EXPERIMENTAL ECOSYSTEM ACCOUNTS FOR SOUTH AFRICA'S ESTUARIES

Extent, Condition and Ecosystem Services Accounts

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Front cover: Historic breaching of Bot/Kleinmond mouth - Jean Tresfon

PREFACE

Natural Capital Accounting (NCA) is a growing field of work globally and in South Africa. It includes accounting for environmental assets such as water, minerals and energy, with an international standard, the System of Environmental-Economic Accounting (SEEA), in place for these accounts. A more recent aspect of NCA is ecosystem accounting, which focuses on accounting for ecosystem assets and ecosystem services.

South Africa has a relatively long history of producing natural capital accounts. Since 2014, Statistics South Africa (Stats SA) has been co-leading projects with South African National Biodiversity Institute (SANBI) on ecosystem accounting as a subset of natural capital accounting. Stats SA and SANBI have collaborated with the Department of Environment, Forestry and Fisheries (DEFF), in consultation with a range of national and sub-national stakeholders, on piloting SEEA Experimental Ecosystem Accounting. These projects have contributed to global experimentation and learning around ecosystem accounting, informing global guidelines. Advances in ecosystem accounting in South Africa will assist entities investing in ecological infrastructure, as well as entities that have a direct impact on the state of ecological infrastructure. In this project, the Council for Scientific and Industrial Research (CSIR) has worked with SANBI and Stats SA, in partnership with the departments responsible for environment, water and fisheries, to take this project forward.

However, thus far the South African initiative has not included estuaries. Estuaries constitute highly diverse habitats in the coastal space providing disproportionally high socio-economic benefits to society per unit area compared to other natural systems (e.g. nursery areas for important fisheries, carbon sequestration). Estuaries, thus, form part of the set of small high-value ecosystem types (< 5% of South Africa's territory) that function as critical ecological infrastructure that should be prioritised for planning, management and protection. Indeed, so critically important are these sensitive ecosystems that South Africa's National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICM Act) explicitly distinguishes estuaries as being unique ecosystems of exceptional value warranting dedicated management protocols and planning processes. Stemming from their disproportionally high socio-economic value, it is critical to prepare their ecosystem accounts separate and not aggregate these systems within larger freshwater or marine ecosystem accounts – running the risk of grossly under-valuating, or masking, their ecosystem service benefits to society.

It is within this context that the CSIR, in collaboration with DEFF and the Nelson Mandela University (NMU), undertook this research to develop ecosystem accounting methodologies for South Africa's estuaries and to prepare the first extent, condition and ecosystem services accounts for this often over-looked ecosystem realm. The study largely made use of available country-level information generated as part of the recently completed National Biodiversity Assessment 2018. The work was undertaken in consultation with SANBI and Stats SA through a range of interactive workshops and reviews, including presenting preliminary results (e.g. National Estuarine Condition Index findings) for discussion at the first Natural Capital Accounting Forum hosted by Stats SA in 2019.

This report is published as a discussion document to contribute to advancing the knowledge on NCA through application in a developing country context. It is envisaged that the research findings presented here will be used for, and enriched by, further engagement with global and local Natural Capital Accounting processes (e.g. development of South African Oceans Accounts). The authors thus welcome engagement on the outcomes.

The project was funded through the CSIR Parliamentary Grant from the Department of Science and Technology (South Africa) that supports research pertaining to sustainable development and governance of natural resources (research in support of a capable state).

KEY FINDINGS: ECOSYSTEM ACCOUNTS FOR SOUTH AFRICA'S ESTUARIES

- *South Africa's estuarine estate comprises 200,730 ha with most of this situated in the Subtropical biogeographical region (55%) followed by the Warm Temperate (22%), Cool Temperate (19%) and Tropical biogeographical (4%) regions.*
- *In 2018, the total the aquatic habitat (open water area) comprised 58,994 ha (29% of the total estuarine area), while floodplain habitat comprised 141,742 ha (71%). The total biotic habitat area (represented by a subset of important estuarine vegetation types) amounted to 39,772 ha. Salt marsh habitats (supratidal -4,979 ha, subtidal -568 ha) have been severely reduced, and nearly 300 ha of mangrove habitat also has been lost. Mangrove loss, however, has been offset by the establishment of new mangrove area in the uMhlathuze and Richards Bay estuaries to the extent that overall national mangrove habitat has increased by 97 ha.*
- *The National Estuarine Ecosystem Condition Index, providing a high-level overview of the condition of the national estuarine resource, is estimated at 63.7 (out of 100) indicating a severe decline in overall estuary condition. A comparison of the condition of South Africa's estuaries from natural (~1750) to 2018, showed a significant decline with only 21% of the country's systems still in a natural state and 40% in a near-natural state. Nearly 7% of estuaries were severely/critically modified. Even more concerning, is that by area only 23% is in a natural/near-natural state and 63% is in a heavily modified state or worse.*
- *Ecosystem service accounts showed the overall decline in condition has resulted in a concomitant decline societal benefits derived from South Africa's estuaries. There has been a nett loss of 1,365,323 Mg (Megagram) in 'blue' carbon sequestration potential (a regulating service) owing to a decline in the extent and condition of the estuarine biotic habitat*
- *The nursery function for important fisheries (a provisioning service) has been highly compromised. Remaining productive nursery area (represented by natural to moderately modified systems) is estimated at between 22 % (for Dusky kob) and 56% (Elf) of natural functionality, with 70 to 94% of important nursery areas also being overfished.*
- *Habitat and refugia (a supporting service) for rare and endangered endemic estuarine species (Botriver klipvis, Knysna seahorse, Estuarine pipefish and Sawfish) showed a decline in the overall number of estuaries that support these species, with Estuarine pipefish now occurring in only three out of five systems and Sawfish extinct from South Africa. Reduction in freshwater flow and declining estuary condition also plays a role in increased vulnerability of these culturally significant species.*
- *Considering the direct pressures on estuaries, high water resource use has reduced freshwater flows to estuaries by about 12,000 million m^3 per annum, with only 67% of natural flows remaining. Land-use within estuarine functional zones (EFZs) has contributed significantly to estuary degradation, with 29% of EFZ area already subjected to severe land-use pressure. Over 3,730 tons of fish are caught annually, with 21% of estuaries subjected to high or very high fishing pressure. It is estimated that about 840 million m^3 of wastewater is discharged daily to estuaries directly affecting 42 systems, with 11% severely impacted. Artificial breaching of estuary mouths is practised in at least 45 estuaries, affecting more than 60% of the total estuarine extent.*
- *Biological invasion pressures (an indirect pressure) on estuaries also have increased. A third of the country's systems have invasive terrestrial plants occurring within the EFZ, and 10% of the nation's estuaries are under severe pressure. Aquatic invasive plant species occur in 8% of estuaries, while alien and extralimital (translocated) fish species is present in 25% of estuaries.*

EXECUTIVE SUMMARY

Approach and Methods

The framework is informed by international guidelines (e.g. as provided by the United Nations Statistics Division (UNSD)) as well as experiential knowledge from the project team which has extensive scientific expertise on estuarine ecosystem functioning, management and policy analysis, as well as development planning relating to estuaries. This phase of the study focuses on developing an approach and methodology for the preparation of **ecosystem extent and condition accounts**. Although it explores physical accounting linked to **ecosystem services flows and benefits**, the intension is to further develop these in the next phase of this study.

Unless otherwise indicated, the **opening stock** in the estuarine accounts is an estimate of **natural conditions (~1750),** while the **closing stock** in these accounts reflects the situation in **2018**.

*The **Estuary Functional Zone** (EFZ) is defined as the area that not only covers the estuary water body, but also areas that support physical and biological processes and habitats necessary for estuarine function and condition. The latter includes areas influenced by long-term estuarine sedimentary processes (i.e. sediment stored or eroded during floods), changes in channel configuration, aeolian transport processes, and changes due to coastal storms. The EFZ also encompasses flood plain ecotones and estuarine vegetation that contribute detritus to the base of the estuarine food chain and provide refuge to estuarine biota during high flow events from strong currents.*

This assessment focuses on the 290 estuarine systems, as defined in South Africa's National Biodiversity Assessment of 2018 (hereafter referred to as NBA 2018). Individual estuaries are delineated by the **Estuary Functional Zone (EFZ)** which serves as the primary unit of assessment within the ecosystem accounting area. This represents the Ecosystem Accounting Area for the estuarine ecosystem accounts in South Africa.

