquini* (IUCN listing of Near Threatened) in winter along with substantial numbers of (small) shorebirds (i.e., curlew sandpiper *Calidris ferriuginea,* grey plover *Pluvialis squatarola*, common whimbrel *Numenius phaeopus* and common greenshank *Tringa nebularia*) in summer, and larger pisciverous birds (i.e., cormorants, herons and egrets) in winter. Intertidal mudbanks along the Ashmead Channel and at Brenton (below the bridge) were found to support mostly invertebrate feeders, while piscivorous species exploited shallower areas between the road and railway (Martin *et al.* 2000).

Turpie *et al.* (subm.) compared CWAC data from the 70-80s with data from 2014-2019 and found greatest losses in bird numbers were from estuaries on the west and south-western coasts but reported that densities in Knysna had not significantly changed (Figure 13).

Generally, widespread declines were evident in numbers of terns, waders and gulls along with planktivorous waders (i.e., lesser flamingos *Phoenicopterus minor*) and waterfowl – pelicans and kingfishers were also reported to have declined (Turpie *et al.* subm.). These findings are supported in preliminary analyses of the complete CWAC dataset (1993-2019) that show declines in wader, tern and gull abundances along with yellow-billed ducks *Anas undulata* and Cape shovelers *Anas smithii* in Knysna (Russell pers. comm.). In that analysis, increasing trends in numbers of red-billed teal *Anas erythrorhyncha*, greater flamingo *Phoenicopterus ruber* as well as Cape cormorant *Phalacrocorax capensis* and African reed cormorant *Phalacrocorax africanus* were also evident. Increasing abundance of Egyptian goose *Alopochen aegyptiaca* is in line with national and global trends that show that this species is opportunistic and thrives in human-transformed habitats (Mackay *et al.* 2014, Mangnall and Crowe 2001).

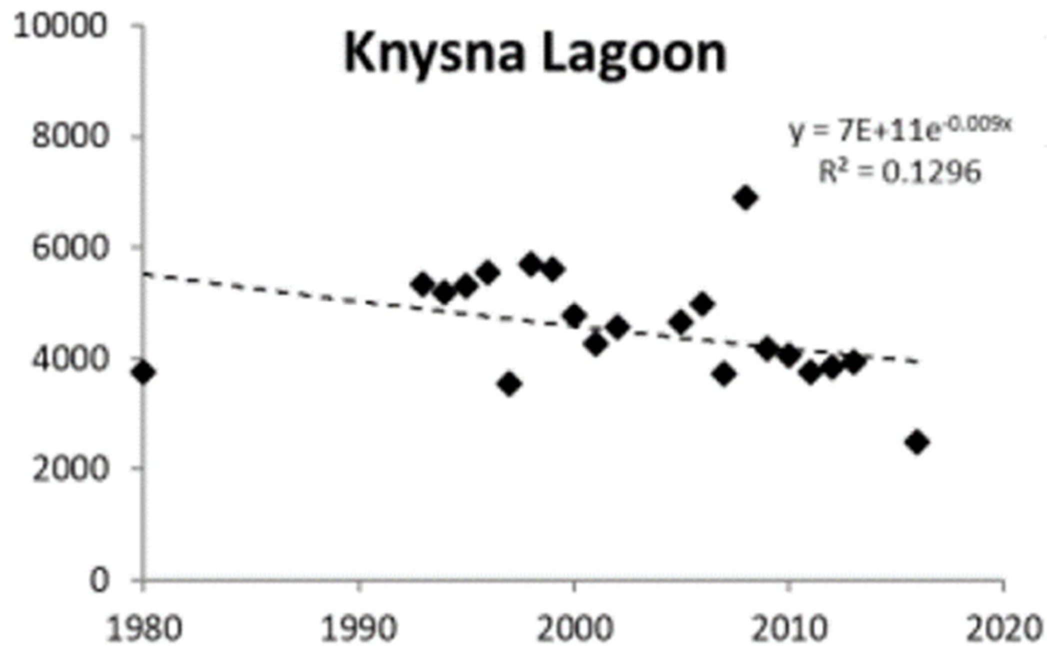

Figure 13: Changes in bird abundances in the Knysna Estuary according to CWAC data collected over 20 different years (from Turpie *et al.* subm.).

The declining trend in waterbird abundances has been observed nationally where recent bird counts have yielded estimates of only 32% of that recorded ~40 years ago (Raimondo *et al.* 2019), while >265 000 waterbirds have been lost from estuaries worldwide - the majority of which are waders from larger estuaries (Van Niekerk *et al.* 2019). Declines are mainly of migratory birds but also include most estuarine groups and are essentially due to global and local pressures including the overexploitation of estuarine fish as well as damaged and/or transformed habitats (Van Niekerk *et al.* 2019).

Low bird abundances in the Knysna Estuary were assumed to be as a result of disturbance from bait collection and recreational activities as well as low invertebrate densities (Underhill *et al.* 1980, Martin *et al.* 2000). Excessive nutrient loads lead to algal blooms that generate high detrital biomass when they die out. This in turn leads to lower concentrations of dissolved oxygen further impacting birds and their invertebrate and fish prey (van Niekerk *et al.* 2019). Recreational boating and water sports including kite surfing can have significant detrimental impacts on waterbirds, and have been shown to result in declines in both resident breeding species, as well as migratory species (van Niekerk *et al.* 2019). Additional pressures on estuarine bird species nationally include dwindling availability of prey due to overfishing and shifts in distributions of prey species likely due to climate change, harassment by dogs, loss of breeding habitat, and hunting along migration routes (Van Niekerk *et al.* 2019).

The Knysna Estuary management plan needs to maintain and improve the overall health of the estuary by also protecting important breeding and foraging areas for waterbirds. Sanctuary areas large enough to protect birds and their prey from human disturbance and exploitation should also be delineated.

3.5. Ecological Status

The present ecological status and desired status were assessed during reserve determination studies for the Knysna Estuary (DWA 2009). The individual scores for each of the components are incorporated into a Habitat health score and a Biological health score. This allows for the determination of the Estuarine Health Index (EHI) Score as illustrated below (Table 4 & 5).

Table 4: Habitat Health Index scores for the Knysna Estuary (after DWA 2009).

Variable	Weight	Score	Weighted score
Hydrology	25	91	23
Hydrodynamics and mouth condition	25	100	25
Water quality	25	72	18
Physical habitat alteration	25	83	21
Habitat health score			**87**
Microalgae	20	69	14
Macrophytes	20	80	16
Invertebrates	20	75	15
Fish	20	62	12
Birds	20	65	13
Biotic Health Score			**70**
Estuarine Health Score			**78**

Table 5: Guidelines for the Present Ecological Status (after DWA 2009).

Estuarine Health Index	Present Ecological Status	General description
91 - 100	A	Unmodified, natural
76 - 90	B	Largely natural with few modifications
61 - 75	C	Moderately modified
41 - 60	D	Largely modified
21 - 40	E	Highly degraded
0 - 20	F	Extremely degraded

The EHI score for the Knysna Estuary, based on the most recent assessment of its present state (DWA 2009), is 78, translating into a Present Ecological Status of a B, i.e., largely natural with few modifications as indicated below. It should however be noted that the Biotic health score was 70 which is a Mid C. In short, the biotic health of the system is not as good as the physical habitat and this must be borne in mind in the management of the system. The present ecological state is given in the National Biodiversity Assessment as a B/C (Van Niekerk *et al.* 2019).

Claassens *et al.* (2020) assessed of the trajectory of change in variables used in ecological health evaluations of the Knysna Estuary, and suggested declines in all variables. Some changes have occurred in the system, notably the spread of alien red algae, and algal blooms in the Ashmead channel in the mid-2010s (Allanson *et al.* 2016) and resultant localised dieback of Cape eelgrass (Human *et al.* 2016) (cf section 5.3.4). Despite this dieback in the Ashmead channel, the coverage of Cape eelgrass has increased overall in the estuary (Wasserman *et al.* 2020), though in Claassens *et al.* (2020), 'declining' macrophytes is given as the underlying reason for many supposed biological changes.

Many of the changes or declines described in Claassens *et al.* (2020) are, however, not backed up by supporting data presented in the publication and thus present mostly as opinions, or do not adequately account for larger drivers of change (e.g. wet-dry cycles; global changes in Palearctic migrant waterbird habitats, etc.) which although possibly affecting local processes and species abundances, need not necessarily indicate a local decline in estuarine condition. Some other examples of omissions or inconsistences are with benthic invertebrate harvesting where the sustainability of use is not addressed; in fish, even though the data presented shows no significant changes, a decline in fish communities is concluded; and recovery of macrophyte beds in the Ashmead channel post disturbance is not assessed or considered. Management recommendations provided by Claassens *et al.* (2020), in some instances, do not account for limitations in managing open access systems (e.g. boating carrying capacity), are managerially impossible with current technologies (e.g. alien biota management), or do not adequately take account of real world financial and capacity constraints, and as such not incorporated further in this review.

Recommended Ecological Category

The present ecological category of the Knysna Estuary is a B/C (Habitat heath = largely natural with few modifications unmodified; biotic health score = moderately modified). The Knysna Estuary falls within a protected area. According to the guidelines for assigning a Recommended Ecological Category, the Knysna Estuary should therefore be classified as a Category A or Best Attainable State (BAS). Achievement of an A is impossible given current developments and pressures; thus, the Recommended Ecological Category is BAS which is a B (DWA 2009, Van Niekerk *et al.* 2019, DWS 2018, DWS 2020).

3.6. Reserve Assessment

An intermediate reserve assessment was undertaken in 2006 (DWA 2007a) in which water use and development scenarios were modelled (Table 6). Of these scenarios 1, 2, 3, 6, 7, 8 and 9 would maintain the Knysna Estuary in the Recommended Ecological Category of a B (Table 5). From the perspective of the Estuarine Biotic Score there is little to separate Scenarios 6, 7, 8 and 9, although it should be noted that the Estuarine Health scores in all of these scenarios are in a C. Furthermore, the trajectory of change with further developments in the area, road reclamation, increasing recreational use, and eutrophication issues is negative.

The system is very marine-dominated with the daily tidal prism approximating the MAR into the system. The estuary is fortunate in that the massive tidal exchange mitigates significantly the elevated anthropogenic nutrient input. Due to the marine nature of the system, any impacts of freshwater abstraction will be felt predominantly in the upper reaches of the estuary above the red bridge. Whilst the abstraction scenarios (2, 3, 6, 7, 8 and 9) all result in the whole estuary having an Ecological Category of a Low B, it must be recognised that the impact of the scenarios in the upper reaches will be far more severe. The system is likely on a negative trajectory, which is driven predominantly by anthropogenic non-flow factors.

Scenario 9 (highest attainable state resembling reference condition) was selected as the Recommended Ecological Water Requirement. A summary of the flow distributions for Future Scenario 9 is provided in Table 7.

Table 6: Summary of the expected estuarine ecological condition for the Knysna Estuary for each of the scenarios (after DWA 2009).

Scenario	Description	MAR to estuary (MCM/a)	%n MAR remaining	Habitat Score	Biotic Score	Overall Score	Overall EC
Reference	Reference condition	83.2	100.0	100	100	100	A
Present	Present day (2008)	68.0	81.7	87	70	78	B
1	Remove alien vegetation	69.9	84.0	87	71	79	B
2	Small dam at Charlesford: 200 l s^{-1} release to estuary	61.5	73.9	84	68	76	B
3	Small dam at Charlesford: 500 l s^{-1} release to estuary	60.7	73.0	84	69	77	B
4	Large dam at Charlesford: 500 l s^{-1} release to estuary	35.4	42.6	73	53	63	C
5	Large dam at Charlesford: 200 l s^{-1} release to estuary	24.7	29.7	71	47	59	D
6	Knysna dam in upper Knysna River: Release into river for abstraction at Charlesford + 500 l s^{-1} released to estuary	63.5	76.3	84	69	76	B
7	Off-channel storage with abstraction near Charlesford with a release of 500 l s^{-1} to estuary	59.0	71.0	85	69	77	B
8	Increased abstraction from Gouna tributary	62.3	74.9	86	69	78	B
9	Knysna dam in upper Knysna River: Release into river for abstraction at Charlesford + 200 l s^{-1} released to estuary	63.4	76.2	85	69	77	B

Table 7: Summary of the flow distribution under future scenario 9 for the Knysna Estuary (after DWA 2009).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99	10.3	11.71	8.55	8.48	7.13	9.96	11.26	15.38	8.39	9.83	12.21	13.31
95	8.03	7.18	4.47	3.39	4.79	4.21	4.88	7.28	5.74	4.69	7.81	11.26
90	6.76	5.92	3.33	2.22	2.88	3.21	3.62	4.28	3.78	3.45	5.68	5.39
80	4.73	3.91	2.23	1.72	1.76	2.51	2.3	2.52	2.45	2.34	3.68	3.84
70	3.47	2.71	1.55	1.02	1.2	2.11	1.69	1.77	1.86	1.97	2.53	3.2
60	2.86	2.15	1.11	0.73	0.83	1.22	1.3	1.42	1.47	1.59	2.18	2.59
50	2.34	1.62	0.94	0.55	0.64	0.87	1.1	1.16	1.17	1.27	1.8	2.19
40	1.78	1.18	0.74	0.47	0.45	0.67	0.79	0.83	0.93	0.99	1.29	1.79
30	1.5	1.01	0.49	0.33	0.26	0.49	0.6	0.58	0.65	0.71	1.09	1.53
20	1.25	0.76	0.32	0.25	0.26	0.26	0.37	0.28	0.4	0.47	0.92	1.34
10	0.89	0.42	0.26	0.25	0.24	0.25	0.25	0.26	0.24	0.31	0.61	0.76
1	0.44	0.27	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.25	0.26	0.41

State	Name	Average Monthly Flow ($m^3 s^{-1}$)
1	Marine dominated, limited to no gradient	<0.05
2	Marine dominated, some gradient	0.5-2.0
3	Marine dominated state with small transitional pulse	2.0-5.0
4	Marine dominated with large transitional pulse	5.0-10.0
5	Freshwater dominated	>10.0

It is recognised that factors such as socio-economic implications, assurances of supply and construction environmental impacts will determine which of Scenarios 6, 7, 8 or 9 will be selected for management of the system. The key issue will be to ensure that improvement in the degree to which man induced non-flow drivers are impacting on the system, is included in any management plan that involves further freshwater removal from the system. The following recommendations have been made (DWA 2009):

- Fishing and bait collecting: Fishing and bait collecting have a significant impact on the trophic functioning of the estuary. It is recommended that stringent policies and enforcement systems be developed and implemented to reduce the impact of such activities on fish stocks and recruitment;
- Boating and disturbance: Boating and other activities have a significant impact on the bird populations on the estuary. A rigorously enforced disturbance and boating plan needs to be implemented;
- Water quality: Water quality in the estuary needs to be improved, all point, and diffuse sources identified and managed. The lower reaches around the Ashmead Channel need specific attention;
- Urban encroachment: Policies around urban encroachment and the impact that this has on supratidal and salt marsh vegetation need to be rigorously enforced;
- Red data species: The EMP needs to take special cognisance of species such as the Knysna seahorse; and
- River Estuarine Interface (REI): The further abstraction of freshwater from the Knysna catchment will mainly impact on the upper reaches of the estuary, with the most significant impacts felt in the REI Zone above the Red Bridge. It is recommended that above the Red Bridge all extractive activities be excluded, no power boating of any sort be allowed, no dogs be allowed, strict setback lines for development are enforced, septic tanks and any point or diffuse water sources be monitored, and all alien vegetation be removed.

3.7. Estuarine Biodiversity and Conservation Importance

3.7.1. Conservation Importance

Estuaries are habitats that form at an interface between river and sea, which allows mixing of waters that have different physico-chemical properties (pH, salinity, dissolved oxygen, conductivity, temperature, particulate organic matter, etc.) thus creating unique ecosystems. Estuaries provide several ecological services such as being nursery areas for juvenile fish, providing sediments and nutrients for inshore coastal habitats, increase aesthetic values of surrounding areas which can be exploited through recreational activities and providing resources that can be used by surrounding communities for socio-economic development (Turpie 2004). Out of the 290 estuaries in South Africa with 22 estuarine ecosystem types recently revised, the Knysna Estuary is considered one of the most unique habitats as it is an estuary that is classified as an estuarine bay and is the only one that occurs in the warm temperate bioregion in South Africa (Van Niekerk *et al.* 2019).

The assessment of South Africa's biodiversity through the NBA 2011 led to the introduction of two headline indicators, ecosystem threat status and ecosystem protection level. The ecosystem threat status informs about the degree to which the ecosystem is still intact whilst the protection level informs how well or under protected the environment is (Driver *et al.* 2012). Modification to these indicators were later added in the NBA 2018, to include species levels for each indicator (Skowno *et al.* 2019). This essential addition highlights the importance of conservation not only at ecosystem level but inclusive at species level, as there are several endemic species (both flora and fauna) of different taxonomic groups that occur in South Africa's estuaries and specifically in the Knysna Estuary such as the Knysna seahorse, the critically endangered false/pulmonate limpet *S. compressa*, the endangered dusky kob *Argyrosomus japonicus* and white steenbras and the endangered Cape eelgrass

An important component of conservation is to maintain healthy environments. Though the Knysna Estuary is a protected environment under the NEM: PAA, is managed by SANParks (as the area falls in GRNP) and is considered to be largely natural with few modifications (habitat health) to moderately modified (biotic health) (Category B/C), the system does face several pressures.
Fishing and bait collection has increased over the years (Simon *et al.* 2019, Van Niekerk *et al.* 2019), habitat modification due to developments such as roads, fences, bank stabilization in low lying areas (Claassens *et al.* 2020, Van Niekerk *et al.* 2019, Raw *et al.* 2020), climate change (Adams 2020), nutrient enrichment at times in some areas by run-off from catchment and effluent from waste water treatment works (Adams *et al.* 2020a, Claassens *et al.* 2020, Van Niekerk *et al.* 2019) and occasional macroalgal blooms in some areas (Allanson *et al.* 2016, Barnes 2018a, Pollard *et al.* 2018).

3.7.2. Biodiversity Importance

The variation in genes, species and populations to ecosystems interacting with the abiotic elements in nature is what creates the unique biodiversity that we have. Couple this with the only estuarine bay ecosystem in the warm temperate biogeographic region with a permanently open mouth, then you have an estuary, Knysna, which has been rated as the most important in terms of conservation importance and ecosystem service provision in South Africa, with an estimated 42% of the country's estuarine biodiversity existing in it (Turpie *et al.* 2002, Turpie and Clark 2007, Claassens *et al.* 2020). This rating was determined by comparing biota (plants, invertebrates, fish and birds), size, biogeographic zone, rarity of estuary type and habitat diversity across all estuaries in the country (Turpie *et al.* 2002).

In order to address the conservation of estuarine biodiversity, draft biodiversity targets were initially set through the National Estuary Biodiversity Plan 2011 (Turpie *et al.* 2012). The targets essentially attempt to conserve representation of populations of species and habitat types and ensure survival through time (Driver *et al.* 2012). These targets were however limited to birds, fish, habitats and ecosystem types of estuaries. Within the plan, a target of 20% estuarine area was used. Hopefully with time, more information will be available and include other important groups such as plants and invertebrates.

Though protected areas play an important role towards the conservation of biodiversity, in the long run, the need to involve different interested and affected stakeholders from all levels is crucial if a resource such as the Knysna Estuary is to be sustainably utilised and managed well (Driver *et al.* 2005).

4. ECOSYSTEM SERVICES

Ecosystem services refer to the material and non-material benefits that people derive from nature. Various classifications of ecosystem services typically distinguish between provisioning services (e.g., water, food and raw materials), maintenance and regulating services (e.g., flood attenuation, climate regulation, water purification, nutrient dispersal, pollination and soil formation) and cultural services (e.g., recreational and spiritual experiences that people have with nature). An ecosystem services framework is useful for highlighting the connections between people and nature, and for mapping flows of services (and sometimes disservices) as well as identifying trade-offs, synergies and tensions between different services.