Extent of South African Estuaries

South Africa's estuarine estate covers some 200,730 ha. More than half of South Africa's estuarine area is in the Subtropical region (55%) followed by the Warm Temperate (22%), Cool Temperate (19%) and the Tropical biogeographical (4%) regions. Estuarine Lakes comprise 56% of estuarine extent, while Predominantly Open estuaries comprise about 20%. Estuarine Bays and Lagoons make up less than 3% of total extent, with Large Temporarily Closed and Fluvially Dominated types comprise about 8% and 7%, respectively. Small Temporarily Closed systems only comprise about 2% of the total extent, while Arid Predominantly Closed and Small Fluvially Dominated estuaries contribute less than 1% to total extent. Overall, estuary size varies greatly with the Greater St Lucia/uMfolozi Lake system (in the Subtropical biogeographical region) representing more than half of South Africa's estuarine surface area, while more than 70% of estuaries are less than 50 ha in size.

Comparing the change in the extent of South African estuaries from the opening stock (~1750) to the closing stock (2018) accounts (expressed in terms of the 'number of estuaries') revealed an increase from 289 to 290 systems. This change occurred in the Subtropical biogeographical region where, in the 1970s, an estuarine lake (uMhlathuze) was subdivided into an estuarine bay (Richards Bay Estuary) and a predominantly open system (uMhlathuze Sanctuary) to facilitate commercial port development. Although the total EFZ area of estuaries remained the same, this modification did result in a redistribution of EFZ area among estuary functional types.

South Africa has incomplete data to populate opening (natural) accounts for abiotic habitat. Therefore, only the closing (2018) account is populated as a baseline for future habitat accounting. In 2018, the total aquatic habitat (open water area) comprised 58,994 ha (29% of EFZ extent), while floodplain habitat comprised 141,742 ha (71% of EFZ extent). The extent account for biotic habitat (as represented by key estuarine vegetation types) amounted to 39,772 ha. The greatest loss in biotic habitat occurred in supratidal salt marsh habitats (supratidal -4,979 ha and subtidal -568 ha) as a result of urban development and agricultural land-use. Although the area covered by mangroves in South Africa is small, they form an important ecological component providing numerous ecosystem services. It is estimated that nearly 300 ha of mangrove habitat has been lost over time due to development, resource utilisation, grazing and changes in mouth condition. However significant new mangrove habitat has established in the uMhlathuze and Richards Bay estuaries as a result if increased tidal fluctuation caused by port development in the 1970s. So significant is this increase in new mangrove area that overall national mangrove habitat has increased by 97 ha. Submerged macrophyte coverage declined by 180 ha as a result of declining water quality.

Condition of South African Estuaries

This report refers to three different indexes that are used at various levels of aggregation, namely:

ESTUARY ECOSYSTEM CONDITION INDICATORS: *Abiotic (4) and biotic (5) indicators which are used to express the condition of individual estuaries and which serves as input data for the Estuary Health Index. These indicators can also be aggregated at various scales to evaluate change in abiotic and biotic processes and patterns.*

ESTUARY HEALTH INDEX: *Applied to individual estuaries to determine their conditions based on an aggregation of the individual Estuary Ecosystem Condition Indicators. This index is used extensively in environmental flow requirements and biodiversity assessments. Serves as the primary data set by which condition status of estuaries (290) can be aggregated at biogeographical regions, functional types or any other measure of choice.*

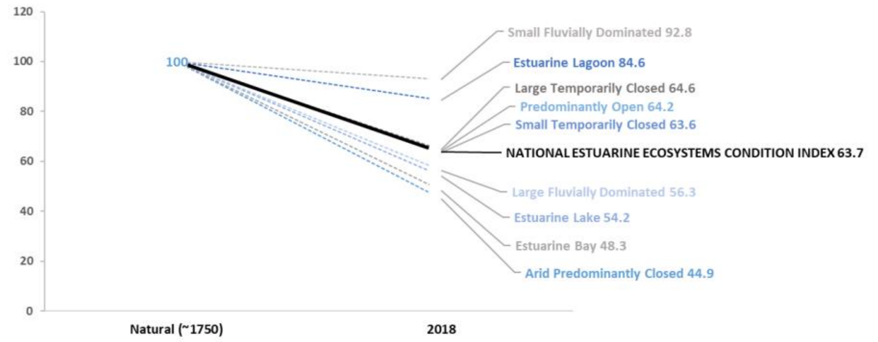
NATIONAL ESTUARINE ECOSYSTEM CONDITION INDEX*: An index that provides a high-level overview of the condition of South Africa's estuaries, comprising a single value that is derived from the aggregation of the Estuary Health Index condition values of all estuaries (290). National Ecosystem Condition Indexes monitor change at the realm level – rivers, estuaries, marine.*

The condition of all 290 estuaries, determined using the Estuary Health Index, served as the primary data source for the condition accounts in this report. The Estuarine Health Index reflects change as a percentage similarity (0 – 100%) to a defined natural state which is calculated for both abiotic and biotic condition indicators using various data and information sources. Ratings for Estuary Ecosystem Condition Indicators are weighted (25% for each abiotic and 20% for each biotic indicator) and aggregated (50:50) to provide an overall percentage deviation from natural.

These percentage values are translated into six ecological condition categories, ranging from natural (A) to critically modified (F). For ecosystem accounting purposes, categories E and F were aggregated, resulting in five ecological condition categories, ranging from a natural to severely/critically modified state. These categories also represent declining functionality in process and pattern, from natural to little remaining.

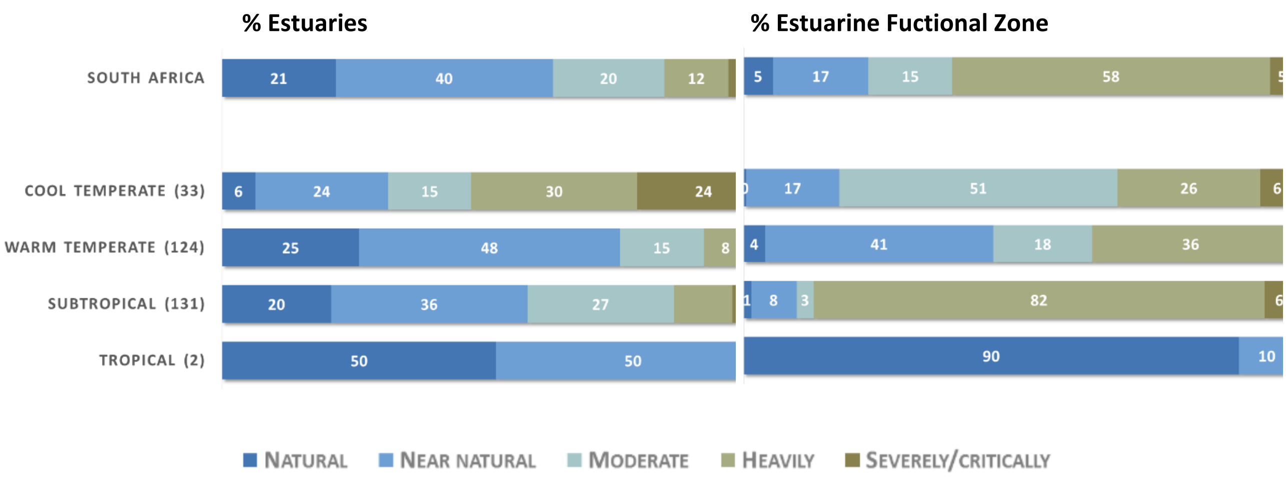
The **National Estuarine Ecosystem Condition Index, providing a high-level overview of the condition, is estimated to be 63.7** (out of 100), with Arid Predominantly Closed systems (only 45% of processes and functioning intact) contributing the most to decline in condition and Small Fluvially Dominated systems (93% largely natural) the least.

Condition accounts of South Africa's estuaries showed a significant decline with only 21% of the country's systems still in a natural state, 40% in a near-natural state, 20% in a moderately modified state, 12% in a heavily modified state, and 7% in a severely/ critically modified state. More concerning, is that in area only 23% of the estuarine estate remains in a natural/near-natural state with 63% already in a heavily modified state or worse.



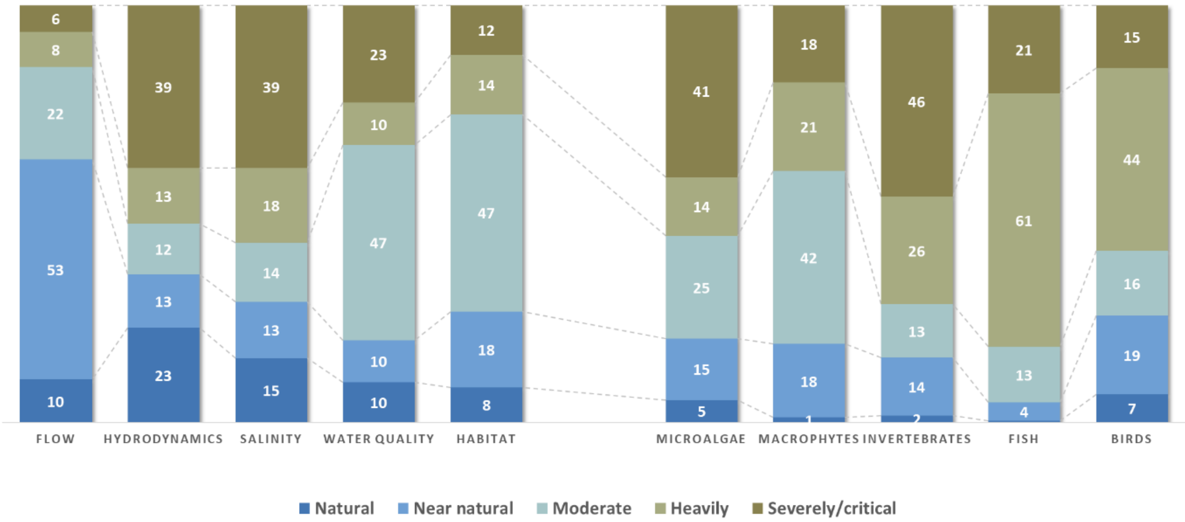
National Estuarine Ecosystem Condition Index agregated from the nine estuary functional types (arithmetic mean)

Systems remaining in natural and near-natural conditions were mainly located in the Warm Temperate (73% of systems in the region) and Subtropical (50% of systems in the region) regions, while the estuaries in the Cool Temperate region were most heavily to severely/critically modified (55% of systems in the region).



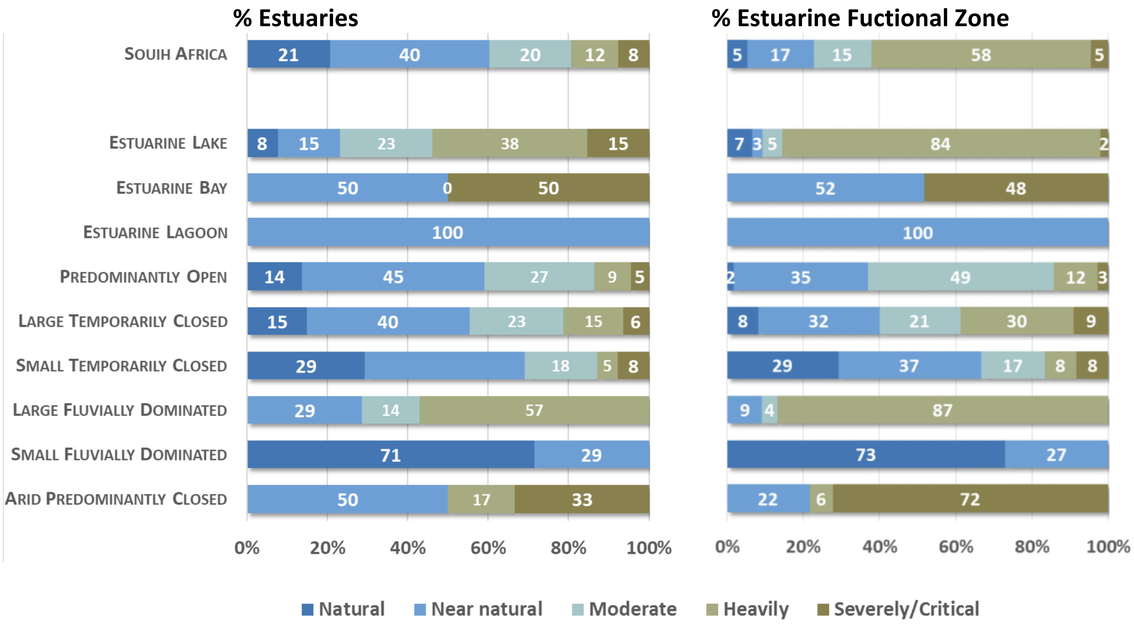
Relative distribution of estuary condition across biogeographical regions (2018) - expressed as percentage estuaries in a region (left) and a percentage of total EFZ area in a region (right)

However, when the condition is expressed in terms of 'percentage EFZ area', only 5% still remain in natural, and 17% in near-natural states mostly located in the Warm Temperate and Tropical regions. More than 58% of EFZ is already in a heavily modified state (partly an artefact of the largest estuary in South Africa, the St Lucia /uMfolozi system, falling within this category), and an additional 5% critically modified. The difference in 'number of estuaries' and 'EFZ area', indicates that smaller estuaries tend to be in better condition, not subject to the same level of human pressures as the larger, more productive systems. Typically, larger estuaries are more heavily affected by catchment and direct exploitation and/or development pressures, resulting in their overall poorer condition. However, larger systems are more resilient to human pressures than smaller systems.



The overall distribution of condition across abiotic and biotic ecosystem indicators in South African estuaries (2018) (expressed as a percentage of EFZ area)

Expressing condition in term of specific **Ecosystem Condition Indicators**, results show that the **hydrology** in 63% of systems (using total EFZ area as a measure) remains in a relatively good condition (natural/near-natural state). In contrast, the only 36% of EFZ area is still in good condition measured in term **hydrodynamics**, primarily due to artificial mouth manipulation. Condition in terms of **salinity** and **water quality** also decreased markedly from natural (~1750) to 2018, with only 28% and 20% respectively, remaining in good condition, primarily associated with flow modifications and pollution. Similarly, **physical habitat** (benthic substrate) has been markedly modified with only 26% of EFZ area still in a good condition, mostly as a result of alterations in flood regimes and inappropriate land-use in the EFZ. Interestingly, the condition of biotic indicators also tends to gradually decrease along the trophic scale, from **microalgae** (20%), to **macrophytes** (19%), through to **invertebrates** (16%), and ultimately to the **fish** (4%) components. This suggests the cumulative effects of human pressures along trophic levels. In contrast, **birds** show less of a decline, with 26% still in good condition, highlighting the robustness of bird communities to anthropogenic pressures.