Estuaries are rich and productive systems that are highly valued for the critical ecosystem services they provide to society including food and recreational opportunities. In a 2013 study, a participatory modelling process was used to identify the ecosystem services that were thought to be supplied by different land types in the broader Knysna Catchment Area (Mander & Van Niekerk 2013). Based on this study, the range of ecosystem services supplied by the Knysna Estuary, and their relative service supply levels, are shown in Figure 14 where they are arranged according to the classification mentioned above, with the addition of a class for bequest or existence value (i.e., a non-use value associated with knowing that the ecosystem and its biodiversity exists and if protected can be available to future generations too).

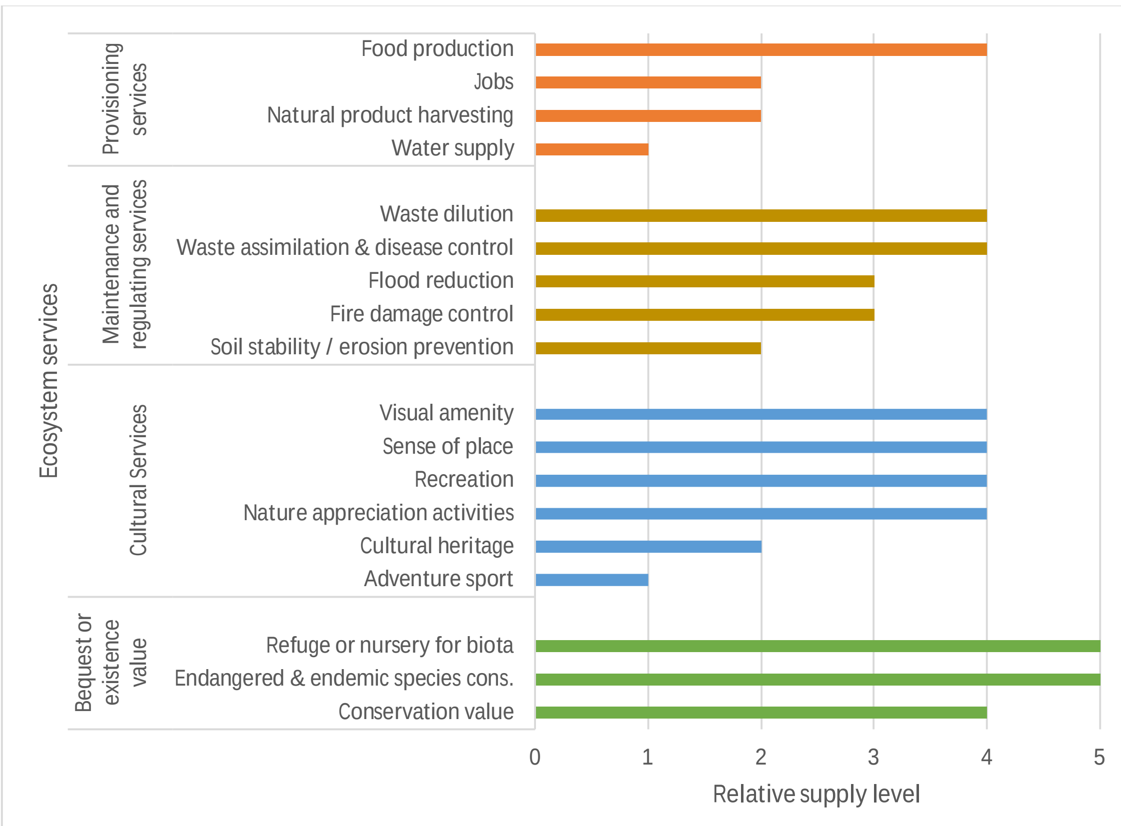

Figure 14: Ecosystem services supplied by the Knysna Estuary and their relative service supply levels (where 1 is low and 5 is high), based on Mander & Van Niekerk (2013).

There have in recent years been several studies to determine the direct (e.g. water, food and raw materials) and intangible (e.g. cultural and religious) values derived from ecosystem services. For example, the value of total global ecosystem services in 2011 was estimated to be US$125 trillion per year (Costanza *et al.* 2014). The same authors estimated that global land use changes between 1997 and 2011 have resulted in a loss of ecosystem services of between $4.3 and $20.2 trillion per year. Similarly, the value of ecosystem services supplied by Knysna Estuary has been estimated at between R1.2 and R1.3 billion per year (Royal

HaskoningDHV 2018). The latter is based on studies undertaken up to 2005 and both the methods used and values estimated at that time would probably be outdated by now.

An alternative approach to assess ecosystem services is to look at their specific sources, flows and beneficiaries, possible trade-offs and synergies, and how services can be enabled and their equitable distribution be encouraged. However, to our knowledge no such work has been done in relation to Knysna Estuary. Below is a preliminary list of ecosystem services based on expert views of the authors of this report, which could potentially serve as a basis for more detailed studies. For this list, the main river drainage systems feeding into Knysna Estuary were included but their catchments excluded.

4.1. Provisioning Services

- Freshwater from the Knysna River and polluted water from the Bongani and Salt rivers (the latter represents a disservice);
- Water from the estuary for the desalination plant (not in use at present);
- Fish for food, via livelihood/substance (see Napier *et al.* 2009) or small-scale commercial (permitted, allowed to sell) fishers. A wide variety of fish species are used;
- Wide variety of invertebrates harvested for bait; and
- Jobs: direct and indirect.

Of these provisioning services, more detailed overviews for fisheries and bait collecting are provided below. Note that recreational fishing, including for sport or competition, could also be regarded as a cultural ecosystem service (see Table 10).

4.1.1. Linefisheries

Linefishing, from the shore or from a boating platform, and using handlines or rod and reel is a popular recreational and important livelihood activity undertaken in many estuarine systems (Lamberth 2007). Fishing pressure on estuaries can be high due to the proximity of urban developments, general ease of access, all year round fishability, and as an indirect impact of the beach driving ban effected more than two decades ago shifting coastal pressure onto estuaries (Mackenzie 2005). Both recreational and subsistence fishers target a wide range of species. The latest NBA (2018) highlighted that recreational and subsistence fishing effort occurring on estuaries is increasing. Over-exploitation of living resources by linefisheries can have both direct and indirect consequences for estuarine ecosystems (Whitfield & Cowley 2010) including changes in population size, biomass, sex-ratios, size/age distributions, community composition and trophic structure (Whitfield & Cowley 2010). Furthermore, species population collapse has social and economic implications with the total value of estuarine and estuary-dependent fisheries in South Africa estimated at R1.251 billion (Lamberth & Turpie 2003).

<u>Participation and Effort</u>

Interviews conducted during 2008 and 2009 indicated that most fishers on the estuary were local (~79%) from either Knysna or surrounding communities, ~6% came from within the Garden Route and a further ~14% were national visitors. During this same period approximately 29% of anglers indicated they were fishing for subsistence purposes which corresponded to 32% of interviewees having no income or an income below R1000 per month (SANParks unpublished data). Interviews conducted in 1996 indicated a high subsistence-type component to the linefishery with almost 74% of local anglers using hand lines, and 17.4% admitted to setting plant lines; whereas tourists exclusively used rod & line (Hodgeson *et al.* 2000b). A small sector of the fishery set plant lines comprising 50 to 60 hooks on a long-line on the mud banks at low tide and leave them to soak over the high tide cycle to be collected again the following low tide. It is presumed that these fishers used to belong to the subsistence sector but have since found that plant lines are a more lucrative undertaking.

In the early 2000s it was estimated that 30 full-time and a further 200 part-time subsistence fishers operated on the estuary (Napier *et al.* 2009) although unpublished data from SANParks indicates that the proportion of subsistence fishers has increased with up to 500 full- and part-time fishers being active (Simon *et al.* 2019) depending on local unemployment rates and economic opportunities. With the high level of unemployment in the Knysna area (Anon 2018) it is not surprising that there is a significant subsistence fishery operating on the estuary. In terms of total angler participation, results of SANParks monitoring (unpublished data) indicates that participation fluctuates annually with between 2 000 and 4 200 individual anglers participating in fishing activities on the estuary.

Full-time subsistence fishers expended twice as much effort as part-time fishers (122 vs 61 days per year) (Napier *et al.* 2009) and fish for longer periods than recreational anglers (SANParks unpublished data). Fishing effort occurs heterogeneously throughout the estuary, with certain areas showing consistently higher fishing effort (Figure 15). Hodgson *et al.* (2000b) revealed that amongst local anglers, the most effort by shore-based anglers occurred in areas that were easily accessible such as Thesen's Jetty, Loerie Park and close to the Knysna Angling and Diving Association (KADA) clubhouse. Only 6.5% of local anglers interviewed were boat based. In contrast, over half of the tourist anglers interviewed were boat anglers with the shore-based contingent targeting sites at Coney Glen, the Heads and the Railway Bridge. Local anglers also mostly walked to their selected fishing sites while tourists tended to use boats or cars. Most fishing outings for all those interviewed exceeded two hours, with more than 35% fishing for longer than four hours (Hodgeson *et al.* 2000b). Data collected by SANParks shows the average fishing duration is 4 hours 30 minutes but can range from 1 hour to over 12 hours.

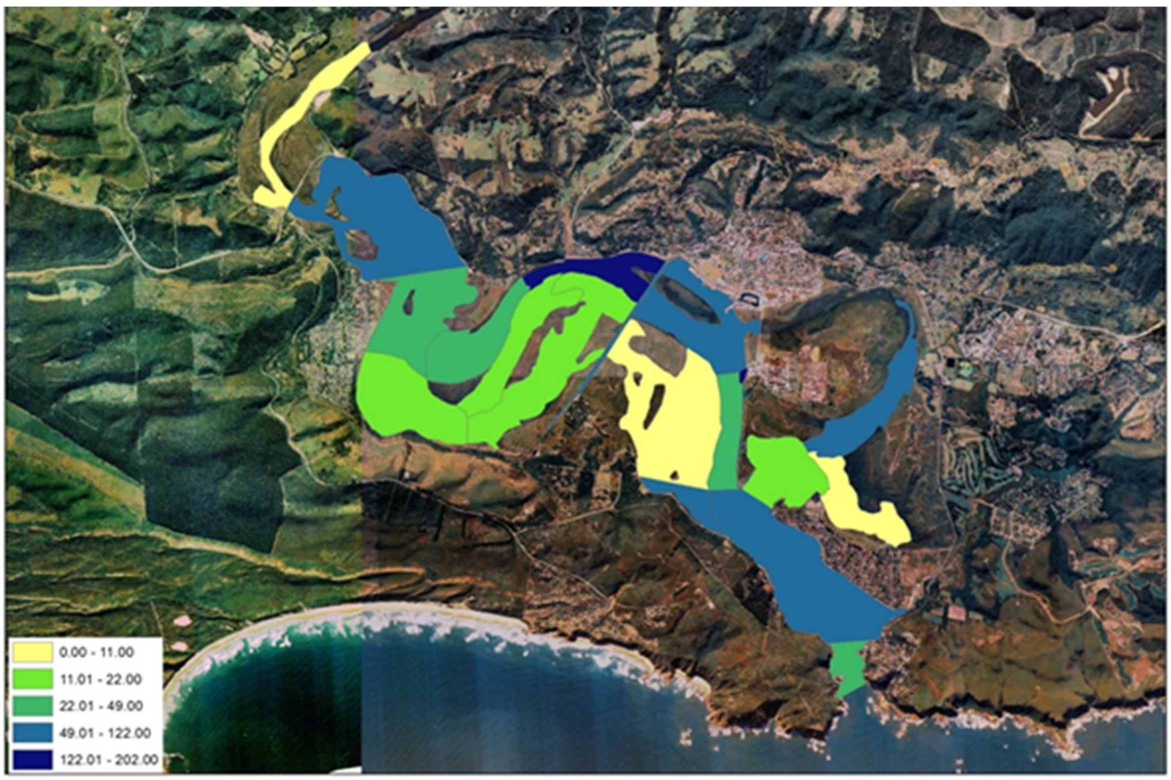

Figure 15: Total observed fishing effort on the Knysna Estuary during 2014. Note the area from Costa Sarda through to the bridge leading onto Thesen Island was not surveyed.

Between 2008 and 2014 the proportion of boat versus shore fishers was relatively constant across years with most anglers (73%, range 67%-80%) fishing from the shoreline. The remaining fishers use some form of boating platform including rowing boats, motorboats or kayaks (SANParks unpublished data). While some anglers may anchor and fish in one area, others will drift with the tide; more effort is expended in the region of the White Bridge during summer when the dusky kob are in the vicinity; this pattern changes to areas closer to the mouth (White Poles) in winter when white steenbras usually make their appearance.

Being a popular tourist destination fishing effort on the estuary increases during holiday periods (Napier *et al.* 2009). Monitoring fishing effort on a monthly basis over a six-year period confirmed that fishing effort on the estuary follows seasonal trends with an increase in fishing effort occurring over school holidays. With particular emphasis over the summer (December and January) and autumn (April) periods (SANParks unpublished data). During this period (2008 to 2014) total annual fishing effort, including recreational and subsistence fishing fluctuated between 17 700 and 25 189 angler outings.

Catch

During the first year of surveys, most anglers on Knysna (45%) indicated that they were not targeting specific species and would be happy catching anything (Smith & Kruger 2013). Spotted grunter was the most commonly targeted species (17%) followed by white steenbras (10%), Cape stumpnose (6%) and strepie *sarpa salpa* (5.5%). However, analysis of angler's catches (Table 8) shows that despite not being actively targeted, Cape stumpnose was the most frequently caught species (44%), followed by strepie (19%) and white steenbras (12%). Subsistence fishers are less likely to be targeting specific species than recreational counterparts and are generally happy to catch anything that is edible. Their catches are dominated by smaller bodied species including Cape stumpnose, strepie, sand steenbras *Lithognathus mormyrus* and juvenile blacktail *Diplodus capensis* and white steenbras. Recreational catches are dominated by spotted grunter, Cape stumpnose, white steenbras and garrick *Lichia amia*. Spotted grunter are found in the system all year round with the best catches over summer, and according to local anglers there has not been a noticeable decline in catches in the last five years.

Historically, dusky kob has been caught mostly in summer, but recently an abundance of juveniles has begun to appear during winter. Unlike other large open systems like the Breede, Gamtoos and Mbashe, the Knysna system is not favoured by the large dusky kob, and although the occasional large fish is caught, specimens of 5 to 6 kg are considered big for this estuary. White steenbras are a predominantly winter fish, and catches of large fish (> 10 kg) have declined in the last 10 years. During upwelling events, recreational anglers also target species moving into the estuary seeking out warmer water. This includes various shark species and white musselcracker.

Table 8: Target rates (%) and species catch composition (%) for the Knysna Estuary over a two-year period (adapted from Smith & Kruger 2013). *Any fish species* indicates anglers were not targeting specific species. *Other* includes a number of different species targeted at very low frequencies.

Target Species	Knysna			
	2008 – 2009		2009 – 2010	
	Targeted (%)	Catch composition (%)	Targeted (%)	Catch composition (%)
Any fish species	46		46	
Cape stumpnose	6	43	7	33
Spotted grunter	17	4	16	8
White steenbras	10	12	12	12
Leervis	5	2	6	3
Strepie	5	18	4	16
Other	11	21	9	28

Catch-per-unit-effort (number of fish caught per angler per hour) (*cpue*) has shown slight annual fluctuations with an average *cpue* of 0.32 fish angler^{-1} hour^{-1} (range 0.23 – 0.57). Two years stood out with higher catch rates and these were 2008 and 2010 (SANParks unpublished data). Retention rates for all species has been high for both recreational anglers and subsistence fishers with recreational anglers keeping around 74% of the catch and subsistence anglers 91% (Smith & Kruger 2013). Subsistence fishers using handlines removed an estimated 50 000 fish from the estuary per year with Cape stumpnose accounting for 73% of the annual handline fish catches (Napier *et al.* 2009). Although SANParks monitoring includes both subsistence and recreational sectors total annual catches have fallen to 14 687 (2014) from 51 194 (2009) fish, well below the estimation by Napier *et al.* (2009). Lamberth & Turpie (2003) estimated that 250 t could be harvested sustainably from the Knysna Estuary, although this is considered an overestimate and taking the SANParks data into account is unlikely to be realistic.

During the Napier *et al.* (2009) study, the researchers noted that a large proportion of retained catch was undersized. Although Smith & Kruger (2013) also noted that undersized fish were retained by recreational anglers, the proportions varied between species and in general was lower than that reported in the earlier study for subsistence fishers (Table 9). The high proportion of juveniles in subsistence catches is not surprising, given the function of estuaries as nursery grounds for many fish species and the motivations of this sector in fishing for food. Although fewer white steenbras were retained compared to other species over 65% of those retained were undersized (Table 9). This is concerning as the population of this species has collapsed and the species is listed as endangered on the IUCN red data list. Proportionally more undersized Cape stumpnose were retained than other species whilst relatively few undersized spotted grunter were noted during the project period (Table 9).

Table 9: Recreational fishing retention rates (%) for two years of sampling on the Knysna Estuary. The proportion (%) of undersized fish is given in brackets. Taken from Smith & Kruger (2013)

Species	Knysna	
	2008 - 2009	2009 - 2010
Overall	74 (31)	76 (18)
Cape stumpnose	75 (44)	69 (25)
Spotted grunter	81 (4)	88 (6)
White steenbras	67 (89)	63 (65)

4.1.2. Bait Harvesting

The exploitation of invertebrate species used as bait by recreational and subsistence fishers take place in virtually all estuaries along the South African coast (Wooldridge 2007) and is particularly prevalent in those estuaries within or close to densely populated areas, or systems that are popular for holiday makers/visitors (Jooste 2003). Although bait collection and fishing go hand in hand and the possible impact of bait fisheries has been raised by a number of authors over an extended period of time (e.g., Hill 1967, Baird *et al.* 1996) there are only a limited number of studies in South Africa that have addressed aspects of bait fisheries. These include 1) assessing the standing stock of bait organisms (Hanekom *et al.* 1988, Wynberg & Branch 1994, Hodgson *et al.* 2000a), 2) quantifying the amount of bait harvested from estuarine systems and documenting harvesting practises (e.g. Hanekom & Baird 1992, Wynberg & Branch 1991, Hodgson *et al.* 2000b, Potts *et al.* 2005, Simon *et al.* 2019) or 3) assessing harvest impacts on target organisms (Wynberg & Branch 1994, Jooste 2003), habitats and other biota (Wynberg & Branch 1994, Wynberg & Branch 1997).

<u>Amount harvested</u>

The amount of bait resources used by recreational and subsistence users in the Knysna Estuary was first quantified by Cretchley (1996). The bait collectors studied were divided into two user groups, namely recreational fishers removing ± 59 prawns per person per day, and subsistence fishers using ± 102 (double the legal quota) prawns per person per day. Subsistence fishers comprised 77% of collectors, and accounted for 85% of prawns removed (Hodgson *et al.* 2000b). Overall Hodgson *et al.* (2000b) estimated that 2.85 million mudprawn were harvested annually within the estuary which represents about 0.9% of the entire standing stock. Napier *et al.* (2009) estimated that subsistence fishers removed less than 600 000 mudprawns per year or less than 0.3% of standing stock. Although not quantified Simon *et al.* (2019) showed that subsistence fishers collected more mudprawns more frequently than recreational fishers. Over a 6-year monitoring period SANParks (Smith 2016) estimated that between 578 408 and 1 041 373 mudprawn were harvested annually on the estuary by recreational and subsistence fishers. During this monitoring 24 bait species were recorded as being used by fishers with mudprawn being the most popular bait species in terms of frequency of use and numbers harvested (Smith 2016).