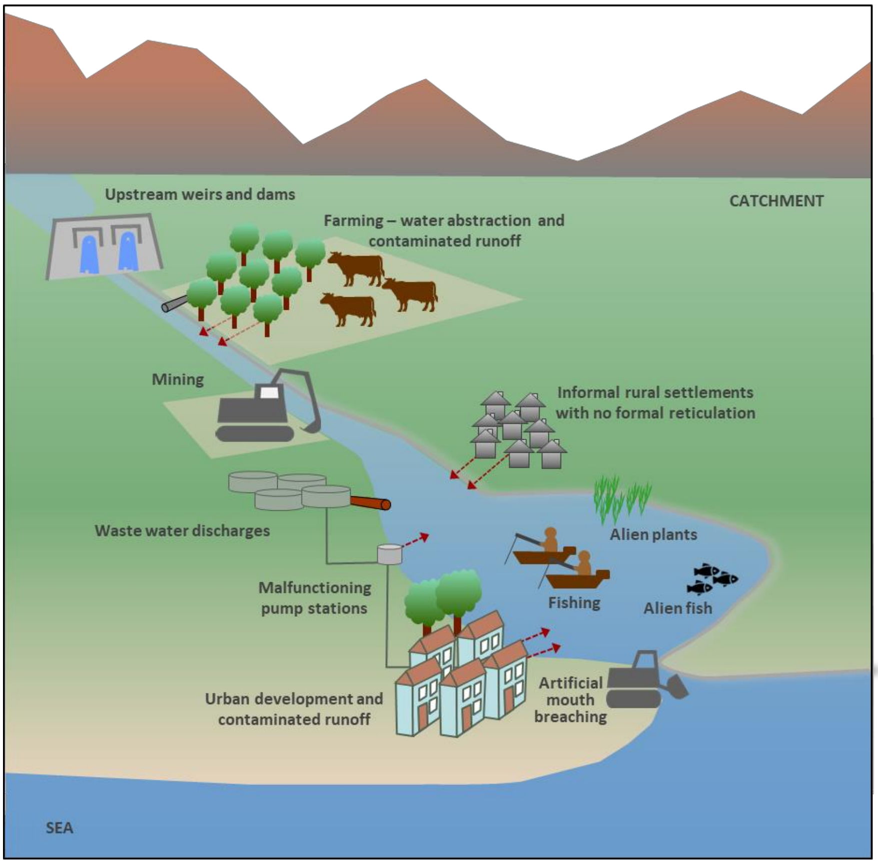


Comparison of estuarine condition across ecosystem types (2018) expressed as a percentage of estuaries per functional type (left) and a percentage of total EFZ area per functional type (right)

Comparing change in condition from natural (~1750) to 2018 across **estuary functional types**, four types (Estuarine Bays, Estuarine Lagoons, Large Fluvially Dominated and Arid predominantly closed estuaries) no longer exist in a natural state. Only two estuary functional types (Estuarine Lagoons and Small Fluvially Dominated estuaries) remain fully in natural or near-natural states, while 66% and 52% of EFZ area, respectively associated with Small Temporarily Closed and Estuarine Bay systems remain in natural or near-natural condition. Predominantly Open estuaries are largely moderately modified (49% of EFZ area), with another 12% being heavily modified. Especially of concern are Estuarine Lakes, where only 10% of the EFZ area remains in natural or near-natural condition. Eighty-four (84) % of Estuarine Lake area has already been heavily modified and another 2% severely/critically modified.

Large Fluvially Dominated systems are 87% heavily modified, with Arid predominantly closed systems also showing a bleak picture, with 72% being severely/critically modified. Thus, proportionally Estuarine bays, Estuarine lakes, Large Fluvially Dominated and Arid predominantly closed systems are in the worst condition with 53%, 50%, 57% and 50% of systems being in heavily to critically modified states, respectively. Proportionally, Large and Small temporarily closed systems, and Small Fluvially Dominated systems remain in relatively good condition, with 55%, 69% and 100% still remaining in natural/near-natural condition, respectively.

Pressures on South African Estuaries



To secure optimum use of estuarine resources in a changing world, it is important to understand the extent of anthropogenic pressures on estuaries and concomitant response in the condition of these systems, also referred to as 'ecosystem disservices' (information captured in the pressure accounts should also be used to inform the development of 'Ecosystem Services Supply and Use' accounts for estuaries). Direct anthropogenic (human) pressures on estuaries can be grouped into six categories, namely water resource use, land-use, exploitation of living resources, pollution and artificial breaching (manipulation of estuary mouths). Pressures were rated from 'low' to 'very high' depending on the magnitude of the pressure and the degree of impact it was having on the resource, with 'low' pressure ratings associated with processes and/or biota remaining in a largely natural state and 'very high' associated with severely or critically modified processes and/or biotic responses.

By 2018, **water resource use** had reduced freshwater flows to estuaries by about 12,000 million m^3 per annum, with only about 67% of natural flows remaining (i.e. 24,800 million m^3 per annum). Nationally, this pressure is ranked 'very high' in 24 systems (9%), 'high' in another 31 systems (11%) and 'medium' in 40 systems (14%). Land-use within EFZs has contributed significantly to deterioration in estuaries. Only 28 estuaries can be considered to be in a near-pristine state. Overall, 29% of South African estuaries are subject to severe (high and very high) pressure from **land-use**. Over 3,730 tonnes of fish are caught annually, with 21% of estuaries subjected to high or very high **fishing pressure**. It is estimated that about 840 million cubic meters of **wastewater** are being discharged daily into 42 systems country-wide, either directly into estuaries, or to river reaches just upstream of estuaries. Effluent is mostly derived from municipal wastewater treatment works (WWTW). Nationally, the deterioration of estuarine water quality, associated with wastewater discharges, is ranked as 'high to 'very high' in at least 11% of estuaries, mainly those in and around the large urban centres. **Artificial breaching** of estuary mouths is practised in at least 45 systems nationally. Although this amounts to only 15% of the total number of estuaries along the coast, the affected systems represent more than 60% of the total national estuarine habitat.

Biological invasions, considered an indirect pressure on estuaries, include **invasive plants** and **alien/extralimital (translocated) fish.** A third of estuaries have **invasive terrestrial plants** occurring within the EFZ, and 10% of the nation's estuaries experience a high degree of impact. Aquatic invasive plant species occur in 8% of estuaries. **Alien and extralimital (translocated) fish** occur in 25 % of South Africa's estuaries, of which 6% and 14% are experiencing severe (high to very high) impact from this pressure, respectively.

Insights into Estuarine Ecosystem Services

For this study, three important ecosystem service accounts were also considered, namely carbon sequestration, nursery function for important estuarine and marine fisheries, and habitat and refugia for rare endemic estuarine species. Due to a decline in overall estuary condition, there has been a concomitant decline in the benefits society derive from them. For example, there has been a **nett loss of 1,365,323 Mg in 'blue' carbon sequestration potential** of South Africa's estuaries as a result of the ongoing decline in habitat extent and condition, specifically salt marsh habitat.
This is based on internationally derived values of soil carbon content and does not include values for 'teal' carbon as captured in swamp forest. These accounts will need updating once better local estimates of soil carbon content are available. The development of a national **carbon sequestration** account will support initiatives on developing opportunities for Blue Carbon trading and Ecosystem-based Adaptation (EbA) interventions moving forward.

The ability of South Africa's estuaries to support provisioning services such as nursery function for estuarine and marine fish of economic importance has been severely reduced. This is influence by biogeographical range contraction of White steenbras and expansion in the case of Spotted grunter, driven by a combination of overfishing and climate change. Nursery function for selected estuarine-dependent species is supported by between 52 and 88 estuaries, with Elf being the most restricted and Mullet the least selective in critical nursery areas. Historically, key estuaries along the west coast would have also contributed extensively to nursery function for Steenbras, but as a result of excessive fishing pressure and population collapse, only Langbaan Estuarine Lagoon still has a viable biomass of White steenbras (loss provision services in five estuaries). In contrast, as a result of climate change, Grunter occurs in more estuaries (+8) that provide nursery function for this important estuarine fisheries species. Freshwater recruitment signals that assist fish with locating and recruiting into estuaries, using mean unusual runoff (MAR) still reaching estuaries as a proxy, showed that key nurseries have lost between 49% (Leervis and Elf) and 20% (Grunter) of their recruitment signal; with Steenbras recruitment signal declining by about 46%, and Dusky kob and Mulllet recruitment signal declining by about 35% and 34% respectively. The remaining extent of highly productive key nursery estuaries capable of supporting fisheries (remain in a natural to moderately modified state) varies between 22% to 32% for Dusky kob, Grunter and Mullet, and between 79% to 84% for Steenbras, Elf and Leervis. As a final measure, the percentage EFZ areas of important nursery estuaries under high to very high fishing pressure was also calculated. In most cases, 70% to 91% of key nurseries are overfished thus reducing overall productivity. Spawner biomass per recruit (SBPR % of pristine in the absence of fishing), a measure of breeding potential that represents the ability of a stock to recover, is critically low at < 2% and 6% for Dusky kob and White steenbras respectively. Leervis spawner biomass per recruit is estimated at 14%, Grunter at < 25%, Elf < 25% and harder (Southern Mullet) 24%, all indicating a collapsed state. Southern Mullet is the directed catch of the commercial and small-scale beach-seine and gillnet fisheries in the sea and important to the livelihoods of most coastal communities on the West Coast. The status of these resources is a global concern with Dusky kob listed as critically endangered, White steenbras as endangered, and Grunter, Leervis and Elf as vulnerable on the IUCN Red List.

The supporting services account dealing with habitat and refugia for rare endemic estuarine species found no change in ranges or geographical distributions of three of the iconic fish species dealt with for this study. However, Sawfish that used to occur in the Subtropical and Tropical biogeographical region are extinct from South Africa and no longer occurring in these regions or anywhere else along the coast. Overall, the populations of rare endemic estuarine species were supported by a few (2-7) key estuaries. By way of example, historically the Estuarine Pipefish occurred in five systems while in 2018 it is only documented in three. Historically the core distribution of Sawfish also used to be supported by only four estuarine systems. Floods and synchronised estuary mouth opening play an important role in ensuring genetic exchange between these isolated communities. Using MAR still reaching estuaries as a proxy, the account indicated that opportunities for genetic exchange have declined by 21% for Botriver klipvis; 15% for Knysna seahorse and about 18% for Estuarine pipefish. Ironically marine estuarine connectivity (mouth status) largely remains still similar to reference for systems that used to be important for Sawfish. Botriver klipvis; Knysna seahorse and Estuarine pipefish are all small-bodied species and therefore are not impacted by standard fishing activity. However, gillnet fisheries (mostly illegal) have decimated South Africa's population of sawfish. The vulnerability of these severely restricted communities to changes in estuary condition is reflected in their IUCN Red Listing; the threat status of Botriver klipvis and Knysna seahorse is endangered and Estuarine Pipefish critically endangered. Sawfish are extinct from South Africa.

Ecosystem Accounting in Support of Estuary Management

This ecosystem accounting exercise on South Africa's estuaries highlighted the ongoing, national-level decline in the condition of these valuable natural systems. Strategic interventions across multiple sectors are required to not only conserve, but also to start restoring estuarine condition to protect their benefits to people. To avoid further compromising the benefits derived from estuaries, the NBA 2018 advocated a Strategic Estuarine Management Framework focusing on implementation and compliance across key sectors – including freshwater allocation, fish resource use, water quality management, land-use planning, agriculture and mining. Complex ecosystems, such as estuaries, require an integrated approach to address the ongoing decline in condition. To be effective all management actions and programmes need to be integrated into one coordinated framework with regular feedback to ensure implementation. Estuarine Ecosystems Accounting provides a platform for tracking progress in this regard. Key actions that should be supported and monitored include recommendations to:

- Increase estuarine protection levels and share the benefits of estuarine protected areas equitably among coastal communities through the setting of short- to medium-term targets for Estuarine Protected Areas. Progress can be reflected in a set of focussed Protected Areas Accounts (extent and condition) for estuaries (including Ramsar and Critical Biodiversity Areas). Sub-accounts can be generated for habitat types within protected areas to reflect efforts to increase protection of salt marsh, seagrass and mangrove habitats.
- Several estuarine-dependent fish species are threatened by overfishing, declining water quality, and reduced flows with their concomitant influence on recruitment and marine connectivity. The NBA 2018 recommended that stock/population recovery be facilitated by reducing fishing pressure, increased compliance, ensuring adequate freshwater inflow, decreasing nutrient pollution, managing noise pollution and boating activity. The estuaries ecosystems services accounts and pressure accounts provide the ideal vehicle to report on progress on this cross-sectorial approach in an integrated manner.
- Healthy functional estuaries support the cultural, aesthetic, commercial, recreation and subsistence benefits upon which coastal communities depend. In support of this, the NBA 2018 called for a comprehensive 'Pollution Reduction Strategy' for estuaries, with a focus on reducing impacts from municipal WWTTW, agricultural return

flow and urban stormwater. Thus, in addition to refinements in condition and pressure accounts, progress in this regard can also be captured in restoration accounts or focused industry/sector accounts.

- Similarly, extractive activities that have disproportionally large ecological impacts, such as mining, may need sector-specific sub-accounts (e.g. fraction of sediment extracted to available estuarine and coastal sediment budgets, land-use change [ha]) to reflect on change from an ecosystem perspective vs a sector perspective, i.e. not just accounting of the monetary value or total resource extracted (e.g. tonnage of sand).
- The NBA 2018 highlighted a pressing need for a National Estuary Restoration Programme to halt, and reverse the on-going decline in estuary condition and the wealth of ecosystem benefits derived from them. Such a programme would focus on degraded and novel systems, with an emphasis on the larger systems of high biodiversity importance and the socially important urban systems. The ecosystem extent and condition accounts developed here are seen as a way to report on restoration progress as an increase in habitat and/or estuary condition will be reflected in the proposed estuarine physical accounts. It may even require the development of a more focussed 'Restoration account' to highlight progress in this regard.
- Lastly, it may be of value to develop an account that reflects progress in governance activities that support wise use and protection of estuarine resources, such as: completed ecological water requirements /classification studies, implemented Estuary Management Plans, or progress in long-term monitoring or national survey programmes. This information, in turn, can be fed into national reporting frameworks such as Outcome 10 and global indicators such as the Sustainable Development Goals (SDGs).

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ABBREVIATIONS/TERMINOLOGY

a	annum
ANCA	Advancing Natural Capital Accounting
C	Cool Temperate biogeographical region
CBD	Convention on Biological Diversity
CSIR	Council for Scientific and Industrial Research
d	day
DEA	Department of Environmental Affairs (historical department)
DEFF	Department of Forestry and Fisheries, and the Environment (since 2019)
DWA	Department of Water Affairs (historical department)
DWAF	Department of Water Affairs and Forestry (historical department)
DWS	Department of Water and Sanitation (since 2019)
EEA	Experimental ecosystem accounting
EFZ	Estuary Functional Zone
GDP	Gross Domestic Product
ha	Hectare
ICM	National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008)
ICM Act	National Environmental Management: Integrated Coastal Management Act (2008)
IMO	International Maritime Organisation
m^3	Cubic meters
MAR	Mean Annual Runoff
Mg	Megagram (metric ton)
$Mg\ C\ ha^{-1}$	Megagram of Carbon per hectare
MLRA	Marine Living Resources Act (No. 18 of 1998)
MPA	Marine Protected Area
NBA	National Biodiversity Assessment
NCAVES	Natural Capital Accounting and Valuation of Ecosystem Services
NEMA	National Environmental Management Act (No. 107 of 1998)
NGO	Non-government organisation
NMU	Nelson Mandela University
NWA	National Water Act (No. 36 of 1998)
NWRS	National Water Resources Strategies
S	Subtropical biogeographical region
SA	South Africa
SANBI	South African National Biodiversity Institute
SEEA	System of Environmental-Economic Accounting
SNA	System of National Accounts
Stats SA	Statistics South Africa
t	Tonne (1,000 kilograms)
T	Tropical biogeographical region
Tg	Teragram (1 million metric tonnes)
UN	United Nations
UNEP	United Nations Environmental Programme
UNSD	United Nations Statistics Division

USD/ US$	United States Dollar
W	Warm Temperate biogeographical region
WMA	Water Management Area
WWTW	Wastewater Treatment Works
3	No data available
-	Not applicable
0	Figure too small to publish

1. INTRODUCTION

1.1 Rationale

Natural Capital Accounting (NCA) is a growing field of work globally and in South Africa. It includes accounting for environmental assets such as water, minerals and energy, with an international standard, the System of Environmental-Economic Accounting (SEEA), in place for these accounts. A more recent aspect of NCA is ecosystem accounting, which focuses on accounting for ecosystem assets and ecosystem services.

South Africa has a relatively long history of producing natural capital accounts following the SEEA Central Framework and more recent experience with the SEEA Experimental Ecosystem Accounting (SEEA EEA). Stats SA has produced accounts for water, energy, fisheries and minerals since as early as 2000 (available from the www.statssa.gov.za). Since 2014, Stats SA has also been co-leading projects with SANBI on ecosystem accounting as a subset of natural capital accounting. These projects include implementing a country pilot project on ecosystem accounts as part of a global initiative called Advancing Natural Capital Accounting (ANCA)[1] (2014-2015) (UN 2014a,b) and another called the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) Project[2] that began in 2017 and is scheduled to be completed by June 2020. Stats SA and SANBI have collaborated with the Department of Environment, Forestry, Fisheries and Environment (DEFF), in consultation with a range of national and sub-national stakeholders, on piloting SEEA Experimental Ecosystem Accounting. These projects have contributed to global experimentation and learning around ecosystem accounting, informing global guidelines. The standardised approach being developed in the SEEA EEA will allow for the international comparison of ecosystem-related statistics across different countries as more countries adopt this approach.