Spatial distribution in harvesting

Both Hodgson *et al.* (2000b) and Simon *et al.* (2019) monitored six sites within the estuary for bait harvesting effort (Figure 16). Hodgson *et al.* (2000b) showed that there was no significant difference in baiting effort between the majority of sites with only Thesen Island and Ashmead being significantly different (increased activity at Thesen Island and lower activity at Ashmead). Twenty-five years later Simon *et al.* (2019) found that subsistence harvesters preferred the mudbanks around Thesen Island whilst recreational fishers utilised the intertidal area around Leisure Island. In contrast to this, Napier *et al.* (2009) indicate that the Railway bridge and Ashmead were preferred harvesting sites for mudprawn.

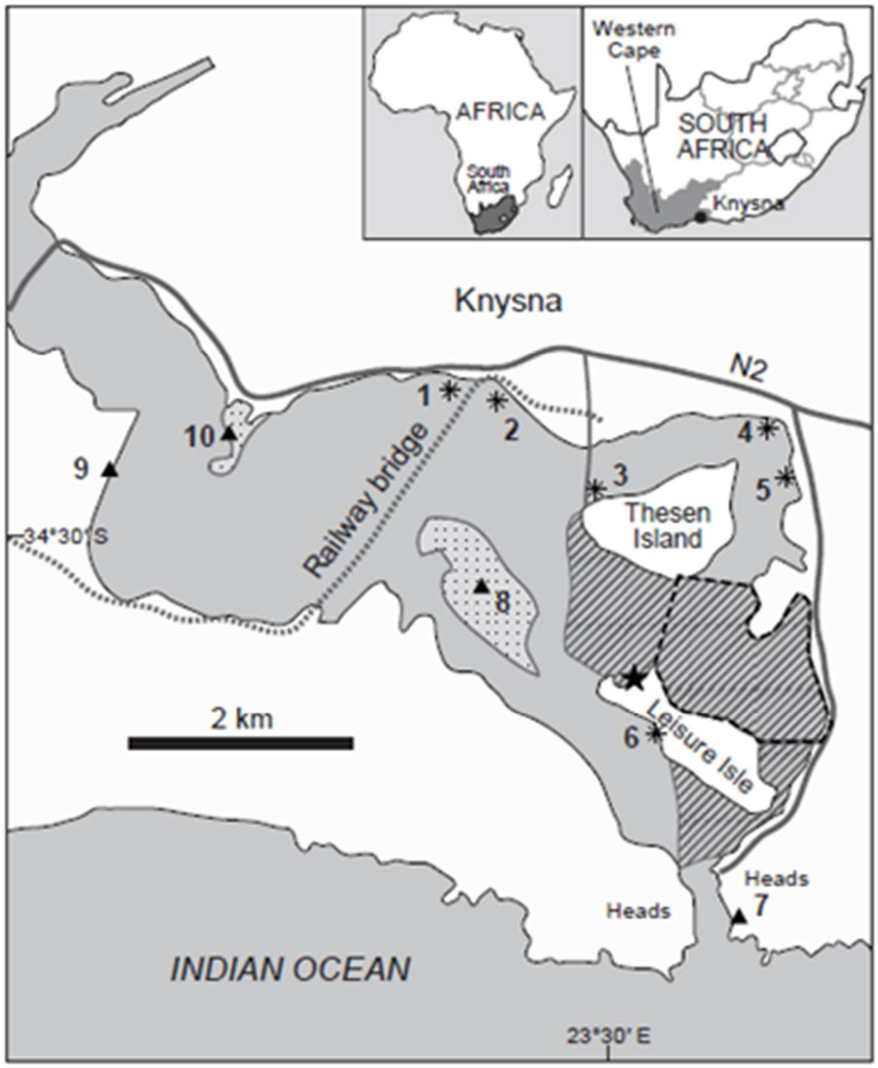

Figure 16: Map of the Knysna Estuary showing the six bait-collecting sites in Simon *et al.* (2019) (sites marked with *): 1 Railway Bridge; 2 KADA; 3 Thesen Island; 4 Costa Sarda; 5 Loerie Park; 6 Bollard Bay (replaces Kingfisher Creek (star) in Hodgson *et al.* (2000b)). Sites marked with triangles: 7 Coney Glen; 8 Middle Banks; 9 Belvidere; 10 The Point, are additional bait collecting sites mentioned in Hodgson *et al.* (2000b). Hashed area denotes the Invertebrate reserve (IR No-Baiting). The area with dark outline denotes IR boundary during the study of Hodgson *et al.* (2000b). Figure taken from Simon *et al.* (2019).

Both Hodgson *et al.* (2000b) and Simon *et al.* (2019) restricted their monitoring to six sites and hence patterns in baiting effort are not representative of the entire system. Annual monitoring of the local fisheries undertaken by SANParks included counts of bait harvesters observed throughout the Knysna Estuary from the White bridge down to the Heads. Results indicate annual fluctuations in harvesting pressure on intertidal areas but that observations of bait harvesters were consistently higher in some areas (Figure 17). These include the intertidal areas falling within the bait reserve, Loerie park, Costa Sarda and the intertidal areas opposite Thesen Island and up towards the railway bridge. Importantly this work indicates that bait harvesting pressure and hence direct and indirect pressures on harvest species and habitats occurs throughout the estuary.

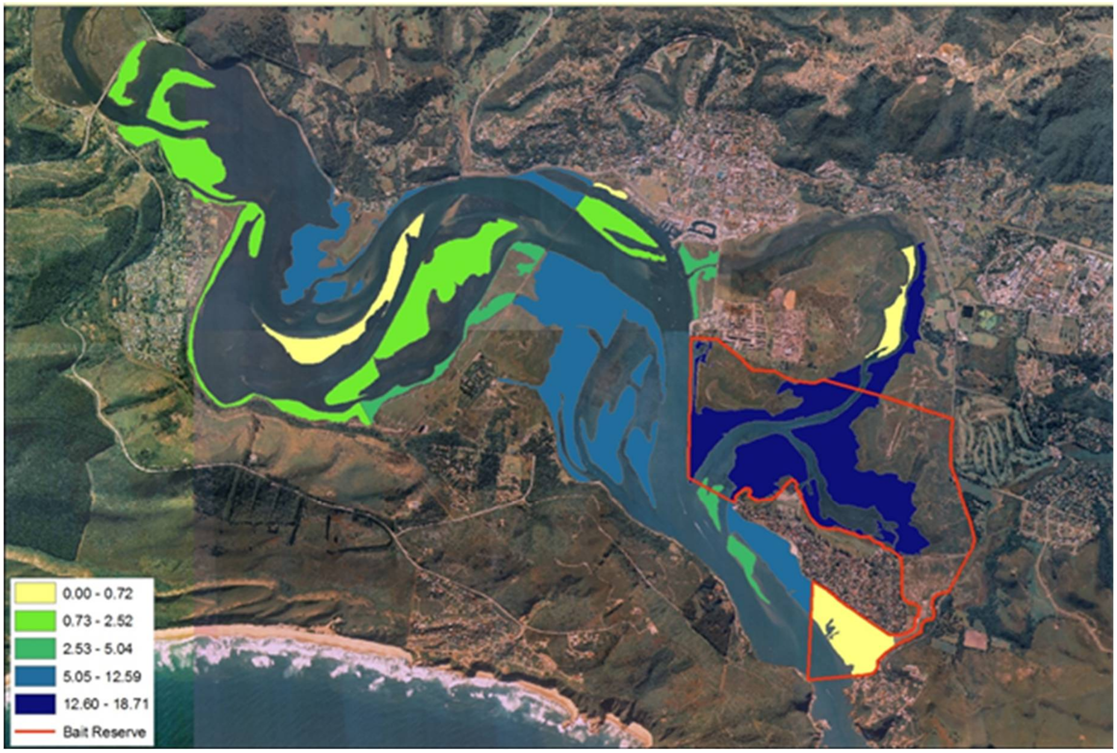

Figure 17: Spatial distribution of bait harvesting effort on the Knysna Estuary during 2014. Data presented as percentage of total observed bait harvesting effort per section.

4.2. Maintenance and Regulating Services

- Waste dilution due to tidal water movement and open bay. Although not acceptable, we have come to rely on this service;
- Wetlands, especially along the north-eastern shore, regulate rain and storm-water flows and help to purify water; and
- Seagrass beds serve as an important carbon sink.

4.3. Cultural Services

Here we distinguish between eight sub-classes of cultural ecosystem services (based on Roux *et al.* 2020) and in Table 10 provide brief explanations of the relevance of each of these sub-classes in the context of the Knysna Estuary, as well as notes on threats to and enablers of some of these services.

Table 10: Sub-classes of cultural ecosystem services and their relevance to the Knysna Estuary based on experiences of SANParks staff members.

Sub-class of cultural ecosystem service	Relevance to Knysna Estuary
Aesthetic value – appreciation of natural scenery/ beauty of landscape or waterscape	• A view of the estuary has a direct link to property value (Turpie *et al.* 2004) • Important contributor to overall attractiveness of Knysna as a holiday destination as well as an event and film location

Sub-class of cultural ecosystem service	Relevance to Knysna Estuary
	• For everyone to enjoy Threats: pollution, eutrophication, overuse, red tide (caused by an introduced species), inappropriate/insensitive development (e.g. modification of the skyline), incompatible land use
Recreation – enjoyment of nature through activities such as walking, dog walking, horse riding, swimming, angling and mountain biking	• Water-based activities: sailing, water skiing, boating, kayaking, windsurfing, rowing, water polo, canoe-polo, swimming, triathlon, houseboats, cruises, whale-watching boats, jet skiing, kite-surfing, snorkelling, scuba diving, canoeing, recreational fishing (including sport or competition anglers) • The estuary provides a safe environment for training in many of the recreational activities • Shoreline activities: hiking, birding, dog walking, running, cycling Enablers: event organisers, concessionaires, SANParks, self-recreation, commercial operators, clubs, tour operators/tourism agencies Threats: over-crowding (boats vs fishers); overexploitation, habitat degradation (physical and water quality), solid waste pollution Challenges: to regulate access in a fair manner; pandemic, rapid population/urban growth, unemployment (more people use estuary as food source)
Sense of place – sensory experiences fostering a sense of authentic or emotional attachment and belonging	Threats: rapid development, breaking skyline, drones, insensitive architecture, alien plants
Spiritual experiences	Baptisms and associated gatherings/services along the shore
Scientific knowledge – gathering of scientific knowledge from the study of ecosystems	Universities, Research NGOs, citizen scientists, agency scientists, long-term monitoring by the South African Environment Observation Network (SAEON) Enablers: Research infrastructure such as laboratories, weather station and other monitoring infrastructure/equipment.
Social relations – socialising with friends and meeting people	Fisher women (subsistence/supplementary fishers), families and groups on holiday, cruises (e.g. year-end functions) Group photo opportunity, getting engaged, picnics
Cultural heritage – appreciation of local history and culture	Fishing museum at old jail, Knysna museum, rail crossing, historic photos and artefacts are somewhat scattered in various buildings, shipwrecks, monument at Old Drift, old rubbish dump next to old airfield, jetty and buildings on Thesen Island
Environmental education – instruction in ecological processes; raising of awareness about biodiversity and	SANParks' Social and Environmental Transformation department has calendar campaigns and takes school groups Honorary Rangers take people on educational tours

Sub-class of cultural ecosystem service	Relevance to Knysna Estuary
ecosystem services in visitor centres or educational activities	SANParks' Knysna seahorse educational display on Thesen Island

5. IMPACTS OR POTENTIAL IMPACTS TO THE ESTUARY

5.1. Environmental Hazards

5.1.1. Mariculture

Oyster culture in the Knysna Estuary was first attempted in 1948 with the Cape rock oyster *Striostrea margaritacea*. This venture slowly gained momentum through the 1950s and 1960s and by the mid-1960s enjoyed government support which funded a program to develop and promote the industry. By 1973 the Cape rock oyster had been replaced with the Pacific oyster *Crassostrea gigas*. Since this introduction of the Pacific oyster in the estuary in 1973 there have been no incidences of the exotic species having established populations outside of the previous culture areas. According to Van der Walt *et al.* (1990) three concession holders used to be permitted to operate in the estuary covering a total area of 23 hectares. However, oyster farming ceased in the estuary in 2010 for a number of reasons, including profitability.

5.1.2. Alien Species

Biological invasions constitute the second largest threat to biodiversity globally, after direct habitat destruction (Walker & Steffen 1999). Aliens threaten indigenous plant and animal species, with invaded ecosystems often having altered species composition and community structure (Vitousek *et al.* 1997), as well as altered disturbance regimes. However, there are limited studies on the impacts of alien species in South African estuaries and most of the recorded invertebrate species are characterised as data-deficient (Van Wilgen & Wilson 2018). Within the Knysna Estuary 22 alien species have been documented (Table 11) covering a range of taxa. Eight species belong to the Class Ascidiacea, five to the Class Malacostraca (Subphylum Crustacea) and four to the Mollusca (two Bivalve and two Gastrapoda).

The red sea plume is an extremely successful invader and is regarded as one of the most widespread invasive seaweed species globally (Williams & Smith 2007). The species was first noted in the Leisure Island Small Boat Harbour in 2009 (Bolton *et al.* 2011), but since then it has spread throughout most of the estuary (Wasserman *et al.* 2020). No information of the impact of the red sea plume on the ecology of the estuary is available. Likewise, the ecological and economic impacts of the presence of ascidians in the estuary are presently unknown. However, as they are relatively small encrusting species which appear to occur at relatively low densities it is estimated that they are unlikely to have significant ecological effects (Robinson *et al.* 2005). Within South Africa, the lagoon snail *Littorina saxatilis* is restricted to sheltered salt marshes and lagoons, where it is found on the stems of the cord grass. In the Knysna Estuary the present population status is unknown and no ecological effects of the invasion are known (Robinson *et al.* 2005). It has been suggested that they may form an abundant food source for wading birds and crabs (Robinson *et al.* 2005). Although for most of these species very little is known some research has been conducted on the Mediterranean mussel *Mytilus galloprovincialis* and the moonshine worm, which is expanded on below.

The Mediterranean mussel is a globally successful marine alien invasive species that has been shown to occupy all artificial hard substrata in the embayment of the estuary (Pollard & Hodgson 2016). The density of the Mediterranean mussel within the system is spatially variable, ranging from 200 to 1 200 per 0.1 m^2 with the highest densities found at the railway bridge and Thesen Island Warf (Pollard & Hodgson 2016), both areas with high tidal currents. With the exception of mussels at Thesen Island Wharf, the mussels in the sheltered embayment had a greater average size and size range than those at the wave-exposed Heads. Furthermore, the condition index and gonadosomatic index (which are important indicators of physiological status) were greatest in mussels where there was little wave action (Pollard & Hodgson 2016) suggesting that mussels within the sheltered regions of the bay may invest more energy into growth and reproduction which would contribute to invasion success. Following on from Pollard & Hodson's (2016) work Radloff *et al.* (2021) compared temporal and spatial settlement patterns of the Mediterranean mussel within the Knysna Estuary. Settlement differed significantly between study sites and over time with peaks occurring in summer and early autumn and fewer settlers as one moved away from the mouth of the embayment. Differences between years is likely to be due to hydrographic and environmental factors which could impact larval supply (Radloff *et al.* 2021).

Mussel beds have been shown to modify the local environment and are regarded as ecosystem engineers (Borthagaray & Carranza 2007). In the embayment regions of the estuary, the beds of the Mediterranean mussel have created a new habitat with their own associated macroinvertebrate communities (Hodgson *et al.* 2021). A total of 65 taxa (mainly Crustacea and Mollusca) have been found to be associated with the mussel beds. Forty- three percent of taxa (23 species) were new records for the estuary. Four alien species were recorded, none of which were recorded previously by Day *et al.* (1952) or Allanson *et al.* (2014). Species richness and diversity were significantly different among sites with those closest to the mouth of the estuary (the Heads and Featherbed) having the highest species richness and diversity in contrast to sites further into the embayment. A negative relationship between species diversity and macrofaunal abundance was observed with few species being abundant at each site (Hodgson *et al.* 2021).

The moonshine worm is a popular bait species first documented as being used by recreational and subsistence fishers in early 2000's (Napier *et al.* 2009) and has increased in popularity (Simon *et al.* 2019). The taxon was not detected during surveys of the macrobenthos conducted in Knysna in the 1940s (Day *et al.* 1952) and 1990s (Allanson *et al.* 2014) suggesting that it appeared for the first time in the estuary in the last three decades. Moonshine worm has now been shown to occur throughout most of the estuary although distribution is patchy (van Rensburg *et al.* 2020). High densities occur south of White bridge, the mud banks of Leisure Isle, east and north of Thesen Island, around the Train Bridge and at Brenton Bay. Areas more susceptible to freshwater have lower abundances to none whilst there seems to be a positive relationship between water flow and occurrence with areas of high density having high tidal flow (van Rensburg *et al.* 2020). As ecosystem engineers, they can potentially influence the biodiversity of intertidal and subtidal habitats, which will indirectly influence abundance and distribution of other important fauna and macrophytes such as bloodworm, sand and mud prawns and Cape eelgrass (van Rensburg *et al.* 2020).

Table 11: Alien species recorded within the Knysna Estuary (adapted from Claassens *et al.* 2020)

Taxon	Species	Common name	Origin
Annelida Class Polychaeta	*Diopatra acciculata*	Moonshine worm	Australia
	Polydora cf nuchalis	Mudworms	
	Polydura hoplura		Mediterranean
Bryozoa	*Watersipora subtorquata*	Red-rust bryozoan	Caribbean
Crustacea Class Malacostraca	*Jassa slatteryi*	Hitchhiker amphipod	Pacific North America
	Monocorophium acherusicum	Stout-antenna amphipod	North Atlantic
	Orchestia gammarellus	Beach hopper	Europe
	Platorchestia platensis	Beach flea	Unknown
	Sphaeroma terebrans	Isopod	Unknown - cosmopolitan
Seaweed	*Asparagopsis taxiformis*		
Mollusca Class Gastropoda	*Littorina saxatilis*	Lagoon snail	North Atlantic and Mediterranean shores
	Myosotella myosotis	Mouse ear snail	Europe
Class Bivalve	*Mytilus galloprovincialis*	Mediterranean mussel	Europe
	Crassostrea gigas	Japanese oyster	Japan

Taxon	Species	Common name	Origin
	Teredo navalis	Shipworm	Europe
Chordata Ascidiacea	*Ugula neritina*		
	Ascidiella aspersa	Dirty sea squirt	Europe
	Ascidia sydneiensis	?	?
	Ciona intestinalis	Vase tunicate	Europe
	Clavelina lepadiformis	Light-bulb sea squirt	Europe
	Diplosoma listerianum	Jelly crust tunicate	Europe
	Microcosmos squamiger	Blunt-spined microcosmus	Australia
	Styela plicata	Pleated sea squirt	Unknown (Asia)

5.1.3. Climate change

Estuaries are vulnerable to climate change impacts because drivers of change in the system can have terrestrial, freshwater or marine origin (SANParks 2021). James *et al.* (2013) provides an overview of expected impacts of climate change on South Africa's estuaries and associated fish fauna (summarised in Figure 18). These range from wind regime shifts (affecting rainfall and ocean circulation patterns) to increasing air temperature; modification of terrestrial climatic and hydrological processes (precipitation and freshwater inflow; salinity regime and extent of saline intrusion; land-derived biochemical inputs; sediment deposition / erosion cycles and floods; contaminant behaviour and accumulation); ocean acidification and estuarine pH shifts; sea level rise; increasing wave energy; increasing frequency and intensity of coastal storms; upwelling and biogeochemical inputs from coastal waters; and temperature shifts within estuaries (James *et al.* 2013, Van Niekerk *et al.* 2019). The degree of impacts is likely to vary between estuaries and will be dependent, in part, on individual system characteristics (e.g., estuary type, catchment size) (SANParks 2021).