South Africa has good foundational data on ecosystems across all realms (e.g. terrestrial, rivers, estuaries and marine), which have enabled the development of a range of ecosystem accounts produced thus far, including for river ecosystems (Nel and Driver 2015) and for terrestrial ecosystems (upcoming Stats SA publication). To date, however, accounts for estuary ecosystems had not been included. Estuaries are nested as a unique sub-system at the interface between marine ecosystems and inland freshwater ecosystems. They constitute highly diverse habitats in the coastal space, providing disproportionally high socio-economic benefits to society per unit area compared to other natural systems (e.g. nursery areas for important fisheries, safe recreational spaces, carbon sequestration). Estuaries therefore, form part of the set of small high-value ecosystem types (<5% of South Africa's territory) that function as critical ecological infrastructure that should be prioritised for planning, management and protection (Skowno et al. 2019). Indeed, so critically important are these sensitive ecosystems that South Africa's National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICM Act) explicitly distinguishes estuaries as being unique ecosystems of exceptional value warranting dedicated management protocols and planning processes. Stemming from estuaries disproportionally high socio-economic value, it is critical to prepare their ecosystem accounts separately and not aggregate these systems within larger freshwater or marine ecosystem accounts. Doing so would run the risk of grossly under-valuating, or masking, their ecosystem service benefits to society.

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[1] In the ANCA Project, South Africa was one of seven pilot countries in this project, which was led by the UNSD in partnership with UN Environment and the Convention on Biodiversity, with funding from the Government of Norway. In this project, Stats SA and SANBI worked in partnership with the CSIR, Ezemvelo KZN Wildlife, DWS and DEA (now DEFF).

[2] The NCAVES project was launched in 2017 by the United Nations Statistics Division (UNSD) and United Nations Environment Programme (UN Environment) with funding from the European Union (EU). South Africa is one of five countries (along with Brazil, China, India and Mexico) participating in this international project, which aims to advance the global knowledge agenda and initiate testing of SEEA Experimental Ecosystem Accounting, which focuses specifically on accounting for ecosystems. In South Africa, the NCAVES project was led jointly by Statistics South Africa (Stats SA) and the South African National Biodiversity Institute (SANBI).

It is within this context that the CSIR, in collaboration with Department of Environment, Forestry and Fisheries (DEFF) and the Nelson Mandela University (NMU), undertook this research to pilot the implementation of ecosystem accounting in the estuarine realm, guided by global SEEA EEA frameworks and drawing on SA's experience of ecosystems accounting in other realms to date.

1.2 Concept of Ecosystem Accounting

Society derives invaluable benefits from ecosystems. In recognition of the strong coupling between human-nature systems the concept of 'ecosystem services' emerged which has become a common lens used in science, management and governance, to explicitly link ecological infrastructure with benefits to societies and economies (Villa et al. 2014; Weber 2014; Badura et al. 2017). In 2012 the United Nations (UN) launched the first international statistical framework for the environment, the System of Environmental-Economic Accounting (SEEA), as a counterpart to the System of National Accounts (SNAs) (UN 2014a).

The SEEA is a framework for capturing and organising information on the environment, including its contribution to socio-economic activities and the impact of socio-economic activities on the environment. The framework is based on internationally agreed accounting concepts in terms of gathering and organising information in a consistent manner that enables integration with socio-economic information such as the SNAs. Most recently the UN introduced Experimental Ecosystem Accounting (EEA) (UN 2014b, UN 2017) that includes the measurement of stocks of ecosystem (or natural capital) assets, its condition, flows of services and goods provided by such assets, and its estimated value to communities, governments and businesses (based on either market transactions or non-market valuation) (Figure 1.1) (UN 2017).

The SEEA EEA therefore envisions the following five ecosystem accounts (UN 2017, Figure 1.1):

1. Ecosystem extent account – physical terms;
2. Ecosystem condition account – physical terms;
3. Ecosystem services supply and use account – physical terms;
4. Ecosystem services supply and use account – monetary terms; and
5. Ecosystem monetary asset accounts – monetary terms.

Ecosystem accounting, a subset of Natural Capital Accounting (Chenoweth et al. 2018), aims to quantify and track changes in ecosystem assets and ecosystem services over time. It is intended to inform a range of policy, planning and decision-making processes relating to the management of ecosystems and the use of ecosystems services, as well as to enable links to be made between the measurement of ecosystems and the measurement of the economy. Ecosystem accounts can support strategic decision making in natural resources management and assist with trade-offs between different ecosystem services, for example in the food-water-energy nexus. Ecosystem accounting can also provide a powerful set of indicators for measuring and reporting on sustainable development and progress in resource protection.

Ecosystem accounting can be applied at different scales for different purposes. For example, at the national and international level, accounts can be used for raising awareness of the benefits derived from natural ecosystems, reporting on Sustainable Development Goals, or setting estuary management priorities. At the provincial or local scales, accounts can be used to inform resource allocation (e.g. freshwater flow or fisheries allocations), progress in restoration projects or to evaluate impacts of policies and programmes at regional levels.

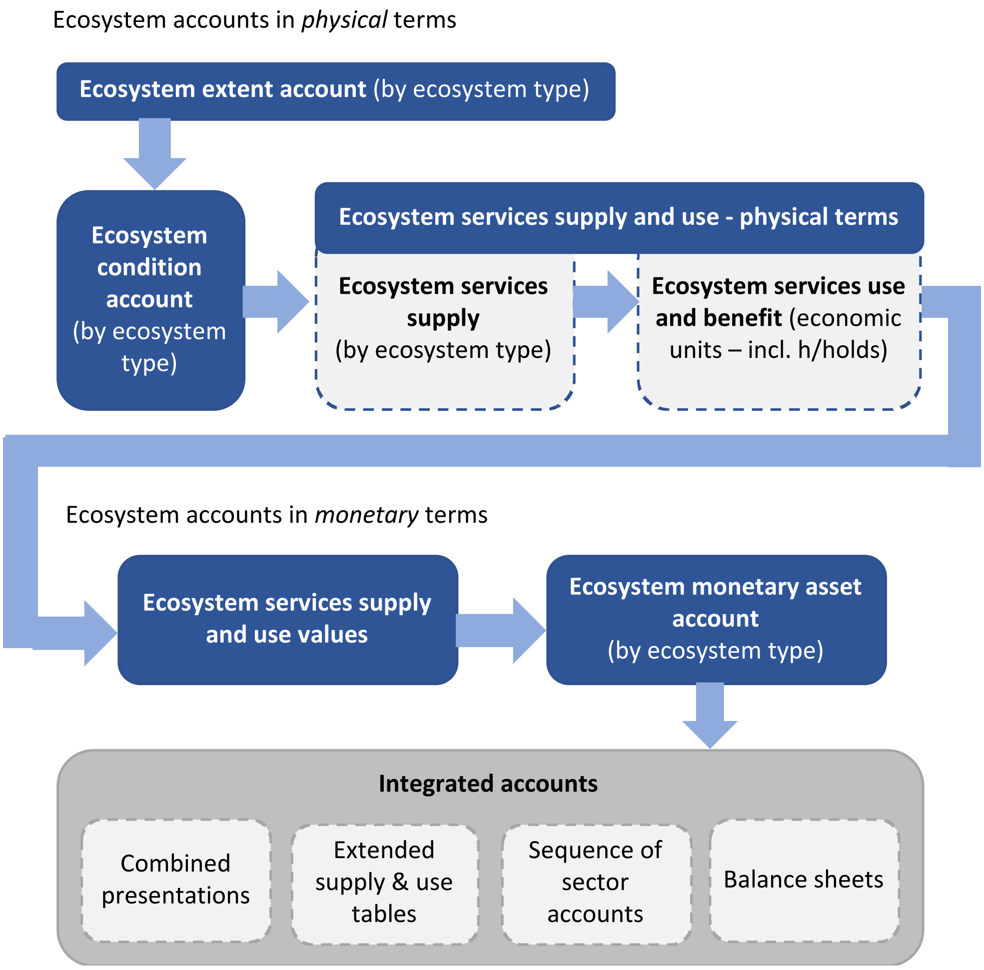


Figure 1.1: ***Five core ecosystem accounts – the ecosystem extent account, the ecosystem condition account, the ecosystem services supply and use accounts in physical and monetary terms, and the ecosystem monetary asset account (Source: UN 2017)***

1.3 Scope of these Accounts

For this work, the geographical area for which the ecosystem accounts for estuaries are compiled (referred to as the ecosystem accounting area (EEA) in SEEA EEA) is the national extent of estuarine ecosystems in South Africa.

The latest delineation of estuarine functional zones identifies 290 estuaries. These serve as the primary spatial ecosystem assessment units for the NBA 2018 and these accounts. South Africa's estuary classification system (revised in 2018; Van Niekerk et al. 2019) groups these estuaries into 22 distinctive estuarine ecosystem types. These ecosystem types nest into four biogeographical regions (also called biogeographical regions) across nine estuary functional types. Micro-estuaries are not addressed in this phase of the study but will be included in later refinements.

For the purposes ecosystem accounting, estuaries are aggregated and reported in terms of both the biogeographical regions (of which there are four) and the estuary functional types[3] (of which there are nine). Both groupings are used in the presentation of the accounts to: 1) reflect the uneven distribution of South Africa's estuarine estate/assets (e.g.

[3] Estuary Functional type refers to a group of similar-type estuaries supporting a characteristic suite of estuarine processes and biodiversity

the Subtropical biogeographical region host more than half of all estuarine area in the country); 2) the different level of resource use in the different climatic regions (e.g. more freshwater abstracted in the arid Cool Temperate region); and 3) the dissimilar levels of resource uses on the estuary functional types (e.g. more fishing occurs in large open types than small closed types).

The accounts produced in this study are all in physical terms, including:

- **Ecosystem extent and condition accounts** for estuaries;
- **Estuarine habitat accounts** (biotic and abiotic habitats being important to the provision of ecosystem services);
- **Ecosystem pressure account** (that considers the change in anthropogenic pressures on estuaries); and
- **Ecosystem service accounts** for three ecosystem services, namely carbon sequestration, nursery function for important estuarine and marine fisheries, and supporting habitat and refugia for rare endemic estuarine species.

Note that statistics on estuaries are sometimes determined as a percentage of their number and sometimes as a percentage of their areal extent. It is important to consider both as they highlight different aspects of information pertinent to South African estuaries. For instance, by number 'more than 60% of South African estuaries are relatively healthy, but this amounts to only 22% of total estuarine extent, consisting mostly of small estuaries' (Van Niekerk et al. 2019).

1.4 Purpose and Intended Users

Within the context of the above, this study aims to **develop and pilot an ecosystem accounting framework for estuaries.** The purpose of this investigation, therefore, is as follows:

- **Develop an approach and methodology** within the SEEA EEA context, specifically focusing on national extent, condition and ecosystem services accounts;
- **Prepare South Africa's first experimental ecosystem accounts for estuaries** to test the methodology;
- **Highlight important data requirements** to be provided by various national departments (e.g. water and sanitation, fisheries, environment) on a 5-yearly basis to enable updates of estuary ecosystems accounts in the future; and
- **Recommend future refinements and further developments** of estuarine ecosystem accounting.

The framework is informed by international guidelines (e.g. as provided by the United Nations Statistics Division (UNSD)), as well as experiential knowledge from the project team which has extensive scientific knowledge on estuarine ecosystem functioning, management and policy analysis, as well as development planning relating to estuaries.

It is envisaged that estuarine accounting will become valuable to a diversity of environmental management initiatives, such as biodiversity planning, natural resource allocation and rehabilitation/restoration planning through, for example:

- Contributing to expanding the suite of ecosystem accounts produced in South Africa to include ecosystem assets and services across all realms;
- Contribute lessons from this experience into national and global dialogues, particularly those related to refining SEEA EEA guidance;
- Amalgamation into South Africa's Ocean Accounts for Sustainable Development (UN GOAP 2019);
- Assisting with meeting and measuring progress related to the 2020 SDG 15.9 requirement to "integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts";
- Contributing towards the 2030 SDG 17.19 that requires all countries to "develop measurements of progress on sustainable development that complement the gross domestic product and support statistical capacity-building in developing countries"; and

- Making it accessible to policymakers to consider in resource allocation and restoration planning across the national, bioregional, provincial/water management area levels (i.e. presenting complex ecosystem data and information - necessary for such planning - in an easily accessible format comparable with traditional accounting formats. Ecosystem pressure accounts also can serve as proxies where ecological monitoring data on ecosystem condition is lacking, and are also a useful means of reporting on sector-based resource utilisation (e.g. water, fisheries) and associated societal benefits.

2. BACKGROUND ON SOUTH AFRICA'S ESTUARIES

Estuary ecosystems are complex, dynamic and diverse. The classification and delineation of estuarine ecosystems face a different range of challenges to ecosystems in other realms, such as the terrestrial environment. This section provides the reader with a description of what an estuary is, the classification system used to define them, and a brief overview of their diversity. This provides a foundation for understanding the data and terms used in the accounts for estuaries produced in this report. This section covers:

- Estuarine ecosystems in South Africa (what is an estuary?);
- Classification of estuarine ecosystems (biogeographical regions and functional types);
- Estuarine functional zones (how are estuaries delineated?);
- Estuary ecosystems biodiversity (habitats and species); and
- Estuary Ecosystem Condition.

2.1 Estuarine Ecosystems in South Africa

The NBA 2018 defines an estuary as '*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 formerly 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*' (Van Niekerk et al. 2019). A defining feature of this definition is that complex estuarine abiotic processes distinguish estuaries from other aquatic ecosystem types i.e. restricted tidal action, mixing of fresh and salt water, increased retention and/or increased water levels under closed mouth conditions.

2.2 South Africa's Estuarine Classification System

The NBA 2018 developed a revised classification system for South Africa's 290 estuaries (Van Niekerk et al. 2019a; Van Niekerk et al. 2020a), derived from the interplay between **biogeographical regions** and **estuary functional types,** stemming from the country's diverse climatic, oceanographic and geological drivers.

2.2.1 Biogeographical regions

Historically, the biogeographic distribution of South Africa's estuaries comprised three regions, viz. Cool Temperate, Warm Temperate and Subtropical (Harrison 2002). However, an analysis of species data indicated that there is significant ingress of marine tropical species typical of tropical Mozambique into the estuaries north of Cape Vidal. For this reason, the NBA 2018 subdivided the historical Subtropical region to include a Tropical transition zone to the north of Cape Vidal to reflect the tropical character of these systems. This subdivision essentially includes the uMgobezeleni and Kosi systems as tropical and aligns with the current marine biogeographic distribution that includes the Natal-Delagoa tropical region (Adams et al. 2016; Sink et al. 2019; Van Niekerk et al. 2020a). Based on this revision the four biogeographical regions for estuaries comprise (Figure 2.1):

- Cool Temperate (Orange to Ratel);
- Warm Temperate (Uilkraals to Mendwana);
- Subtropical (Mbashe to St Lucia); and
- Tropical (uMgobezeleni to Kosi).

2.2.2 Estuary functional types

The estuary classification for South African estuaries recognises that these systems may not necessarily have a 'free connection with the sea' but are 'either permanently or periodically open to the sea' (Day 1980; Whitfield 1992, Van Niekerk et al. 2020a). Thus all 'rivers or streams with outlets on the coast' were evaluated and categorised as either 'estuaries' or 'micro-systems', based on an expert panel review of biological (specifically vegetation and fish) information and data sets, as well as anecdotal information (Figure 2.1). The next step was for the 290 estuarine systems to be categorised into nine functional types, namely Estuarine Lake, Estuarine Bay, Estuarine Lagoon, Predominantly Open, Large and Small Temporarily Closed, Large and Small Fluvially Dominated, and Arid Predominantly Closed.