The Knysna Estuary, classified as an estuarine bay has a large permanently open mouth, relatively deep channels and the lower portions are therefore heavily influenced by marine processes (Largier *et al.* 2000, Schumann 2000). As such, the system is more likely to respond to biogeochemical inputs and marine temperature changes caused by altered ocean circulation patterns including upwelling rather than increases in land temperature (SANParks 2021). Changes in upwelling frequency and intensity are likely to increase the importance of Knysna Estuary as a temporary thermal refuge for a number of shark and fish species.

As much as 80% of the Knysna Estuary shoreline is currently modified under hardened structures (Claassens *et al.* 2020) and some 490 ha of the estuarine functional zone is under some form of development. Predicted sea level rise will have consequences for habitats such as salt marshes, which occur within defined tidal regimes (SANParks 2021). The ability of these habitats to respond to sea level rise, either through elevation or migration is dependent on situational contexts. In the Knysna Estuary, development and the presence of artificial structures (e.g., sea walls, gabions) limits migration opportunities. Research by Raw *et al.* (2020) showed that salt marsh covers an area of 778.6 ha (measured from the N2 bridge to the mouth) with a predicted loss of 60.4 ha if developments are not managed with the goal of making suitable areas available for landward migration. The authors also found that surface elevation change in lower intertidal salt marsh was variable along the length of the estuary channel. Importantly only two sites within the study showed positive surface elevation change (accretion) at a rate high enough to keep pace with the calculated relative sea level rise (Raw *et al.* 2020). They concluded that if the current regimes of accretion and sedimentation continue some areas of the lower and middle reaches of the estuary could be lost to flooding.

Coastal erosion of sea walls within the estuary, including Leisure Island, reveal the impacts of storm surges on the coastline (O'Donoghue *et al.* 2021). Whilst development on the surrounding hills and an increase in hard surfaces (e.g., roads) increases surface runoff exacerbating flooding events and increasing sedimentation (O'Donoghue *et al* 2021). To enable climate ready initiatives relies on reliable information, integrated government structures and strong implementation steps.

In this regard, not only must authorities and citizens be aware of the potential changes and impacts but there must be the required capacity and resources to adapt and respond to those changes. However, limited budgets and conflicting priorities currently forces decisions based on immediate needs over long-term adaptation planning and implementation (O'Donoghue *et al* 2021). In Knysna it has been shown that this results in initiatives for climate change being undertaken by the private sector which may have unintended consequences. Adapting to new conditions brought by climate change will be challenging, will demand strategic and creative thinking from planners and others with clear and ongoing communication (O'Donoghue *et al* 2021).

Driver	Physical response	Fish response	Zone
Wind regime shift	Increased frequency and intensity of upwelling	Fish kills Species range contractions	Cool- and warm-temperate
Increasing air temperatures	Increasing estuarine water temperatures	Physiological effects Species range changes Alterations in community composition	Cool- and warm-temperate, subtropical
Increasing SST	Increasing coastal and estuarine temperatures	Physiological effects Species range changes Alterations in community composition	Subtropical
Increasing rainfall and foods	Increasing runoff Changes in mouth state Increasing sediment delivery Increasing turbidity	Alterations in community composition	Subtropical
Decreasing rainfall	Decreasing runoff Changes in mouth state Increasing salinity Decreasing nutrients Increasing sediment deposition and decreasing estuarine surface area	Decreasing species diversity Decreasing fish stocks	Cool-temperate
Acidification	Decrease in coastal and estuarine pH Changes in solubility of nutrients and metals Decrease in prey abundance (calcifying organisms)	Physiological effects Alterations in community composition	Cool- and warm-temperate, subtropical
Sea level rise	Habitat loss Mouth closure	Decreasing species diversity Decreasing fish stocks	Cool- and warm-temperate, subtropical
Increasing wave energy	Habitat loss Mouth closure	Decreasing species diversity Decreasing fish stocks	Cool- and warm-temperate, subtropical
Increasing frequency and intensity of coastal storms	Habitat loss Mouth closure	Decreasing species diversity Decreasing fish stocks	Cool- and warm-temperate, subtropical

Figure 18: Major climate change drivers and likely impact on estuaries and estuary-associated fish assemblages in the 3 biogeographic Provinces (taken from James *et al.* 2013).

5.2. Land Use and Infrastructure Development

The town of Knysna, located within a national coastal corridor, as well as a national development corridor and eco-resource production region, is the primary regional service centre and a prominent national tourist destination (Knysna Municipality 2020).

Over the years, Knysna has seen extensive development and transformation of the estuary's shoreline and surrounds. Both high and low density, rich and poor settlements have become established on the hilltops surrounding the Estuary to the north and east, along the N2 and to the south along the coastline (Knysna Municipality 2020). Infrastructure includes water, wastewater, electrical bulk facilities and reticulation networks, road and non-motorised transport movement networks, broadband networks and social services infrastructure.

Ecological systems are also recognised as an integral, inseparable part of the infrastructure system that services Knysna (Knysna Municipality 2020). The rivers supply water and transport away the treated wastewater. The health of the rivers is key to the security of supply of these services (Knysna Municipality

2020). This is also key to the functionality of the wetlands and estuary that also provide ecosystem services and significantly escalate land values and thereby revenue generated by the Municipality (Knysna Municipality 2020).
The maintenance of bulk infrastructure is critical to ensuring that the environmental systems are not compromised and in turn, the economy is not threatened. Numerous challenges are experienced in this regard with aging infrastructure, a strained wastewater treatment plant which frequently results in estuarine pollution, significant backlogs in the rehabilitation and upgrade of the roads, and storm water systems, which are all directly leading to pollution of the Knysna Estuary and the consequent negative ecosystem impacts. These impacts are not only environmental but also impact the economy of Knysna. The Knysna Municipality (2020) also recognises the importance of social infrastructure and the current shortages in education facilities and residential accommodation. This in turn continues to place significant developmental pressure on the town and consequentially, the estuary.

5.3. Water Quantity and Quality

The potential for pollution of the Knysna Estuary is high, with in excess of 111 drainage pipes, drainage ditches and culverts discharging storm-water from residential and industrial areas directly into the estuary.

5.3.1. Metals

Watling & Watling (1977) reported the concentration of metals in water samples and surface sediments for the most part to be low, though some were elevated above true background values as determined for other south-eastern Cape estuaries (Watling & Watling 1980, 1982). Transitional anomalies were high such as mercury levels near The Point, and certain of the town drains are responsible for the input of zinc, copper, nickel, cobalt and mercury. It was concluded, however, that there was no real indication of metal build up, or of levels which could be considered as a pollution hazard, (Watling & Watling 1980, 1982), and the ecological impact of these inputs was low (Watling & Watling 1977, Grindley 1985). More recently, Calvo-Ugarteburu (1998) reported that metal levels in water samples were not detectable and that the concentrations of metals in the surface sediments were similar to those reported by Watling & Watling (1977). Monteiro *et al.* (2000) cited in Allanson *et al.* (2000a) however have found that Copper and Zinc in storm-water discharges from the industrial site in Knysna are above the detection limits of 5 $\mu g\ l^{-1}$ and 25 $\mu g\ l^{-1}$ respectively set by the South African Marine Quality Guidelines (DWA 1995). Calvo-Ugarteburu (1998) measured the levels of metals in the soft tissue of the Pacific oyster in 1998 finding that, with the exception of lead and cadmium, levels were similar to those found by Watling & Watling (1976). None of these measured levels are above the maximum tolerable standards for heavy metal in the water column in South Africa (DWA 1995).

5.3.2. Carcinogens

The development of the Knysna Quays Marina in 1996 exposed sands contaminated with creosote. Investigating the possible presence of polynuclear aromatic hydrocarbons, Allanson *et al.* (2000a) found that napthalene was the dominant moiety in the creosote-contaminated groundwater seepage (3200 $\mu g\ l^{-1}$) followed by fluorane (74 $\mu g\ l^{-1}$) and phenanthrene (25 $\mu g\ l^{-1}$). The remainder of the array of chemical components commonly found in creosote approached or were below detectable limits (0.1 $\mu g\ l^{-1}$). An initial creosote residue (as phenol) of 350 $\mu g\ l^{-1}$ was found to decay to close to 40 $\mu g\ l^{-1}$ within 24 days once the seepage was contained.

5.3.3. Persistent bioaccumulative toxic substances

Calvo-Ugarteburu (1998) reported DDT and HCB as not being detectable in sediments below oyster culture racks in Knysna Estuary, while Dieldrin returned levels ranging from 0.01 ng g^{-1} to 7 ng g^{-1} dry mass. Fresh oyster tissue collected at the same time gave traces of DDD (3.5-10.6 ng g^{-1}); DDT 0.08 ng g^{-1} and HCB 0.07-0.60 ng g^{-1}. Dieldrin was not detectable. None of these results is cause for concern at present (Allanson *et al.* 2000a).

5.3.4. Nutrients

In the Ashmead channel, in the region of the overflow from the Knysna sewage treatment works, elevated nutrient concentrations, increased pH, supersaturation of oxygen, and high coliform bacilli (1800 100 ml^{-1}) concentrations have previously been recorded (Grindley & Eagle 1978). It was noted in this study, however, that with the exception of potential pathogenic bacteria, the effects of effluent discharge on water chemistry, substratum, and biota, at the time of sampling, did not appear to be serious (Grindley & Eagle 1978). Later studies indicated elevated nitrogen and phosphorous levels in the region of the sewage works outfall (Grindley & Snow 1983), though due to the short residence time of water in the lower estuary eutrophication was considered unlikely.

In 2014-2015 there was a bloom of opportunistic macroalgae, with sea lettuce as the dominant species, covering portions of the estuary, and particularly in the Ashmead channel (Allanson *et al.* 2016). Sediments in the cannel were found to be anoxic, and exceptionally high concentrations of NH_4+ and Soluble reactive phosphorus (SRP) were found in the waters in the channel and particularly the Bongani Inlet near the waste water treatment works inlet (Human *et al.* 2016). The concentration of NH_4+ within the water column had increased by several orders of magnitude since Switzer's (2003) study. Where Switzer (2003) recorded NH_4+ concentrations within Ashmead Channel of 2 to 4 μM, Human *et al.* (2016) recorded concentrations of between 20 and 160 μM. This change was primarily due to remineralisation of organic matter in anoxic sediments resulting from a combination of the release of a large quantity of sludge into the Ashmead Channel in 2007 following failure of the waste water treatment works (Human *et al.* 2016) along with urban run-off (Adams *et al.* 2020a). The algal bloom that followed the release of sediments covered a large proportion of the Cape eelgrass beds in the channels, resulting in a significant dieback of Cape eelgrass and change in macrofauna intertidal diversity within the Ashmead channel. (Human *et al.* 2016, 2020, Adams 2020). It is thought that to some extent, the bloom could become self-supporting by recycling nutrients upon decomposition and allowing uptake later (Human *et al.* 2016).

Later studies found nutrient fluxes in the Ashmead channel to be significantly higher than the other regions in the estuary because of the presence of anoxic sediments, reduced flushing, and a legacy of pollutant and organic matter retention (Human *et al.* 2020) The flux of nutrients from sediments in the Ashmead channel was considered to be similar to that exhibited in a system that is eutrophic (Human *et al.* 2020). Chang *et al.* (2021) investigated the degradation of nitrate in Knysna Estuary sediments, finding that denitrification (DNF), anaerobic ammonium oxidation (ANA), dissimilatory of reduction of nitrate to ammonium (DNRA) all play a role in NO_3^- reduction with variation across the estuary, with the DNF having a bigger contribution. The DNRA plays a role in retention of nitrogen. Crucial controlling environmental factors for NO_3^- reduction were sediment water contents, organic matter degradation states and sulphide concentrations.

Chang *et al.* (2021) estimated that the N loss in Knysna Estuary was approximately 160 t N km^{-2} $year^{-1}$, though the retention of bioavailable NH_4+ via the DNRA process reached about 42 t N km^{-2} $year^{-1}$, suggesting that a large percentage of inorganic N from external sources might be retained in Knysna Estuary. Thus, the budgets of N suggest that sources and sinks may be out of balance, representing a potential factor responsible for the eutrophication and algal blooms in Knysna Estuary. Human *et al.* (2020) theorised that the condition can only be improved by removing wastewater input and dredging of anoxic sediments, though cautioned that the ecological impacts of dredging requires careful consideration. Adams *et al.* (2020b) highlight urgent interventions needed to reduce nutrient enrichment of estuarine systems, including compliance monitoring, engineering solutions to reduce stormwater and wastewater input, prudent application of agricultural fertilisers, and improved coastal and estuarine legislation and policy particularly relating to permitting of effluent discharges and effluent standards, which are no longer effective in preventing eutrophication.

One of the significant sources of effluent and nutrients into Knysna Estuary, and particularly the Ashmead channel region, is discharges from the Knysna waste water treatment works (Lemley *et al.* 2014). In an assessment undertaken by Claassens *et al.* 2020 the final effluent from the Knysna waste water treatment works was found to be non-compliant in terms of its water use license since 2013, particularly concerning nutrient concentrations. The waste water treatment works complied with its water use license in terms of ammonium concentrations only 18% of the time between 2013 and 2017 (Harvey 2019). It is estimated by Claassens *et al.* (2020) that the waste water treatment works contributes an average of 4 112 kg $month^{-1}$ NH_{4^+} (in terms of the Knysna waste water treatment works license limit of 1 mg l^{-1} NH_{4^+}.This should be 162 kg month^{-1}); 268.2 kg month^{-1} total oxidised nitrogen (this is within the license limit); and 232.5 kg month^{-1} SRP (in terms of the Knysna waste water treatment works limits limit of 1.5 mg l^{-1} SRP this should be 178.8 kg month^{-1}). Although the volume of effluent discharged into the channel from the dissolved inorganic phosphorus has not increased notably since 2004, there has been a large shift in the stoichiometric proportions of N: P, where dissolved inorganic nitrogen (DIN) loads have tripled, and dissolved inorganic phosphorus (DIP) loads have halved (Claassens *et al.* 2020) (Table 12).

Table 12. Median values for daily flow and daily inputs of DIN and DIP (of all monthly values in time series) from the Knysna WWTW between 2004 and 2017 (after Claassens *et al.* 2020).

Parameter	January 2013–July 2017 Monthly audits (Knysna Municipality)	August 2004–February 2013 (Lemley *et al.* 2014)
Operational daily flow (Ml d^{-1})	5.8	6.35
DIN (kg d^{-1})	41.77	127.34
DIP (kg d^{-1})	13.92	6.22

5.3.5. Microbes

Claassens *et al* (2020) summarised *E. coli* monitoring data determined from water samples collected from 2009-2019 by the regional municipality in several stormwater inlets and rivers draining into Knysna Estuary, the waste water treatment works outlet, and some positions within the estuary (Table 13).

Table 13. Summary of *E. coli* monitoring data collected from 2009 to 2019 (Garden Route District Municipality). Concentrations given as colony forming units per 100 ml (cfu 100 ml^{-1}), and compliance with the standard for recreational water use (500 cfu 100 ml^{-1}) (after Claassens *et al.* 2020).

Site	N	Mean (±SD)	Maximum	Percentage compliance (%)
Bongani River	108	3 655.4 (6 364.3)	>30 000	19.4
WWTW	17	6 366.5 (10 301.9)	>30 000	35.3
Queen Street culvert	122	2 740.9 (6 002.9)	>30 000	36.9
Station culvert	128	1 878.5 (4 108.7)	>30 000	44.5
Long Street culvert	124	2 096.7 (5 280.7)	>30 000	49.2
KADA culvert	130	777.1 (1 077.5)	4 200	66.9
Bigai Howard Street	103	474.4 (754.3)	3 700	73.8
Salt River	89	456.2 (993.3)	7 200	82.0
Ashmead Channel	104	2 458.1 (5268.2)	>30 000	47.1
Belvidere	102	267.4 (614.3)	3 000	72.5
Thesen Island Ashmead	36	462.7 (825.01)	3 000	77.8
Green Hole	125	232.8 (429.6)	2 419	84.8
Bollard Bay	126	373.8 (2 225.9)	24 192	91.3
White Bridge	102	134.1 (487.51)	3 000	95.1
Thesen Island Causeway	24	113.8 (257.09)	1 260	95.8
The Heads NSRI	27	106.5 (219.9)	1 120	96.3
The Heads	98	60.8 (104.9)	613	99.0

Discharges from all inlets were at the time found to periodically exceed limits for recreational water use (500 cfu 100 ml^{-1}) (DEA 2012) with sites that were non-compliant more than 50% of samples including Bongani River, Long Street culvert, Queen Street culvert, Station culvert and discharges from the waste water treatment works (Table 13). Lower than 50% compliance also occurred within the Ashmead channel. The inflow of faecally contaminated water from the town into the estuary is chronic in that it is widespread, long-standing and ongoing.

5.4. Exploitation of Natural Resources

Over-exploitation poses the single biggest threat to estuarine fish conservation (Whitfield & Cowley 2010). Unfortunately, relatively few species are targeted within South African estuaries meaning that both recreational and subsistence fishing effort is concentrated on a small number of species which includes white steenbras, dusky kob, spotted grunter, garrick and Cape stumpnose (e.g., see Pradervand & Baird 2002, Cowley *et al.* 2013). Fishery assessments indicate that of these popular species spotted grunter is over-exploited whilst the populations of white steenbras, garrick and dusky kob have collapsed (Cowley *et al.* 2013). Furthermore, Whitfield *et al.* (2018) highlight that present-day stocks of Cape stumpnose are much smaller than those in the pristine state. They argue that urgent management measures need to be considered and implemented to prevent further decline in populations of this species.

Although a high proportion of angler outings on the Knysna Estuary are not target specific (i.e., anglers are happy to catch anything) spotted grunter has been the most commonly targeted species (17%) followed by white steenbras (10%), Cape stumpnose (6%) and strepie (5.5%) (Smith & Kruger 2013) (cf. section 4.1). Similar trends, although with higher percentages, were shown in an earlier study on Knysna Estuary which specifically looked at subsistence fishers (Napier *et al.* 2009) where 46% of interviewed fishers identified spotted grunter as their main target species, 42% named white steenbras with Cape stumpnose being the third most targeted species.

Both Napier *et al.* (2009) and Smith & Kruger (2013) have highlighted concerns around the high number of undersized fish being retained within both the subsistence and recreational fisheries. Further Smith and Kruger (2013) documented high retention rates by recreational fishers and poor knowledge of fishery regulations by both fisheries with roughly 30% of fishers knowing the species-specific size limits for the fish they were targeting and only 40% knowing the respective bag limits.

In general, the sustainability of estuarine fisheries has been questioned due to high targeting effort, large proportion of undersized fish being retained, poorly informed fishers and limited monitoring and law enforcement (Cowley *et al.* 2013). Elements of these concerns are valid for the Knysna Estuary. In particular, we need to concentrate on improving compliance to current regulations, promoting catch and release, ensuring effective law enforcement and evaluating the potential for closed areas within the estuary.

5.4.1. Impacts of bait harvesting

The primary direct impact of bait harvesting is the reduction in density of target species. However, the preferential extraction of larger individuals may lead to changes in the size structure of target populations. Indirect impacts of bait collecting, mainly related to the disturbance of sediment associated with harvesting can be far greater than direct impacts (e.g., Wynberg & Branch 1994, 1997). High-intensity collecting has been shown to have long-term negative effects on the densities of prawns, bacteria and microflora in the sediment, and on biomass and species richness of meio- and macrofauna (Wynberg & Branch 1991, 1994, 1997). Sediment disturbance may also lead to higher prawn mortality than through direct extraction, resulting in as much as an additional 25% reduction in prawn densities (Wynberg & Branch 1991). Similarly, Hanekom & Baird (1992) estimated that mortality of mudprawn populations in Swartkops Estuary increased by 18% through disturbance compared to 18% loss of the annual somatic production through consumption by bird and fish predators and only about 2% removed by bait collectors. The impacts of bait collecting are amplified when combining the effects of trampling, harvest method and numbers harvested. Sediment trampling is an unavoidable disturbance of bait exploitation, with harmful impacts on macro- and meiofauna and prawns comparable to that of pumping (Wynberg & Branch 1997). The impact of bait collecting is further exacerbated by illegal activities including the illegal collection of bait after dark, exceeding daily bag limits (Fielding 2007, Smith 2016), illegal sale of bait organisms and using banned implements like forks and shovels. In particular, the use of implements to illegally dig within the estuary is considered the activity most damaging to the Knysna Estuary in terms of macro-benthos (Napier *et al.* 2009, Simon *et al.* 2019).

5.4.2. Law enforcement

The importance of recreational fishery law enforcement and its impact in improving angler compliance has been shown for the St. Lucia system (Mann *et al.* 2002) and the KwaZulu-Natal coastline when compared to other sections of the South African coast (Brouwer *et al.* 1997) with a higher law enforcement effort resulting in lower levels of non-compliance. During roving creel surveys undertaken during 2009, of those anglers interviewed on the Knysna Estuary 71% had at some point had their fishing permit inspected by SANParks law enforcement officials. However, the inspection rate for bait collected and catch caught was much lower (Smith & Kruger 2013). In line with the higher law enforcement, contact rate (71%) the majority of interviewed anglers (82%) on the estuary had a valid fishing licence (Table 14).

Table 14: The proportion of interviewed anglers on the Knysna Estuary (between 2008 and 2009) who had been inspected by SANParks law enforcement (during their entire fishing experience on that water body) and the proportion of interviewed anglers who could produce a valid fishing and bait permit when requested (taken from Smith & Kruger 2013).

Estuary	Permits Inspected	Catch Inspected	Bait Inspected	Produced Fishing Permit	Produced Bait Permit
Knysna	71%	31%	48%	82%	82%

The total number of recorded law enforcement patrols within the estuary over a three-year period was 1 240 with 687 patrols occurring within the first 12 month period. During these patrols 1 557 people were intercepted with 1 302 permit inspections occurring, 163 bait inspections, 32 catch inspections and 58 bait and catch inspections (Table 15). A total of 192 anglers were transgressing one or more of the MLRA laws resulting in 225 actions of which 37 were admission of guilt fines (J534 fines) and 141 verbal warnings and requests to leave (Table 16). Prominent transgressions included no permit (152 people), exceeding bag limit (19 people), illegal fishing method e.g., spearfishing in an estuary / use of throw net after sunset (11 people), and undersized fish (5 people).

Table 15: The number of patrols and number of inspections logged on the cybertracker sequence by law enforcement officials in the Knysna sections of the Garden Route National Park (taken from Smith & Kruger 2013).

Estuary	No. Patrols	No. of People Checked	Check Angling Catch	Check Bait Collected	Check Permit Only	Check Angling & Bait Catch	Check Net Collection
Knysna	1240	1557	32	163	1302	58	2

Table 16: Number of transgressions logged and law enforcement responses between June 2008 and June 2011 in the Knysna sections of the Garden Route National Park (taken from Smith & Kruger 2013).

Estuary	No of Transgressors	No of Reactions	Verbal Warning / Request to leave	Written Fine (J534)	Confiscation of Goods	Report to Police	Arrest	No Reaction	Other
Knysna	192	225	141	37	35	2	0	1	9

5.5. Non-Extractive Uses

The proximity of estuaries to communities and their generally sheltered environment makes them desirable places for recreation (Lepesteur *et al.* 2008) including a variety of watercraft-based activities. On the Knysna Estuary water usage is varied and comprises various tourism related commercial operators, recreational users and a smaller group of boat-based subsistence anglers who use small dingys either with a small motor or which is rowed. Commercial operators include houseboats for hire, sailing charters, fishing charters, ferries, general boat cruises and kayak hire. Whale watching boats use the estuary as a transition area for their seagoing excursions.

The variety of activities and types of watercraft used enables a variety of experiences to be enjoyed but also has the potential to create inter-user conflict. Pigram (1983) defines compatibility as: "*The degree to which two or more activities can coexist in the use of a given recreational resource*". The degree of incompatibility is, in part, a function of the activity, the manner in which it is practised and the characteristics of the site or resource involved. For example, points of conflict have been noted between high-speed boating activities and fishing. Furthermore, the degree of use and type of vessel activity can influence the ecological integrity of estuarine systems.

Recreational boating activities and associated infrastructure are considered to have a variety of potential ecological impacts. The degree of damage depends on a number of factors including the frequency of occurrence, type, size and speed of a particular watercraft. Potential environmental impacts include pollution (engine emissions and sound emissions), disturbance to bird and fish life, habitat damage including aquatic vegetation, bank erosion and resuspension of sediments leading to increased turbidity, and antifouling paint leaching (Saunders *et al.* 2000, Theron 2007).

The physical infrastructure to facilitate water-based recreation ranges from parking areas and launch sites to jetties and swinging moorings. Boatyards and yacht clubs are also essential to many water-based activities. The potential impacts of boating infrastructure may occur both when the facility is being constructed, if it is a new facility, and also while it is in use (Saunders *et al.* 2000). Impacts may be physical in nature, such as destruction of habitat, or biological, such as changes in water quality brought about by development (Saunders *et al.* 2000).

Quantifying recreational use can provide spatial and temporal information about which areas are most heavily utilised, the activities for which they are used and how these change over time (Mulvaney *et al.* 2020). This information can support improved allocation of resources and spatial planning for environmental management, facilities siting, minimising conflicting uses and for safety purposes. Despite the importance in understanding patterns in watercraft activities, counts and other data on the volume of recreational use for estuarine areas in South Africa are limited.

No published data exists on either patterns in watercraft usage of the Knysna Estuary or their impacts. However, since 2008 all watercraft (including non-powered) have had to be registered with SANParks and annual vessel permits allocated. Part of this database has been used to extract trends in the annual number of permits allocated (2014 to 2021). Further, Joubert (2015) undertook an exploratory study looking at spatial and temporal patterns in watercraft activity as part of his Btech degree and carrying on from this SANParks monitored watercraft activities between 2015 and 2017 and then again from 2019 to present.

5.5.1. Vessel Registration (permits)

The total number of vessel permits allocated per year is provided in Table 17, with an annual permit cycle starting on 1st November and ending on 31st October of the following year. Although annual, short term permits (monthly) and exemption permits (e.g., fire, police, internal vessels) are allocated each year we have only shown the data for the sale of annual permits as this constitutes the greatest proportion of permits. With a 138.8% increase over the previous year, the 2015 to 2016 permitting period experienced the highest number of annual permits sales with a total of 2 400 allocated. However, during this seven year period the number of annual vessel permits sold fluctuates and there is no trend of consistent year on year increases.

It is interesting to note that during the 2019 to 2020 period, which encompasses the first year of the covid-19 pandemic, there was only 6.78% decrease in annual permits sold compared to the previous permitting period. There was a 27.9% increase during the 2020 to 2021 permitting period but it is still lower than the 2015 to 2018 annual cycles.

Table 17: The number of annual vessel permits (all categories) issued for Knysna Estuary between 2014 and 2021.

Permit Cycle (1 November to 31 October following year	Number of vessel permits	% Change
2014 - 2015	1 005	
2015 – 2016	2 400	138.8
2016 – 2017	2 098	-12.54
2017 – 2018	2 151	2.48
2018 – 2019	1 592	-25.99
2019 – 2020	1 484	-6.78
2020 – 2021	1 898	27.90

A breakdown of the number of annual permits allocated per vessel category is presented in Table 18 for the reporting period 1 November 2018 to 31 October 2019. This reporting period has been chosen to illustrate activity usage (in terms of permits numbers) as the 2019 to 2020 and 2020 to 2021 permitting cycles have been influenced by the COVID-19 pandemic. Within the recreational category speedboats were the most popular with 687 annual permits sold (46.29%) during the 2018 to 2019 period. This was followed by rubberducks (semi-rigid) and lagoon or cabin boats (~14% each). During this period motorised boats comprised 82% of all permits with non-motorised comprising the remaining 18%. Of these kayaks/canoes were the most common comprising 12% of all annual permits during that period (Table 18).

Table 18: Number of annual vessel permits issued for the 1 November 2018 to 31 October 2019 permitting period. This period has been used to showcase the number and type of permits allocated.

Activity	Number of Operators (commercial only)	Number of annual vessel permits issued	Area of usage
Commercial			
Houseboats	1	8	All
Kayak hire	3	30	Predominantly Bay
Sailing Charters	3	4	Transition and Bay
Boat cruises	6	9	Predominantly Bay
Ferries	1	4	Bay
Fishing Charters	2	3	All
Whale watching	2	4	Transition through bay
Recreational / Subsistence			
Rubber duck		210	All
Speedboat		687	All
Lagoon / cabin boat		208	All
Dingy - small engine		55	All
Rowing boat		51	All
Sailing		24	Bay
Kayaking / canoeing		176	All
SUP boarding		10	All
Kite surfing		2	Bay
Windsurfing		5	Bay
Houseboat		12	All
Jetski		4	Bay of Biscay

Activity	Number of Operators (commercial only)	Number of annual vessel permits issued	Area of usage
Jetboat		4	All
Pontoon		36	All

Motorised boats ranged from small dingys with small outboard engines (1.5HP) all the way through to large vessels with 600HP combined engine power (Table 19). Only vessels utilising 15HP or less do not need a skippers licence. Smaller engines (< 50HP combined) comprised 24% of all permits whilst vessels with more than 200HP comprised 12% of all permits. The most commonly used HP has been 115 (11%) followed by 90 and 200HP (both 9%), 15 and 60HP (both 7%).

Table 19: Breakdown of engine sizes during the November 2018 to end October 2019 permitting period. Note horsepower is combined motor horsepower.

Engine Size HP	Number of permits	Proportion
1 - 50	289	24
51 - 100	336	28
101 -150	311	26
151 - 200	117	10
201 - 250	91	8
251 - 300	32	3
351 - 400	12	1
401 - 450	6	1
451 - 500	1	< 1
501 - 550	0	0
551 - 600	1	< 1

5.5.2. Vessel Activity Patterns

Instantaneous watercraft counts indicate that the bay portion of the Knysna Estuary is the most heavily utilised with 67% of all observed watercraft occurring within this region (Figure 19). The lagoon region (section 4) experienced 21% whilst the lower and upper estuary regions (zones 5 and 6 respectively) had far lower observations comprising 5% and 4% respectively of all activity. The train bridge across the estuary almost certainly influences patterns in spatial activity as it effectively acts as a barrier for sailing vessels and larger motorboats. Within the bay area, boating activity was equally distributed between zones 1 and 3 with many water users moving between the mouth, Thesen Island and the Knysna Quays. This is also the area where the majority of commercial activity takes place including those who are using the estuary in transition to the ocean.

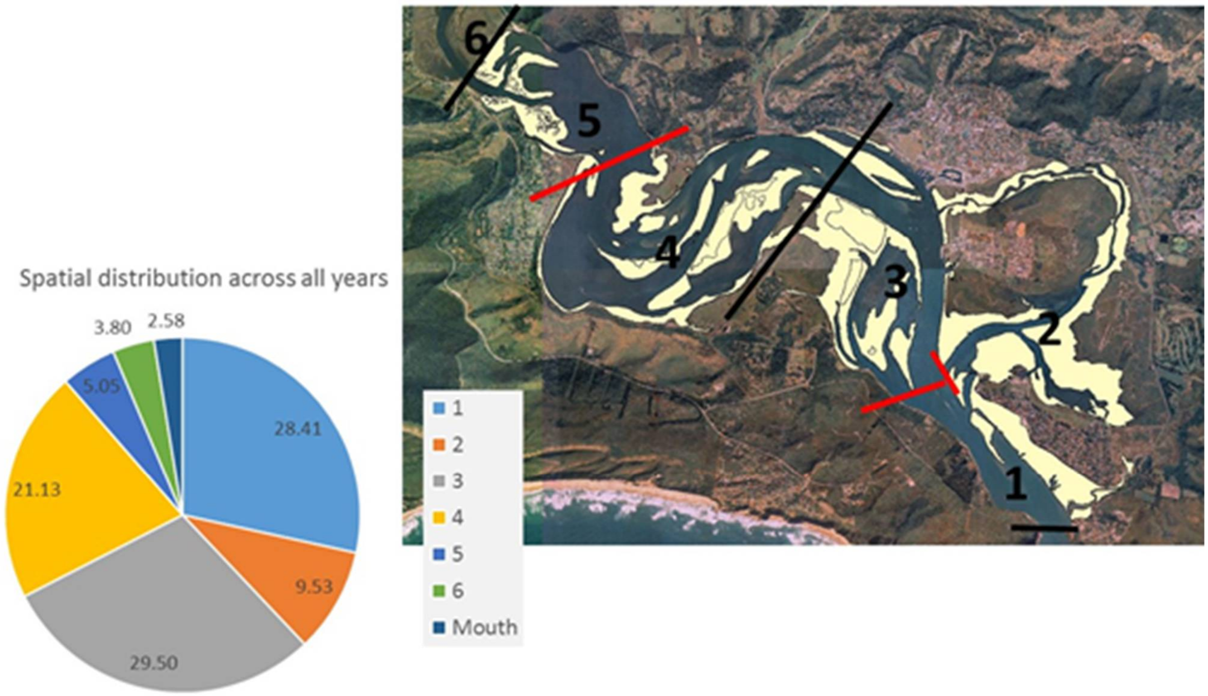

Figure 19: Spatial distribution of all watercraft activities on the Knysna Estuary. Instantaneous counts undertaken between 2015 and 2017 and between 2019 and 2021. Zones 1, 2 & 3 represent the bay portion, zone 4 represents the lagoon and zones 5 and 6 represent the lower and upper estuarine portions respectively.

In terms of type of watercraft, the majority were powered (74%, outboard engines or internal engines). Motor boats (ski-boats, small cabin boats, etc.) were the most frequently observed watercraft making up 52% of all observations whilst rubber ducks comprised a further 9% (Figure 20). These types of vessels would be used in a number of different activities including cruising, skiing and fishing. Houseboats comprised 6.5% whilst the commercial cruise boats (ferries, sight-seeing, sundowners etc.) made up just under 7% of all observations. Kayaks (12%) were the most frequently observed non-powered watercraft followed by rowing boats (4.5%). The majority of these rowing boats would have been used by subsistence fishers although sculling boats were also included within this category. Wind powered watercraft made up just over 7% of all observations and included yachts (4%), sailing dingys (1.5%), kite surfers (1%) and windsurfers (<1%). The yachting category included both recreational private yachts as well as commercial operators providing a yachting experience.

Activity on the water showed temporal patterns at various scales. Although there was an increase in activities over weekends compared to weekdays this was not as marked as expected with an average of 19 watercraft being counted on any instantaneous weekday count and 25 on weekends (Table 20). It is important to note that this does not represent total daily effort, as there would be substantial turnover of activities and individuals throughout the day. A correction factor to upscale the instantaneous counts to daily effort has not yet been calculated. Seasonal patterns have been observed with more activity being noted during summer and autumn and less during winter and spring (Table 21). In particular, there is dramatic increase over the December holiday period and again during the Easter holiday period. The maximum observed number of watercraft on any instantaneous effort count was 216 during December 2020. There has also been a change in type of activity undertaken between seasons with proportionally more fishing occurring during the winter months and an increase in leisure boating and skiing occurring during the summer period.

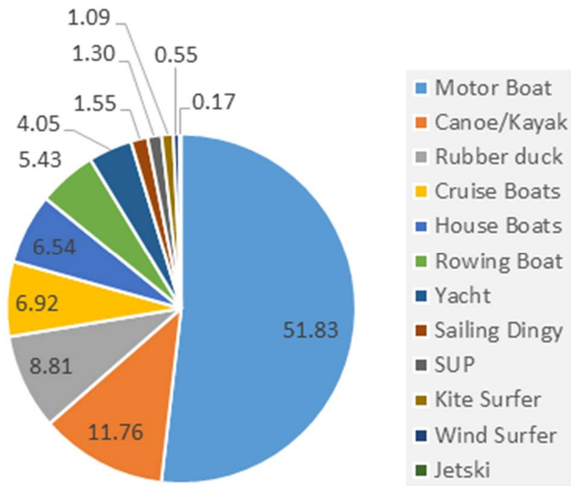

Figure 20: The frequency of different types of watercraft observed during instantaneous effort counts undertaken on the Knysna Estuary between 2015 and 2017 and between 2019 and 2021.

Table 20: Average counts of the various watercraft types between week days (Monday to Friday) and weekend days (including public holidays) on the Knysna Estuary. Instantaneous counts undertaken between 2015 and 2017 and between 2019 and 2021.

Vessel type	Avg. Week	Avg. Weekend
Canoe/Kayak	2.11	3.19
Cruise Boats	1.43	1.37
House Boats	1.11	1.94
Jet Ski	0.03	0.05
Kite Surfer	0.15	0.43
Motor Boat	9.78	12.68
Rowing Boat	1.09	1.14
Rubber duck	1.81	1.76
Sailing Dingy	0.26	0.46
SUP	0.22	0.38
Wind Surfer	0.11	0.11
Yacht	0.62	1.38
Total	**18.83**	**25.29**

Table 21: The average and maximum counts made per season during the instantaneous effort counts undertaken on the Knysna Estuary between 2015 and 2017 and between 2019 and 2021.

Season	Average	Maximum observed number
summer	31.09	216
autumn	22.19	160
winter	13.56	77
spring	14.04	48

6. SOCIO-ECONOMICS

6.1. Demographics

Knysna is one of seven local municipalities that fall within the Garden Route (Eden) District Municipality (DM) along with Kannaland, Hessequa, Oudtshoorn, Mossel Bay, George and Bitou. As the second most populous municipal district in the Western Cape, in 2019 the Garden Route DM had an estimated population of 663 179 people with an annual growth rate of 1.99% (Garden Route District Municipality 2020). The approximate number of households was 198 000 with the average household size observed to be decreasing over the last 10 years from 3.5 to 3.3 individuals per household in 2019.

Among the local municipalities (LMs), Knysna has the third highest average annual population growth rate of 1.1 % and a total population of 76 150 individuals which is projected to increase to 79 426 by 2023 (Knysna Municipality 2019). The demographic profile is made up of 36.1% black African, 40.9% coloured, 21.0% white, 0.4% Indian/Asian and the remaining 1.6% comprising other population groups (StatsSA 2011). Number of households was estimated at 14 935 with an average household size of 3.3 (Knysna Municipality 2019). The population comprises 50.5% females and 49.5% males. Percentage of households with access to the following basic services were: access to water 96.6%; refuse removal 93.1%; electricity 92.5%; and sanitation 94.6% (Knysna Municipality 2019).

Of people aged 20 years and older 29.7% had completed matric, while 12.6% had acquired higher education (StatsSA 2011) and overall Knysna LM had an 89.0% functional literacy rate in 2019 (Garden Route District Municipality 2020). The economically active age category 15 – 64 years comprises 66.9% of the population while unemployment rates had declined from 18.1% in 2011 to 17.1% in 2015 before rising to 18.4% in 2018.

6.2. Economic Profile

The Garden Route DM has 75% of its population concentrated in three principal urban centres i.e., Mossel Bay, George and Knysna with the remaining 25% dispersed within other towns in the district (Garden Route District Municipality 2020). The DM has been classified according to the following functional areas:

- Agricultural Service centres: Calitzdorp, Ladismith, Riversdale, Uniondale;
- Regional service centres: George, Oudtshoorn, Mossel Bay;
- Residential centres: Dysseldorp, Kranshoek, Kurland;
- Residential/Tourism: Groot Brakriver, Herolds Bay, Sedgefield, Stilbaai, Wilderness; and
- Tourism: De Rust, Knysna, Nature’s valley.

Inland areas within the Garden Route District are largely rural comprising farms and small towns which are isolated with limited access to transport and service delivery.

The Regional Gross Domestic Product (GDPR) for the Knysna area was R4.77 billion in 2017 displaying an overall growth of 1.5% over the previous nine years (2008-2017), however economic growth had subsequently slowed to 0.6% between 2014 and 2018 (Knysna Municipality 2019).

The municipality is supported mainly by the tertiary economic sector which contributed R3.44 billion (72.1%) to the GDPR and comprises the following sub-sectors: wholesale and retail trade, catering and accommodation (18.8%); transport, storage and communication (8.3%); finance, insurance, real estate and business services (24.8%); general government (11.6%); and community, social and personal services (8.6%).

The Primary sector is supported mainly by the agriculture, forestry and fishing (AFF) sector which in 2017, contributed R211.4 million (4.4%) to total GDPR. Growing at an average annual rate of 1.8% between 2008 and 2017, the AFF sector was the fourth fastest growing sector in the Knysna LM (along with the Construction sector). Growth in this sector has since declined, dropping to -0.7% between 2014 and 2018 a likely consequence of drought in the preceding years. In the Knysna LM, yields from the primary sector support manufacturing that falls under the secondary sector. Therefore, the decline in growth of the AFF sector in 2017 from 5.2% to -6.8% in 2018 saw a knock-on effect on the manufacturing sector which also decreased from 0.6% in 2017 to -1.1% in 2018 (Knysna Municipality 2019).

In 2017, 26 059 people were employed within the Knysna local municipal area, with the most jobs provided in the tertiary sector (73.4%) following by 17.6% in the secondary sector (manufacturing; electricity, gas and water; and construction), and 9% in the primary sector (AFF; mining and quarrying). Within these sectors most people (27%) were employed in the wholesale and retail trade, catering and accommodation sector under which tourism falls (Knysna Municipality 2019). A total 2 854 jobs were created in Knysna between 2008 and 2017 mainly within the community, social and personal services, however positive gains made in these sectors were eclipsed by notable losses in the AFF and manufacturing sectors likely because of the impact of the drought and increased use of automation. In 2018, the finance, insurance, real estate and business services sector was expected to create the most jobs (122) in the municipal area (Knysna Municipality 2021).

The unemployment rate has been rising since 2015 reaching 18.7% in 2017 before declining slightly to 18.4% in 2018 (Knysna Municipality 2019). This is considerably higher than District (15.2%) and Provincial (17.7%) averages. In 2017, employment was mostly within the semi-skilled (44.5%) and low-skilled (33.2%) categories, however highest growth was seen in the number of skilled and semi-skilled workers (2.4% for both) between 2014 and 2018 with low-skilled work growing at a marginally slower rate (2.15%).

6.3. Social Considerations

Estuaries provide a tranquil and safe environment for tourism and recreation particularly given South Africa's high-energy coastline. The Knysna Estuary is a key tourism attraction in South Africa, drawing both national and international visitors largely due to its natural and scenic appeal including proximity to adjacent forests, fynbos, beaches, and opportunity for birding and adventure activities. Its temperate climate, well development infrastructure (roads, jetties, tourism accommodation, etc.), as well as proximity to airports (George and Plettenberg Bay) make it an attractive and accessible destination for most visitors. Tourism is a key economic driver of income to the Knysna LM, the second largest contributor to GDPR, as well as an important source of employment (Knysna Municipality 2019). In addition, resource extraction, mainly fishing, is an essential estuarine service providing 70.4 tons of fish per annum (Van Niekerk *et al.* 2019).

The exploitation of estuarine resources, both fish and bait, play an important role in the livelihood of the subsistence fishers of the Knysna Estuary (Cretchley1996, Napier *et al.* 2009). Napier *et al.* (2009) estimated that there were approximately 30 full time and 200 part time subsistence fishers operating on the estuary in 2005. Although after the 2010 economic recession SANParks monitoring indicated that the number of subsistence fishers increased with up to 500 part- and full-time subsistence fishers being active (Simon *et al.* 2019). The fishery is dynamic in that participants enter and exit the fishery dependent on financial and employment circumstances (cf. section 4.1).

Both bait and fish are harvested for sale as well as for own consumption. The bait fishery is dominated by the mud prawn. Estimated catches amounted to about 3% of the standing stock, suggesting that the fishery is well within sustainable limits (Hodgson *et al.* 2000b) (cf. section 4.1).
The harvesting of other more valuable bait species, such as worms (*Marphysa* and *Gorgonorhynchus*), is only viable through damaging methods, which poses a threat other estuarine biota including the estuary's endangered Knysna seahorse which may be found in the same habitats. Napier *et al.* (2009) showed that fish catches were dominated by small species and individuals, particularly Cape stumpnose caught with hand lines, but most of the value of the fishery lies in the catches of spotted grunter and white steenbras which are caught with set lines. The subsistence fishery was worth at least R0.7 million – R1.1 million per annum, with full time fishers earning at least R11 000-17 000 per annum from the estuary. The intrinsic value of prawn (as a means to catch fish for personal use) added substantial value to the bait resources being nearly 1.5 times the value of prawns sold as bait (Napier *et al.* 2009).

Pollution from the Khayalethu and Bongani river catchments pose a serious threat to the Knysna Estuary potentially risking its tourism economic value. Prevention of pollution at the source has proved challenging and is almost impossible given the nature of the pollution. A proposal to develop the area into a series of managed wetlands, which will help purify the water through natural processes, was suggested but has not been taken forward (Knysna Municipality 2015). This could potentially have an impact in reducing both pollution and siltation into the estuary. Remodelling of the Knysna wastewater treatment works should also be prioritized to further address the pollution crisis faced by the municipality (Knysna Municipality 2015). Because larger estuarine systems such as the Knysna Estuary are important tourist attractions and a fish nursery area they are therefore of higher ecological and economic importance. These estuaries are also the most impacted indirectly due to poor catchment management and directly from extractive use and development within the estuary functional zone (Van Niekerk *et al.* 2019). Deterioration in water quality and overall estuarine heath, particularly with increased input of microbial contaminants, threatens the socio-economic value (i.e., tourism, real estate, etc.) provided by estuaries, eventually impacting livelihoods and the economy (Van Niekerk *et al.* 2019).

7. HISTORICAL AND CULTURAL HERITAGE

A rich cultural and archaeological heritage surrounds the Knysna Estuary. Middle Stone Age deposits reveal that Knysna had been inhabited for tens of thousands of years by modern human beings. Shell midden deposits from a cave at Knysna's Western Head were recorded by the South African museum (Grindley 1985), and a Strandloper (nomadic Khoi tribes who lived and foraged along the coast) burial site was unearthed close to Knysna during construction of the railway (FitzSimons 1928). Acheulian artefacts (distinct oval tools with pear-shaped edges associated with *Homo erectus*) were recorded in reworked gravels of the Keurbooms Formation east of Knysna (Mortelmans 1945, Davies 1971). In 2016, forty hominin tracks were identified on the ceiling and side-walls of a cave at Brenton-on-Sea, near Knysna, estimated to be 90 000 years old (Helm *et al.* 2018).

Some of the earliest inhabitants of the southern Cape region were the Khoi (pastoralists) and San (semi-nomadic hunter-gatherers) who lived off the coastal plains and forests that abounded with wildlife including herds of buffalo and elephant (Phillips 1963). These communities had minimal impact on the environment given their primitive weapons and small numbers, except for occasional forest fires used to smoke out game while hunting. Following the arrival of Europeans, Khoi and San groups eventually fragmented culminating in many being employed as farm workers (Phillips 1963).

Figure 21. Early Knysna (Millwood House Museum Archives).

The earliest European inhabitants of the area were a group of Portuguese sailors whose ship, Sao Goncalo, was wrecked in Plettenberg Bay in 1630. These seamen were recorded as the first Europeans to harvest wood from the southern Cape forests, which was used to build dwellings, a church and boats. They also traded metal with the indigenous Khoi people for sheep and cattle (Sleigh 1993). By 1763, harvesting of indigenous timber surrounding Knysna began and has continued for >200 years (Grindley 1985). Attempts to control overexploitation and the uncontrolled destruction of forests in 1778 proved challenging and lead to the construction of a timber shed and the drafting of contractual agreements with woodcutters but with limited success in curbing the deforestation (Van der Merwe 1998). The dense Tsitsikamma forest region with its many deep ravines remained impenetrable by Europeans until the late nineteenth century, however artefacts reveal a small Khoi population i.e. Strandlopers had inhabited caves along the rugged coastline (Van der Merwe 2002).

The thriving timber market in the southern Cape caught the interest of the British Royal Navy in 1812 leading to the establishment of a port in the Knysna Estuary despite the treacherous channel through the headlands. This would create faster transportation of timber to the Western Cape. As one of the earliest commercial harbours in the country, the first loading wharf was constructed in 1776 followed by a naval dockyard in 1820 (Reddering & Esterhuysen 1984). At its peak, up to 80 ships and steamers would dock in the Knysna harbour in a year, however the harbour was deproclaimed in 1959 (Reddering & Esterhuysen 1984).

In October 1876, a steam sawmill and boat factory were established at Bracken Hill by the Thesen family after purchasing a well-forested piece of land (The Heritage Portal 2019). Arriving from Norway with sailing and commercial skills, the Thesens' used their vessel, the Albatross to trade along the coast carrying indigenous timber to the Cape for construction and boat building. In 1923, the sawmill and boat factory were relocated to Paarden Island (later renamed Thesen Island) in the Knysna Estuary (Figure 21). A stone jetty was built in 1867 to assist with loading and unloading of cargo, and was replaced by a new jetty or Government Jetty on Thesen Island in 1883 (The Heritage Portal 2019).

Access to and transportation of indigenous timber in and around the Knysna Estuary, coupled with construction and processing factories, and the establishment of the town and associated residences over the last >250 years has impacted and likely transformed the Knysna estuarine system to what we see today.

8. LEGISLATIVE INSTRUMENTS AND RELATED STRATEGIES / PROGRAMMES

In order to ensure that all relevant legislative responsibilities and obligations are met when managing the Knysna Estuary, a list of relevant legislation is set out below. The list includes relevant international treaties, national, provincial and local/municipal legislation, policies, plans, frameworks and strategies. The list is not exhaustive. The estuary (water body) is situated within and wholly managed as part of the National Park, whereas the remainder of the EFZ, coastal zone, river and catchment (within the protected environment) are co-managed by SANParks and other government institutions. The list of legislation includes international obligations and treaties relevant to the estuary and EFZ (Table 22), national legislation, plans and policies (Table 23), provincial legislation, plans and policies (Table 24), municipal legislation, plans, frameworks and policies (Table 25) and various strategies that may be applicable the estuary and its associated catchment. A brief description of each instrument is provided except for the strategies applicable to the estuary and its associated catchment. All references to the acts listed below include any amendments to those legislation as well as regulations promulgated under those acts. The regulations governing the management of the Knysna Protected Environment is discussed under zonation of the estuary.

International agreements and obligations applicable to the estuary:

- Convention Concerning the Protection of the World Cultural and Natural Heritage (1972) (World Heritage Convention);
- Convention on International Trade in Endangered species of Wild Fauna and Flora, 1973 (CITES);
- Convention of Migratory Species of Wild Animals (1979) (Bonn Convention);
- The Convention for the Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (1981) (Abidjan Convention);
- The Nairobi Convention for the Protection, Management and Development of Coastal and Marine Environment of the Western Indian Ocean (WIO) region (1985) (Nairobi Convention);
- United Nations Convention on Biological Diversity (1992);
- Agenda 21 (1992) as reaffirmed at the United Nations World Summit on Sustainable Development -

Johannesburg Summit (2002) and Rio+20 (2012). The Sustainable Development Summit (2015) also added onto the Agenda 21 goals;
- United Nations Framework Convention on Climate Change (1992); and
- Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) (1995).
- Ramsar Convention

National legislation, plans, frameworks and policies applicable to the Knysna Estuary and its catchment:
- The Constitution;
- National Environmental Management Act, 1998 (Act No. 107 of 1998);
- National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008);
- National Water Act, 1998 (Act No. 36 of 1998);
- National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003);
- National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004);
- Marine Living Resources Act, 1998 (Act No. 18 of 1998);
- National Heritage Resources Act, 1999 (Act No. 25 of 1999);
- Sea Fishery Act, 1988 (Act No. 12 of 1988);
- Disaster Management Act, 2002 (Act No. 57 of 2002);
- Minerals and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002);
- National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008);
- National Forests Act, 1998 (Act No. 84 of 1998);
- Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983);
- National Health Act, 2004 (Act No. 61 of 2004);
- Water Services Act, 1997 (Act No. 108 of 1997);
- National Veld and Forest Fire Act, 1998 (Act No. 101 of 1998);
- Environmental Conservation Act, 1989 (Act No. 73 of 1989) (ECA);
- Spatial Planning and Land Use Management Act, 2013 (Act No. 16 of 2013);
- National Coastal Management Programme;
- National Estuarine Management Protocol;
- Garden Route National Park Management Plan; and
- National Biodiversity Framework.

Provincial legislation, plans and policies applicable to the Knysna Estuary and its catchment:
- Western Cape Housing Development Act, 1999 (Act No. 6 of 1999);
- Western Cape Planning and Development Act, 1999 (Act No. 7 of 1999);
- Western Cape Land Use Planning Act , 2014(Act No. 3 of 2014);
- Nature and Environmental Conservation Ordinance, 1974 (Ordinance No. 19 of 1974);
- Land Use Planning Ordinance, 1985 (Ordinance No. 15 of 1985);
- Western Cape Provincial Spatial Development Framework;
- Western Cape Provincial Coastal Management Programme; and
- Western Cape Provincial Biodiversity Spatial Plan.

Municipal legislation, plans, frameworks and policies applicable to the Knysna Estuary and its catchment:
- Local Government: Municipal Systems Act, 2000 (Act No. 32 of 2000);
- Garden Route District Municipality Coastal Management Programme
- Garden Route District Municipality Integrated Development Plan;
- Integrated Garden Route Environmental Policy;
- Garden Route District Municipality Climate Change Adaptation Plan;
- Knysna Integrated Development Plan; and
- Knysna Municipality Spatial Development Framework.

Various strategies developed by the government departments responsible for implementing the above legislative instruments. These include, but are not limited to:

- National Water Resource Strategy
- Breede-Overberg Catchment Management Strategy;
- Western Cape Provincial Climate Change Response Strategy;
- Western Cape Provincial Growth and Development Strategy
- Garden Route DM Integrated Coastal Zone Strategy;
- Garden Route DM Integrated River and Estuarine System Strategy;
- Garden Route DM Integrated Biodiversity Strategy; and
- Garden Route DM Energy and Climate Change Strategy.

Table 22: International obligations and treaties relevant to SANParks-managed estuaries.

Name	Description and applicability to SANParks' Estuary Management Plans
Convention Concerning the Protection of the World Cultural and Natural Heritage (1972) (World Heritage Convention)	The World Heritage Convention links the concepts of nature conservation and the preservation of cultural properties by recognising the way in which people interact with nature as well as the fundamental need to preserve the balance between the two concepts. The Convention sets out the duties of state parties and defines the kind of sites which can be considered for inscription on the World Heritage List (this may include estuaries) as well as the state parties' role in protecting and preserving those sites. As an implementing agent of the Department of Forestry, Fisheries and the Environment (DFFE), SANParks is responsible for identifying natural and cultural assets within National Parks (including estuaries) as well as managing those assets.
Convention on International Trade in Endangered species of Wild Fauna and Flora, 1973 (CITES)	CITES is a treaty protecting endangered plants and animals. The treaty recognises that "wild fauna and flora in their many beautiful and varied forms are an irreplaceable part of the natural systems of the earth which must be protected for this and the generations to come" as well as the "ever-growing value of wild fauna and flora from aesthetic, scientific, cultural, recreational and economic points of view". It also recognises that "peoples and States are and should be the best protectors of their own wild fauna and flora" and that "international co-operation is essential for the protection of certain species of wild fauna and flora against over-exploitation through international trade".
Convention of Migratory Species of Wild Animals (1979) (Bonn Convention)	The Bonn Convention aims to conserve terrestrial, marine and avian migratory species throughout their range (across or outside national boundaries), with special emphasis on endangered species. This is achieved by range states acknowledging the importance of migratory species and agreeing to take action to conserve such species and their habitat whenever possible and appropriate.
The Convention for the Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (1981) (Abidjan Convention)	The Abidjan Convention covers the marine environment, coastal zones and related inland waters and obligates the Contracting Parties to take all necessary measures to prevent, reduce, combat and control pollution as well as ensuring that sound environmental management of natural resources in the convention area. This includes pollution from ships and aircraft, land-based sources, activities related to exploration and exploitation of the sea bed and from or through the atmosphere. The convention requires contracting parties to undertake to prevent, reduce, combat and control coastal erosion and to protect and preserve rare or fragile ecosystems, as well as the habitat of depleted, threatened or endangered species and other marine life in specially protected areas. Additionally, it provides for co-operation in emergency situations and in the fields of scientific research, monitoring and the assessment of pollution and requires the development of national policies and legislation, including those that incorporate the polluter pays principle.
The Nairobi Convention for the Protection, Management and	The Nairobi Convention offers a regional legal framework and coordinates the efforts of the member states to plan and develop programmes that strengthen their capacity to protect, manage and develop their

Name	Description and applicability to SANParks' Estuary Management Plans
Development of Coastal and Marine Environment of the Western Indian Ocean (WIO) region (1985) (Nairobi Convention)	coastal and marine environment in a sustainable manner. It also provides a forum for inter-governmental discussions that lead to better understanding and protection of the member states' shared marine environment and promotes sharing of information and experiences between member states.
United Nations Convention on Biological Diversity (1992)	The Convention's three main goals are the conservation of biological diversity; the sustainable use of its components; and the fair and equitable sharing of benefits arising from genetic resources; achieved by developing suitable national strategies. SANParks' management strategies for estuaries in the GRNP include aspects of all three main goals as provided for under the National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) and the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004).
Agenda 21 (1992) as reaffirmed at the United Nations World Summit on Sustainable Development - Johannesburg Summit (2002) and Rio+20 (2012). The Sustainable Development Summit (2015) also added onto the Agenda 21 goals.	Agenda 21 is a non-binding United Nations action plan for sustainable development. The goals of Agenda 21 were expanded upon to a total of 17 sustainable development goals in 2015. These deal mainly with combating poverty, especially in developing countries, changing consumption patterns, promoting health, achieving a more sustainable population, and the introduction of sustainable settlement patterns in decision-making. It also deals with atmospheric protection, combating deforestation, protecting fragile environments, conserving biodiversity, control of pollution and the management of biotechnology, and radioactive wastes as well as the roles of children and youth, women, NGOs, local authorities, business and industry, and workers; and strengthening the role of indigenous peoples, their communities, and farmers in sustainable development. To achieve the goals, the role of science, technology transfer, education, international institutions and financial mechanisms is also included.
United Nations Framework Convention on Climate Change (1992)	The United Nations Framework Convention on Climate Change objective is to "[stabilize] greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" by "enacting effective environmental legislation, that environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply, and that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries". Additionally, "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) (1995)	The international community, recognising that the impacts of land-based activities on the marine environment was a local, national and regional problem with global ramifications, initiated the GPA to manifest their commitment to preventing the degradation of the marine and coastal environments from land based activities, by initiating actions at the national level and co-operation at the regional level. The primary objective of the GPA is to facilitate "*the realization of the duty of States to preserve and protect*

Name	Description and applicability to SANParks' Estuary Management Plans
	the marine environment. It is designed to assist States in taking actions". The GPA aims at preventing the degradation of the marine environment from land-based activities by facilitating the realization of the duty of States to preserve and protect the marine environment. It is designed to assist States in taking actions individually or jointly within their respective policies, priorities and resources, which will lead to the prevention, reduction, control and/or elimination of the degradation of the marine environment, as well as to its recovery from the impacts of land-based activities. Achievement of the aims of the Programme of Action will contribute to maintaining and, where appropriate, restoring the productive capacity and biodiversity of the marine environment, ensuring the protection of human health, as well as promoting the conservation and sustainable use of marine living resources.
Convention on Wetlands of International Importance especially as Waterfowl Habitat (1971) (RAMSAR Convention)	The RAMSAR Convention is an intergovernmental treaty that provides the framework for local, regional and national actions as well as international cooperation for the conservation and wise use of all wetlands and their resources as a contribution towards achieving sustainable development throughout the world. The convention covers swamps and marshes, lakes and rivers, wet grasslands and peatlands, oases, estuaries, deltas and tidal flats, near-shore marine areas, mangroves and coral reefs, and human-made sites such as fish ponds, rice paddies, reservoirs, and salt pans. The wise use of wetlands is defined in the convention as "*the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development*".

Table 23: National legislation relevant to the Knysna Estuary and its catchment.

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
Act	The Constitution (Act No. 108 of 1996)	The constitution is the supreme law of the Republic of South Africa and provides the legal framework for legislation regulating environmental management as outlined in section 24. This section applies to estuaries; it states: "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 ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." Section 24 therefore guarantees the people in South Africa the right to an environment that is not harmful to their health or well-being, and requires the State

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		to promulgate legislation and take any other reasonable steps that ensure that the right is upheld. This lays the basis for environmental law in South Africa and is a very important justification for the wise use of estuarine biodiversity.
Act	National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA)	The principles of NEMA apply throughout the Republic to the actions of all organs of state that may significantly affect the environment. It also states that environmental management must place people and their needs at the forefront of its concern, and serve their physical, psychological, developmental, cultural and social interests equitably; development must be socially, environmentally and economically sustainable; the consideration of all relevant factors in decision making (e.g. disturbance of ecosystems, loss of biological diversity, pollution and degradation of the environment, disturbance of landscapes and sites that constitute the nation's cultural heritage and waste are avoided, or, where they cannot be altogether avoided, are minimised and remedied; the use and exploitation of non-renewable natural resources is responsible and equitable, and takes into account the consequences of the depletion of the resource and that such resource use does not exceed the level beyond which their integrity is jeopardised). NEMA also provides for co-operative environmental governance and for the incorporation of environmental principles in decisions affecting the environment. NEMA, through mechanisms such as the Environmental Impact Assessment (EIA) Regulations provides for assessment of human resource usage and development impacts on sensitive, vulnerable, highly dynamic or stressed ecosystems (which includes estuaries). NEMA also provides for the promulgation of Specific Environmental Management Acts that are designed to be implemented to protect a specific aspect of the environment e.g. the National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) and the National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008).
Act	National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) (ICM Act)	The ICM Act was promulgated to establish a system of integrated coastal and estuarine management in the Republic, including norms, standards and policies, in order to promote the conservation of the coastal environment, and maintain the natural attributes of coastal landscapes and seascapes, and to ensure that development and the use of natural resources within the coastal zone is socially and economically justifiable and ecologically sustainable. It also defines rights and duties in relation to coastal areas; determines the responsibilities of organs of state

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		in relation to coastal areas; prohibits incineration at sea; controls dumping at sea, pollution in the coastal zone, inappropriate development of the coastal environment and other adverse effects on the coastal environment; and gives effect to South Africa's international obligations in relation to coastal matters. Chapter 4 of the ICM Act deals with estuarine management; with section 33 providing for the publication of a NEMP and Section 34 stipulating the need for EMPs to be developed. Additional provisions of the ICM Act applicable to estuarine management (and which impacts SANParks' management strategy of estuaries) relate to the coastal zone (which includes Coastal Public Property and the Coastal Protection Zone) (Chapter 2), determination of boundaries of coastal areas, including Coastal Management Lines (Chapter 3), protection of coastal resources (which includes coastal leases and environmental authorisations) (Chapter 7), marine and coastal pollution control (which includes discharges into estuaries) (Chapter 8), and miscellaneous matters (specifically existing leases on and rights to coastal public property, unlawful structures on coastal public property and existing lawful activities in coastal zone) (Chapter 12).
Act	National Water Act, 1998 (Act No. 36 of 1998) (NWA)	Fundamental principles of the NWA is recognition of the basic human needs of present and future generations, the need to protect water resources, the need to share some water resources with other countries, and the need to promote social and economic development through the use of water. Additionally, sustainability and equity are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources. Objectives of the NWA include ensuring the protection of South Africa's water resources (i.e. the aquatic ecosystems, including estuaries) by establishing ecological water requirements as well as measures to ensure that these base flows are retained. It also deals with activities and water uses that may negatively impact stream-flow and water quality. The NWA requires that estuaries are assigned a "class" using a gazetted classification process, aimed at determining the amount of abstraction or

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		protection a river would be assigned. For systems that have yet to be classified, the environmental reserve is determined on the basis of recommendations emanating from a reserve determination study using the Resource Directed Measures methodology in conjunction with considerations of the demand for water in the catchment (the classification process described above will effectively standardise the way this is done). In the absence of reserve determination studies for individual estuaries, the ecological state of South Africa's estuaries was predicted at a desktop level as part of the estuary component of the 2018 National Biodiversity Assessment. The ICM Act, however, provides for the authorisation of discharge of effluent into coastal waters via a coastal waters discharge permit but such permit is required to be issued in consultation with the Minister responsible for Water Affairs in respect to estuarine discharges. , Proper management of the fresh water inflow and knowledge of the ecological water requirements of the estuary is needed to maintain the ecological integrity of estuaries. Ongoing engagement between SANParks and the Department responsible for Water Affairs is therefore crucial to ensure that the estuary maintains a healthy ecological state.
Act	National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) (NEM: PAA)	The NEM: PAA provides for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes; for the establishment of a national register of all national, provincial and local protected areas; for the management of those areas in accordance with national norms and standards; for intergovernmental co-operation and public consultation in matters concerning protected areas. Chapter 4 of the NEM: PAA sets out the management requirements for protected areas and includes the development and subsequent periodic review of management plans. The object of a management plan is to ensure the protection, conservation and management of the protected area; which includes estuaries within those protected areas. The Act also requires that marine and terrestrial protected areas with common boundaries must be managed as an integrated protected area by a single management authority.

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		As this is the primary legislation governing the protected areas managed by SANParks, estuary management principles and management interventions must be in accordance with the provisions of the NEM: PAA.
Act	National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) (NEM: BA)	The NEM: BA provides for the conservation of biological diversity. It requires identification of important landscapes, ecosystems, ecological process and species for biodiversity conservation, and promotes monitoring of these. It also provides for the proclamation of protected areas, recognising South Africa's obligations to international conventions. Estuaries are important fish nursery areas and provide a source of food for many fish and migratory bird species. They also provide a source of food and recreation for people and must therefore be managed in accordance with the provisions of the NEM: BA.
Act	Marine Living Resources Act, 1998 (Act No. 18 of 1998) (MLRA)	The MLRA provides for the conservation of the marine ecosystem (which includes estuaries), the long-term sustainable utilisation of marine living resources and the orderly access to exploitation, utilisation and protection of certain marine living resources; and for these purposes to provide for the exercise of control over marine living resources in a fair and equitable manner to the benefit of all the citizens of South Africa. The MLRA defines the species that can be exploited, and protection measures for those species, such as closed areas, closed seasons and size and bag limits. Various types of resource-use permit systems are also defined under this Act.
Act	National Heritage Resources Act, 1999 (Act No. 25 of 1999) (NHRA)	The NHRA introduces an integrated and interactive system for the management of national heritage resources (which include landscapes and natural features of cultural significance). One of the important elements of the Act is that it provides the opportunity for communities to participate in the identification, conservation and management of cultural resources. The NHRA requires that, in areas where there has not yet been a systematic survey to identify conservation-worthy places, a permit is required to alter or demolish any structure older than 60 years. This will apply until a survey has been done and identified heritage resources are formally protected. Anyone who intends

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		to undertake a development must notify the heritage resources authority and if there is reason to believe that heritage resources will be affected, an impact assessment report must be compiled at the developer's cost. Thus, developers will be able to proceed without uncertainty about whether work will have to be stopped if a heritage resource is discovered.
Act	Sea Fishery Act, 1988 (Act No. 12 of 1988)	This act includes estuaries and the estuary bed and has been used to proclaim marine reserves along certain sections of our coast. Collection of shell and shell-grit is regulated under this Act.
Act	National Ports Act, 2005 (Act No. 12 of 2005)	The National Ports Act provides for the establishment of the National Ports Authority and the Ports Regulator; the administration of certain ports by the National Ports Authority; and for matters connected therewith. The Knysna Estuary is a national port and is subject to this legislation.
Act	Disaster Management Act, 2002 (Act No. 57 of 2002) (DMA)	The DMA aims to provide an integrated and co-ordinated disaster management policy with a focus on the prevention and reduction of the risk of disasters, the mitigation of severity of disasters, emergency preparedness, as well as a rapid and effective response to disasters and post-disaster recovery. The Act provides for the establishment of national, provincial and municipal disaster management centres as well as disaster management volunteers to assist metropolitan or district municipalities. At the local level, the Act prescribes that each metropolitan and each district municipality establish a disaster management framework in consultation with local municipalities aimed at ensuring an integrated and uniform approach to disaster management. Each metropolitan and each district municipality must also establish a disaster management centre for its municipal area which, must educate and promote formal and informal prevention, mitigation and response initiatives to encourage risk-avoidance behaviour in all spheres of government, non-governmental organisations and community based organisations. In addition, each municipal entity in the respective framework, must prepare a disaster management plan that must be incorporated into the municipal integrated development plan. With an emphasis prevention and mitigation, the disaster management plan must, *inter alia*: • Identify potential risks in the municipal area;

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		• Identify areas and groups of people at risk to disasters; • Have contingency and mitigation measures in place to reduce the effects of disasters on these areas and groups both before and after disasters; and • Provide for the allocation of responsibilities to various role players and co-ordination of carrying out those responsibilities.
Act	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA)	The MPRDA makes provision for equitable access to and sustainable development of the nation's mineral and petroleum resources. The MPRDA affirms the State's obligation to protect the environment for the benefit of present and future generations, to ensure ecologically sustainable development of mineral and petroleum resources and to promote economic and social development. Chapter 4 of the Act deals with Environmental Management principles as set out in section 2 of the NEMA. The MPRDA requires Environmental Management Programmes that identify a mine's impact on the environment and provide a clear programme on how these will be managed, based on an EIA to be developed. The Act also stipulates that the holder of a right or permit is responsible for any environmental damage, pollution or ecological degradation resulting within or outside the boundaries from the mining activity. To ensure compliance with environmental issues, the MPRDA requires consultation with each department charged with administration of any law that relates to any matter affecting the environment before an EMP may be approved.
Act	National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) (NEM: WA)	The NEM: WA aims to reform the laws regulating waste management to protect health as well as the environment by providing reasonable measures for: pollution prevention, ecological degradation and to secure ecologically sustainable development. The NEM: WA provides for: • institutional arrangements and planning matters; • national norms and standards for regulating the management of waste by all spheres of government; • specific waste management measures; • the licensing and control of waste management activities; • the national waste information system; • compliance and enforcement. The NEM: WA covers a broad range of waste issues ranging from sustainable use of natural resources to pollution prevention, with the following objectives:

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		• to protect health, well-being and the environment by providing reasonable measures for the following: • minimising natural resource use; • avoiding/minimising accumulation of waste; • reducing, reusing, recycling and recovering waste; • treating and safely disposing of waste (as a last resort); • preventing pollution and ecological degradation; • securing ecological sustainable development while promoting justifiable economic and social development; • promoting and ensuring waste service delivery; and • remediating land where contamination presents, or may present, significant risk to health/environment. • ensuring people are aware of impacts of their waste on their health and the environment; and • ensure compliance with the aforementioned points.
Act	National Forests Act, 1998 (Act No. 84 of 1998) (NFA)	The NFA recognises that natural forests and woodlands form an important part of the environment, and need to be conserved and developed according to the principles of sustainable management. A "Natural forest" is defined as any group of indigenous trees whose crowns are largely contiguous and applies to riparian vegetation in the Cape Floristic Region. A licence is required to disturb natural forests.
Act	Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983) (CARA)	The objects of CARA is to provide for the conservation of the natural agricultural resources of South Africa by the maintenance of the production potential of land; the combating and prevention of erosion and weakening or destruction of the water sources (including estuaries); and the protection of the vegetation and the combating of weeds and invader plants.
Act	National Health Act, 2004 (Act No. 61 of 2004) (NHA)	While the Department of Health is the lead agent for the NHA, the implementation of this act is delegated to the local municipal and provincial authorities. Every metropolitan and district municipality must ensure that appropriate municipal health services are effectively and equitably provided in their respective areas. These include (insofar as it influences human health, except in ports): • water quality monitoring;

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		• waste management; and • environmental pollution control.
Act	Water Services Act, 1997 (Act No. 108 of 1997)	The main aspects of the Water Services Act, relevant to infrastructure development, are to provide for: right of access to basic water supply and basic sanitation necessary to secure sufficient water and an environment not harmful to human health or well-being; management and control of water services, in general, including water supply and sanitation; and preparation and adoption of Water Services Development Plans (refer to Section 13 of Act) by water services authorities that should form part of Integrated Development Plans (IDPs).
Act	National Veld and Forest Fire Act, 1998 (Act No. 101 of 1998)	The National Veld and Forest Fire Act intends to reform the law on veld and forest fires to prevent and combat veld, forest and mountain fires. It also provides for the establishment of fire protection associations and the establishment of firebreaks.
Act	Environmental Conservation Act, 1989 (Act No. 73 of 1989) (ECA)	Although many of the provisions of this Act have been repealed by NEMA, the Regulations in terms of the ECA regulating the Outeniqua and Sensitive Coastal Area (OSCA) remain in force until replaced by new regulations.
Act	Spatial Planning and Land Use Management Act, 2013 (Act No. 16 of 2013)	The primary aim of the SPLUMA, insofar as it relates to estuarine management, is for the provision of a framework for spatial planning and land use management as well as to: • Provide for monitoring, coordination and review of spatial planning and land use management systems; • Provide for inclusive, developmental, equitable and efficient spatial planning at different spheres of government; • Provide a framework for policies, principles, norms and standards; • Address past spatial and regulatory imbalances; • Promote greater consistency and uniformity in the application procedures and decision-making processes by local authorities responsible for land use decisions and development applications; • Provide for establishment, functions and operation of Municipal Planning Tribunals; and Provide for facilitation and enforcement of land use and development measures.
Act	Mountain Catchment Areas Act, 1970 (Act No. 63 of 1970)	The Mountain Catchment Areas Act was promulgated to provide for the conservation, use, management and control of land situated in mountain catchment areas, and to provide for matters incidental thereto. This includes fire

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		protection plans and the establishment of fire protection committees.
Programme	National Coastal Management Programme (NCMP)	South Africa's National Coastal Management Programme (NCMP) was released in 2014, and provides the direction and guidance towards a structured and standardised approach to coastal management in South Africa, including an appropriate cooperative governance framework (DEA, 2014). It is strongly founded on the initial precepts of the White Paper (DEAT, 2000) such that the vision and principles of integrated coastal management are the same, and the national mandate, in terms of the ICM Act. The National CMP was developed using a framework of key components of an integrated CMP, where nine key priorities for coastal management were determined (DEA, 2014). These priorities, together with the Vision, function as the pillars of this primary policy directive on coastal management for South Africa. Each is bolstered by a primary goal, specific management objectives, actions and performance indicators to give direction for planning implementation. Collectively, these elements constitute national government's commitment to implementing the ICM Act for a five-year period (2013-2017). Integrating management in estuaries is among these priorities (Priority 3) and the overarching goal echoes that of the ICM Act. The National CMP concludes with a process towards implementation that provides the template for Implementation Plans that should developed up for each individual action. A second generation National CMP is currently being developed which will replace the 2014 National CMP and provide updated objectives and priorities.
Plan	Garden Route National Park (GRNP) Management Plan	The GRNP is a complex of protected areas managed as a single entity, SANParks. The management area includes the previously proclaimed Tsitsikamma and Wilderness National Parks, state forests and mountain catchment areas and the Knysna National Lake Area. The area is zoned and programmes outlined for identified objectives, with actions, indicators and responsibilities. Management of the Marine and Estuarine environments have been highlighted in the GRNP with programmes developed for each outlining management interventions and strategies planned for the Park.

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		The Knysna Estuary has multiple zonations and overlays applied. This is discussed in more detail under zonation.
Protocol	National Estuarine Management Protocol (NEMP)	The NEMP, promulgated in 2013 and amended in 2021, provides the national policy for estuary management and guides the development of individual EMPs. In so doing, it stipulates the minimum requirements for the content of an EMP, prescribes the procedures to be followed in developing an EMP and any potential institutional arrangements. Importantly, the NEMP provides clarity as to which authorities are responsible for the development, coordination, and implementation of an EMP. Where an estuary is within a protected area or is identified as part of a protected area expansion strategy, the management authority responsible for the protected area must develop an EMP in consultation with relevant government departments. Where there is an estuary, which crossed the boundary of a protected area, the protected area management authority must work together with other relevant government departments or agencies to develop a coordinated estuarine management plan. Strategic objectives for effective integrated management of estuaries as outlined in the NEMP include the following: • To conserve, manage and enhance sustainable economic and social use without compromising the ecological integrity and functioning of estuarine ecosystems; • To maintain and/or restore the ecological integrity of South African estuaries by ensuring that the ecological interactions between adjacent estuaries, between estuaries and their catchments, and between estuaries and other ecosystems, are maintained; • To manage estuaries co-operatively through relevant organs of state across all spheres of government; and to engage the private sector and civil society in estuarine management; • To protect a representative sample of estuaries (such protection could range from partial protection to full protection) in order to achieve overall estuarine conservation targets as determined by the NBA of 2011 and the subsequent updates;

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		• To generate awareness, education and training that relate to the importance and value of South African estuaries; and • To minimize the potential detrimental impacts of predicted climate changes through a precautionary approach to development in and around estuaries and with regard to the utilization of estuarine habitat and resources. The following management standards are prescribed under the NEMP: • An estuary must be managed according to the allocated management class and the set of both resource quality and quantity attributes as prescribed in terms of the NWA. In the absence of the allocated class, an estuary must be managed in its current state and/ or improved state in order to achieve national biodiversity targets as outlined in the most recent National Biodiversity Assessment and the subsequent updates. The assessment includes a list of national priority estuaries, their current health; recommended extent of protection and degree of undeveloped margins; • An estuary must be managed to avoid, minimize or mitigate significant negative impacts that include but are not limited to reduced water flows and loss of habitat or species. This will require the participation of Departments responsible for utilization of estuarine resources; • Promoting the integration of land use planning and natural resource management outcomes with estuarine management outcomes; • Management actions should be based on sound scientific evidence and, where lacking, the precautionary approach should prevail; and • The adoption of risk management approaches to address issues such climate change and associated impacts, must be promoted. An EMP must be in line with the National CMP, and where applicable, the Provincial CMP and the Municipal CMP. Where the estuary is located in a protected area, the estuarine management plan must be developed in line with the requirements for the protected area's management plan.
Framework	National Biodiversity Framework (NBF)	The NBF is a requirement under Section 38 of the NEM: BAA. Its purpose is to coordinate and align the efforts of the many organizations and individuals involved in conserving and managing South Africa's biodiversity in support of sustainable development. The NBF must provide for an integrated, co-ordinated and consistent

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		approach to biodiversity management; identify priority areas for conservation action, and for the establishment of protected areas and reflect regional cooperation issues concerning biodiversity management in southern Africa. Informants to the NBF include the National Biodiversity Strategy and Action Plan, the National Biodiversity Assessment and the National Protected Areas Expansion Strategy.

Table 24: Provincial legislation, plans and policies applicable to the Knysna Estuary and its catchment

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
Act	Western Cape Housing Development Act, 1999 (Act No. 6 of 1999)	The Western Cape Housing Development Act determines general principles applicable to housing in the province of the Western Cape and defines the role of the provincial and local spheres of government in housing development. It also needs to ensure that housing development is integrated with all other facets of development in a holistic way.
Act	Western Cape Planning and Development Act, 1999 (Act No. 7 of 1999)	This Act lays down guidelines for the future spatial development in the Western Cape Province in such a way as will most effectively promote the order of the area as well as the general welfare of the community concerned.
Act	Western Cape Land Use Planning Act, 2014 (Act No. 3 of 2014) (LUPA)	The development objectives entrenched in SPLUMA have been assimilated into the LUPA, which in turn sets out a framework for the adjudication of land use planning applications in the Province and requires that local municipalities have due regard to at least the following when doing so: Applicable spatial development frameworks; Applicable structure plans; Land use planning principles referred to in Chapter VI (Section 59); Desirability of the proposed land use; and Guidelines that may be issued by the Provincial Minister regarding the desirability of proposed land use.
Ordinance	Nature and Environmental Conservation Ordinance, 1974 (Ordinance No. 19 of 1974)	CapeNature is the lead agent for Nature and Environmental Conservation Ordinance.
Ordinance	Land Use Planning Ordinance, 1985 (Ordinance No. 15 of 1985) (LUPO)	LUPO provides for decision-making regarding land use and planning issues, including applications for rezoning, sub-division and the amendment of relevant structure and/or spatial plans promulgated in terms of LUPO.
Framework	Western Cape Provincial Spatial	The WCPSDF is pitched at a very broad level, encapsulated in the vision "a

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
	Development Framework (WCPSDF)	home for all in the Western Cape". While the WCPSDF serves primarily as a provincial planning framework for guiding environmentally sustainable development and use of natural resources whilst promoting socio-economic development, it reports and defines policy statements on, *inter alia*, the state of inland waters as well as oceans and coasts within the Province.
Programme	Western Cape Provincial Coastal Management Programme	The 2016 Western Cape CMP is a transversal initiative which needs to be implemented through partnerships between all sectors and spheres of government and other stakeholders. It focuses on growing the blue and green economy through unlocking the economic potential of the Western Cape's coastal assets. It aims to enable a resilient, sustainable, quality and inclusive living environment through improved coastal spatial and development planning, access, protection and Local Government support. Estuary Management is one of the Priority Areas of the CMP, which aims for a "co-ordinated and integrated estuarine management which optimises the ecological, social and economic value of these systems on an equitable and sustainable basis".
Plan	Western Cape Provincial Biodiversity Spatial Plan	The 2010 Western Cape Biodiversity Framework, including subsequent updates integrates all existing biodiversity planning products for the Western Cape into a common, user-friendly framework to guide land-use decision-making. Importantly, it provided a clear indication of all CBAs and Ecological Support Areas (ESAs) identified across the province, covering both the terrestrial and freshwater realms, as well as major coastal and estuarine habitats. These areas require safeguarding as they are crucial for conserving a representative sample of biodiversity and maintaining ecosystem functioning. ESAs, while not essential for meeting biodiversity targets, play an important role in supporting the ecological functioning of CBAs and/or in delivering ecosystem services.

Table 25: Municipal legislation, plans, frameworks and policies applicable to the Knysna Estuary and its catchment

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
Act	Local Government: Municipal Systems Act, 2000 (Act No. 32 of 2000) (Municipal Systems Act)	The Municipal Systems Act (Chapter 5) deals with Integrated Development Planning (which municipalities are obliged to prepare and to update regularly). An IDP is intended to encompass and harmonise planning over a range of sectors such as water, transport, land use and environmental management. It

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
		requires each local authority to adopt a single, inclusive plan for the development of the municipality which: • Links, integrates and coordinates plans and take into account proposals for the development of the municipality • Aligns the resources and capacity of the municipality with the implementation of the plan • Forms the policy framework and general basis on which annual budgets must be based • Is compatible with national and provincial development plans and planning requirements that are binding on the municipality in terms of legislation.
Programme	Garden Route District Municipality Coastal Management Programme	The Garden Route Municipality CMP was developed in accordance with the requirements of the ICM Act. The vision for the Garden Route's coastal zone is included as "*The coastal zone is the Garden Route's most significant asset and must be nurtured through innovative and integrated cooperative management interventions that will ensure both the environmentally sustainable functioning and enhancement of the natural systems, while optimising economic and social benefits, protecting the diverse cultural heritage, maintaining its unique sense-of-place, increasing awareness through education and ensuring the spiritual well-being of all its users*".
Plan	Garden Route District Municipality Integrated Development Plan	The Garden Route IDP advocates the conservation of the environment, natural resources, biodiversity, CBAs and ecosystem services. The IDP clearly reflects the importance of the municipal areas pristine natural assets, which are seen as key to security in the future of the region, as they add to the identity and aesthetic appeal of the region and are large contributors to tourism. Accordingly, protection of the environment features in the first and fourth key strategic objectives.
Policy	Integrated Garden Route Environmental Policy (IGREP)	The IGREP is adopted in 2009, along with its implementation strategy, the Garden Route Environmental Management and Development Framework (GREMDF). The GREMDF requires that the Garden Route develops detailed sectoral strategies to meet the commitments made in the sectoral approaches by giving effect to the environmental principles in IGREP. During the IGREP development process six priority strategies were identified, of which five have been developed
Plan	Garden Route District Municipality Climate	As part of the Climate Change Municipal Support Programme, the Garden

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
	Change Adaptation Plan	Route District Municipality Climate Change Adaptation Plan (Eden DM, 2014) aims to create an enabling environment which will support a district-wide and a coordinated response to climate change in the Garden Route District. Through a series of workshops, the key vulnerabilities, impacts and strategies to address these vulnerabilities and impacts were identified. The plan acknowledges that rivers and estuaries are areas which pose serious disaster risk, particularly in the face of climate change. Furthermore, coastal areas were identified as one of several priority areas for intervention strategies. The key outcomes of the plan include current and proposed climate adaptation interventions identified by each local municipality.
Plan	Knysna Local Municipality Integrated Development Plan	Knysna's IDP for the five-year period 2017-2022 seeks to integrate and balance the economic, ecological and social pillars of sustainability without compromising the institutional capacity required to implement and coordinate the efforts needed across sectors and relevant spheres of government. The IDP includes strategic objectives, including the ideal of promoting a safe and healthy environment through the protection of natural resources. The Municipality acknowledges that Knysna is situated within an ecologically sensitive area, within a proclaimed National Park, with anthropogenic impacts and potential pollution of greatest concern and of key importance. Identified causes include: • Informal settlement areas having limited or no access to adequate toilet and waste water disposal systems; • Leaks and blockages in sewer infrastructure- or sewer pipes are often in close proximity to stormwater pipes; • Private septic tank units leaking or not operating effectively; • Operational failure and constraints at waste water treatment plants; • Illicit disposal of chemicals in stormwater system or natural watercourses; and • Leaks and contamination from industrial and business activities. The IDP highlights the role played by the Municipality in the development of the Eden District Coastal Management Programme.
Framework	Knysna Local Municipality Spatial	The Knysna Spatial Development Framework (SDF) forms part of the

Legislation type	Name	Description and applicability to SANParks' Estuary Management Plans
	Development Framework	municipality's over-arching Integrated Spatial Development Framework (ISDF). The ISDF represents a spatial structuring of Knysna that supports the development plans outlined in the IDP, and incorporates past and present Plans and Frameworks including the Integrated Human Settlement Plan, draft 2016 SDF, Environmental Plan and the Economic Development Strategy. The SDF states that Knysna Municipality's greatest strength is its natural resource base, as it is endowed with a wide variety of unique natural systems and resources, and that rivers, estuaries and vleis are among the most significant of these. Significant destruction of key natural resources is noted, from a variety of causes, and cites as an example the extinction of one type of indigenous vegetation, and the near-extinction of five others, because of urban development on the islands of the Knysna River estuary. It concludes that the value of the natural environment and the current pattern of development have implications for the way in which the municipality should guide growth trends in the future if its most valuable assets are to be retained. Both the Knysna IDP and SDF lay claim to the fact that they cohere with all relevant regional planning and strategies, including the Western Cape Provincial Growth and Development Strategy (iKapa Elihlumayo) and the WCPSDF.

9. RECOMMENDATIONS TO ADDRESS MAJOR INFORMATION GAPS

Past research in Knysna has centred almost exclusively on environmental studies of estuarine biota and processes, leaving a gap in 'transdisciplinary research'. That said, a bathymetric survey of the Knysna Estuary to access the extent and spatial distribution of sediment movement and settlement, along with an assessment of the likely origin of sediments would be beneficial. Implementation of the reserve with disclosure of water use licences issued, levels of compliance, and how this relates to the gazetted reserve for freshwater inflows to the estuarine environment is needed.

Proposed habitat reserves should be compared to, *inter alia*; invertebrate and macrophyte distribution and avifauna presence within the estuary to ensure representative areas are protected. The option of making habitat reserves no access areas (to prevent trampling of submerged macrophytes, to prevent illegal harvesting next to fishing locations, to reduce disturbance of avifauna) need to be assessed, taking into account current areas where bait harvesting occurs.

In environmental science and policy, it has become the norm to acknowledging an inevitable coupling of natural and social systems, as opposed to viewing nature as separate from people. For the Knysna Estuary, nature and society are indeed intertwined into one complex social-ecological system, characterised by sometimes uncertain feedback processes between various components of the system. The overall behaviour of such systems cannot be understood by only studying its constituent parts or any subsystem (nature or society) in isolation from the other. While considerable research effort has been directed to Knysna Estuary, it is striking that this research has centered almost entirely on estuarine biota and processes. Such knowledge are important building blocks for understanding the estuary. However, to improve understanding of the dynamics of the whole system, and effectively inform management decisions, disciplinary research should be complemented with interdisciplinary (studies that draw on and integrate knowledge from across social and natural scientific disciplines) and/or transdisciplinary (studies that incorporate local and practice-based knowledge and involve non-academic stakeholders in a process of co-learning) research. There is little evidence of such system-wide social-ecological research for the Knysna Estuary, at least in the formal scientific literature. A slight exception is past work on ecosystem services (see Section 4). A useful place to start is to better understand the range of ecosystem services (tangible and intangible) derived from the Knysna Estuary, who the beneficiaries are, how services are mobilised and appropriated, and where possible thresholds and conflicts might arise.

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Appendix 1. Fish species recorded in the Knysna Estuary during formal monitoring programmes. Estuary category refers to estuarine guilds (Whitfield 2019).

FAMILY	SPECIES	COMMON NAME	ESTUARY CATEGORY	RELEVANT LITERATURE
SPARIDAE	*Cheimerius nufar*	Santer	a	DEFF; Whitfield 2019
	Diplodus cervinus	Zebra seabream	b	DEFF; Grindley 1985; Whitfield 2019
	Diplodus capensis	Blacktail seabream	b	Pollard *et al* 2017; Whitfield 2019
	Lithognathus lithognathus	White Steenbras	c	DEFF; Grindley 1985; Le Quesne 2000; Whitfield 2019
	Lithognathus mormyrus	Sand steenbras	c	DEFF; Grindley 1985; Whitfield 2019
	Rhabdosargus globiceps	White stumpnose	c	DEFF; Grindley 1985; James and Harrison 2009; Whitfield 2019
	Rhabdosargus holubi	Cape stumpnose	c	DEFF; Grindley 1985; Pollard *et al* 2017; James and Harrison 2009; Le Quesne 2000; Whitfield 2019
	Rhabdosargus sarba	Tropical (Natal) stumpnose	c	Grindley 1985; Whitfield 2019
	Sarpa salpa	Strepie	b	DEFF; Grindley 1985; Pollard *et al* 2017; James and Harrison 2009; Whitfield 2019
	Spondyliosoma emarginatum	Steentjie	c	DEFF; Grindley 1985; Whitfield 2019
MUGILIDAE	*Liza richardsonii*	Southern mullet	b	Pollard *et al* 2017; James and Harrison 2009; Grindley 1985; Le Quesne 2000; Whitfield 2019
	Chelon dumerili	Groovy mullet	c	DEFF; Pollard *et al* 2017; Grindley 1985; Le Quesne 2000; Whitfield 2019
	Mugil cephalus	Flathead mullet	c	DEFF; Pollard *et al* 2017; Grindley 1985; Le Quesne 2000; Whitfield 2019

FAMILY	SPECIES	COMMON NAME	ESTUARY CATEGORY	RELEVANT LITERATURE
	Liza tricuspidens	Striped mullet	b	DEFF; Grindley 1985; Whitfield 2019
	Pseudomyxus capensis	Freshwater mullet	c	DEFF; Whitfield 2019
CLUPEIDAE	*Gilchristella aestuaria*	Estuarine roundherring	d	James and Harrison 2009; Le Quesne 2000; Whitfield 2019
	Sardinops sagax	South African Pilchard	a	DEFF; Whitfield 2019
	Etrumeus whiteheadi	Redeye roundherring	a	DEFF; Le Quesne 2000; Whitfield 2019
ATHERINIDAE	*Atherina breviceps*	Cape silverside	e	DEFF; Grindley 1985; Le Quesne 2000; Whitfield 2019
HAEMULIDAE	*Pomadasys commersonnii*	Spotted grunter	c	DEFF; Grindley 1985; James and Harrison 2009; Le Quesne 2000; Whitfield 2019
	Pomadasys olivaceum	Piggy	c	DEFF; Whitfield 2019
GOBIIDAE	*Caffrogobius natalensis*	Baldy	e	James and Harrison 2009; Whitfield 2019
	Psammogobius knysnaensis	Speckled sandgoby	e	DEFF; Grindley 1985; James and Harrison 2009; Le Quesne 2000; Whitfield 2019
	Glossogobius callidus	River goby	f	DEFF; Whitfield 2019
	Redigobius dewaalii	Checked goby	f	DEFF; Le Quesne 2000
GOBIESOCIDAE	*Apletodon pellegrini*	Chubby clingfish	b	DEFF; Grindley 1985
HEMIRAMPHIDAE	*Hemiramphus far*	Spotted halfbeak	b	DEFF; Grindley 1985; James and Harrison 2009; Le Quesne 2000; Whitfield 2019
	Hyporhamphus capensis	Cape halfbeak	d	DEFF; Le Quesne 2000; Whitfield 2019
SYNGNATHIDAE	*Hippocampus capensis*	Knysna seahorse	d	DEFF; Grindley 1985; Le Quesne 2000; de Villiers *et al* 2019; Whitfield 2019

FAMILY	SPECIES	COMMON NAME	ESTUARY CATEGORY	RELEVANT LITERATURE
	Syngnathus temminckii	Longsnout pipefish	e	DEFF; Whitfield 2019
	Hippichthys spicifer	Bellybarred pipefish	e	Grindley 1985; Whitfield 2019
CARANGIDAE	*Lichia amia*	Leervis/Garrick	c	DEFF; Grindley 1985; Le Quesne 2000; Whitfield 2019
	Trachurus capensis	Cape horse mackerel	a	DEFF
	Caranx heberi	Blacktip kingfish	a	DEFF ; Whitfield 2019
SOLEIDAE	*Solea turbynei*	Blackhand sole	c	DEFF; Whitfield 2019
	Heteromycteris capensis	Cape sole	c	DEFF; Whitfield 2019
	Synapturichthys kleinii	Lace sole	b	Grindley 1985
CLINIDAE	*Clinus superciliosus*	Super klipfish	e	DEFF; Grindley 1985; Whitfield 2019
TETRAODONTIDAE	*Amblyrhynchotes honckenii*	Evileye pufferfish	b	DEFF; Le Quesne 2000; Whitfield 2019
	Lagocephalus laevigatus	Smooth pufferfish	b	Grindley 1985
TRIGLIDAE	*Chelidonichthys capensis*	Cape gurnard	b	DEFF
	Chelidonichthys kumu	Bluefin gurnard	b	Grindley 1985
MONODACTYLIDAE	*Monodactylus falciformis*	Oval moony	c	DEFF; Grindley 1985; Le Quesne 2000; Whitfield 2019
POMATOMIDAE	*Pomatomus saltatrix*	Elf/Shad	b	DEFF; Grindley 1985; Le Quesne 2000; Whitfield 2019
DASYATIDAE	*Dasyatis chrysonota*	Blue stingray	a	DEFF; Whitfield 2019
	Dasyatis pastinaca	Common stingray	a	Grindley 1985
BLENNIDAE	*Omobranchus woodi*	Kappie blenny	e	DEFF; Grindley 1985; Whitfield 2019
DASYATIDAE	*Gymnura natalensis*	Backwater butterflyray	a	DEFF; Grindley 1985; Whitfield 2019
ENGRAULIDAE	*Engraulis japonicus*	Japanese anchovy	a	DEFF

FAMILY	SPECIES	COMMON NAME	ESTUARY CATEGORY	RELEVANT LITERATURE
	Engraulis capensis	South African anchovy	a	Grindley 1985; Whitfield 2019
FISTULARIIDAE	*Fistularia commersonii*	Smooth flutemouth	a	DEFF; Whitfield 2019
OSTRACIIDAE	*Ostracion cubicus*	Yellow boxfish	a	DEFF
ARIDDAE	*Galeichthys feliceps*	White seacatfish	b	DEFF; Le Quesne 2000; Whitfield 2019
SCIAENIDAE	*Argyrosomus japonicus*	Dusky kob	c	DEFF; Grindley 1985; Whitfield 2019
	Umbrina canariensis	Canary drum/ the baardman	a	Grindley 1985
MYLIOBATIDAE	*Myliobatis aquila*	Eagleray	b	DEFF; Grindley 1985; Whitfield 2019
	Aetomylaeus bovinus	Bull ray	a	DEFF
CENTRARCHIDAE	*Lepomis macrochirus*	Bluegill	i	DEFF; Whitfield 2019
ODONTASPIDIDAE	*Carcharias taurus*	Spotted ragged tooth shark	a	Grindley 1985; Whitfield 2019
SCYLIORHINIDAE	*Poroderma africanum*	pyjama shark	a	Grindley 1985
RHINOBATIDAE	*Acroteriobatus annulatus*	Lesser guitarfish	a	Grindley 1985; Whitfield 2019
GYMNURIDAE	*Gymnura natalensis*	Diamond butterfly ray	a	DEFF; Grindley 1985; Whitfield 2019
TORPEDINIDAE	*Torpedo fuscomaculata*	Blackspotted torpedo elctric ray	b	Grindley 1985; Whitfield 2019
ELOPIDAE	*Elops machnata*	Ladyfish	c	Grindley 1985; Whitfield 2019
SYNODONTIDAE	*Trachinocephalus myops*	Painted lizardfish	c	Grindley 1985
TERAPONTIDAE	*Terapon jarbua*	Thornfish	c	Grindley 1985; Whitfield 2019
SERRANIDAE	*Serranus cabrilla*	Comber	a	Grindley 1985
DICHISTIIDAE	*Dichistius capensis*	Galjoen	a	Grindley 1985
ANGUILLIDAE	*Anguilla mossambica*	Longfin eel	h	Grindley 1985; Whitfield 2019
OPHICHTHIDAE	*Ophisurus serpens*	Sand snake eel	b	Grindley 1985; Whitfield 2019

FAMILY	SPECIES	COMMON NAME	ESTUARY CATEGORY	RELEVANT LITERATURE
CONGRIDAE	*Conger wilsoni*	Cape Conger eel	b	Grindley 1985
DIODONTIDAE	*Diodon hystrix*	Spotted Porcupine fish	b	Grindley 1985
POECILIIDAE	*Gambusia affinis*	Mosquito fish	f	Le Quesne 2000; Whitfield 2019