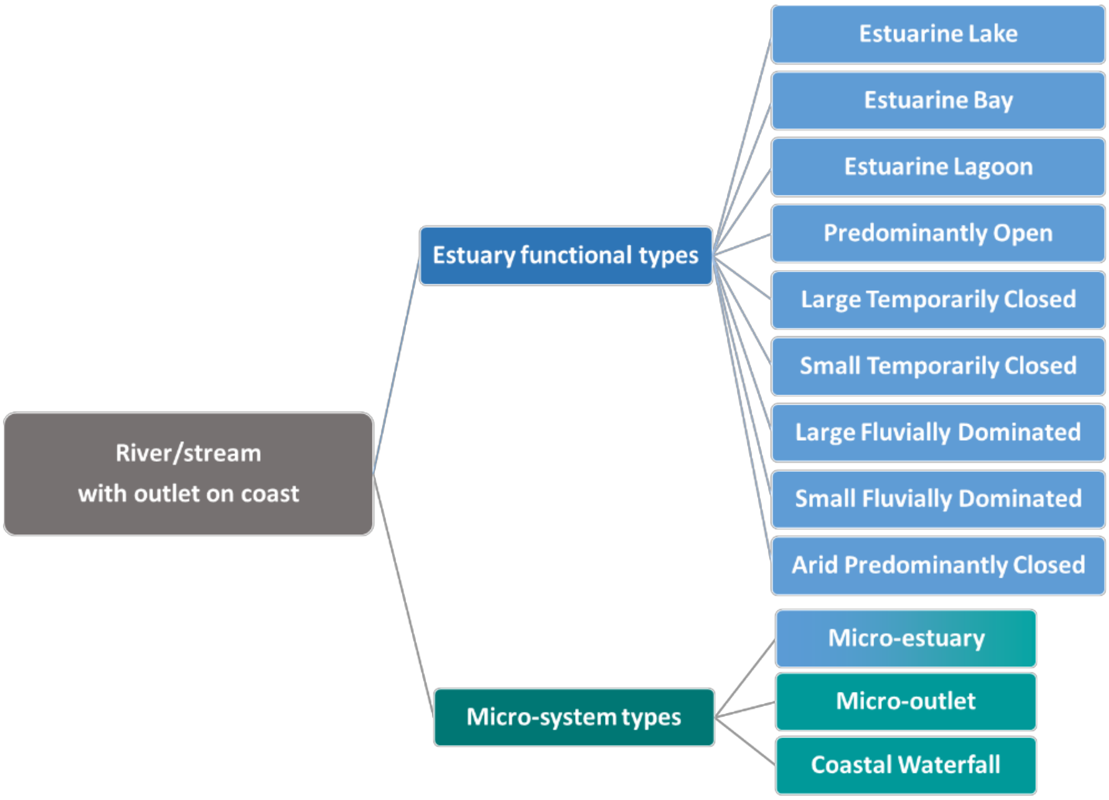


Figure 1.2: ***Revised classification of South African coastal rivers/streams into estuaries and micro-systems (Source: Van Niekerk et al. 2020a)***

Table 2.1 describes the key features and physical processes of nine estuary functional types (Van Niekerk et al. 2020a), while Figure 2.2 display examples of the different estuaries functional types, highlighting the difference in size between types.

Estuarine Lagoons are the rarest South African estuary type with only one representative system in the Cool Temperate region, followed by Estuarine Bays with two systems in the Subtropical- and one in the Warm Temperate region. Arid Predominantly Closed estuaries are limited to six systems in the Cool Temperate region. The Large and Small Fluvially Dominated types comprise seven systems each, occurring in three and two biogeographical regions, respectively. Small Temporarily Closed (116), Large Temporarily Closed (94), and Predominantly Open (44) are the most dominant types occurring across the Cool Temperate, Warm Temperate and Subtropical biogeographical regions. Estuarine Lakes occur in all four biogeographical zones. While not numerically dominant, this type of estuary represents the largest surface area of all estuary functional types, with Lake St Lucia/uMfolozi covering more than half of South Africa's estuarine surface area.

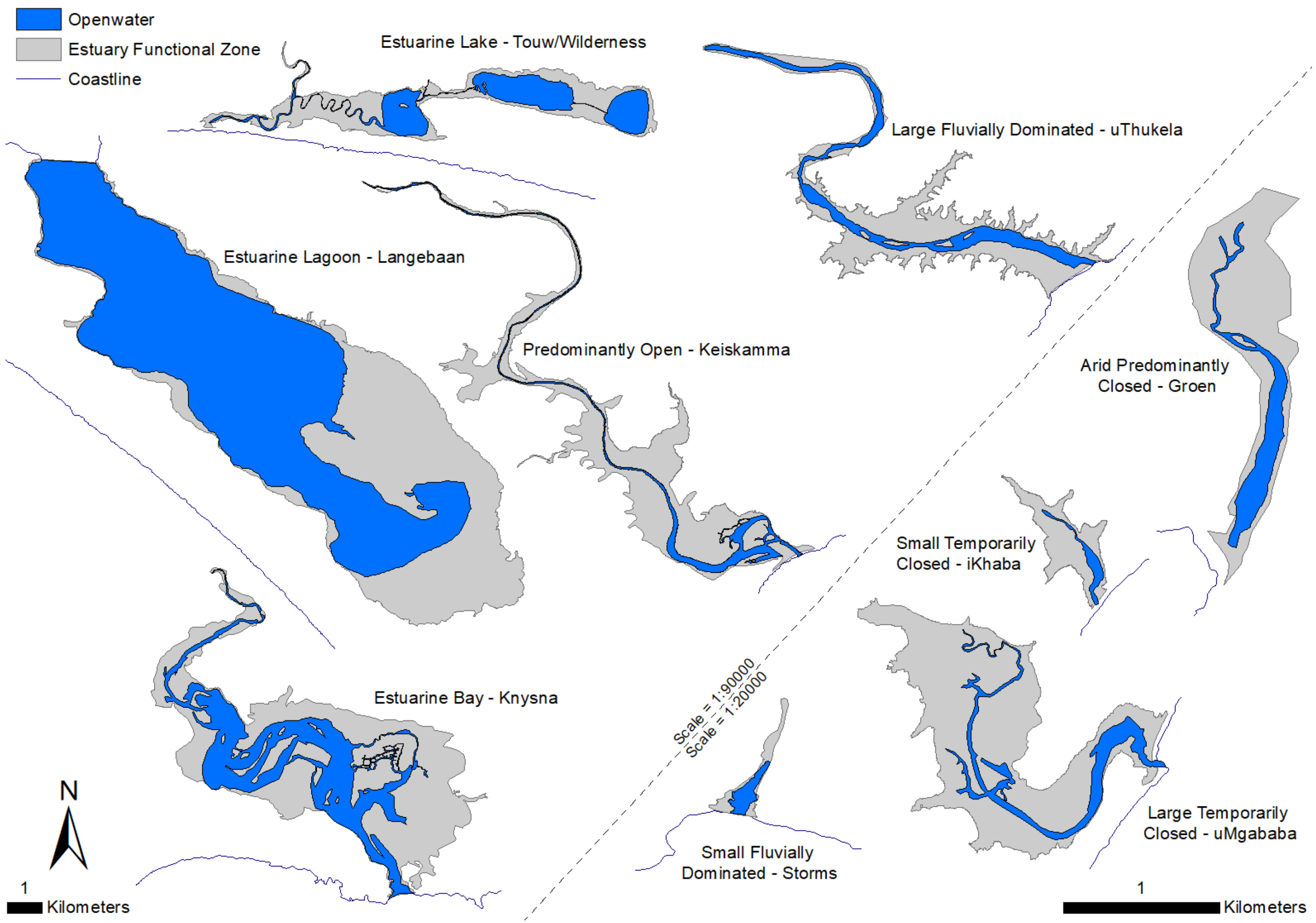


Figure 1.3: Maps showing examples of South African estuary types, with larger types represented at 1:90 000 scale and smaller types at 1:20 000 scale

Table 1.1: Key features and physical processes of nine estuary functional types (Source: Van Niekerk et al. 2020a)

ESTUARY FUNCTIONAL TYPE	ESTUARINE AREA (ha)	% TIME OPEN TO THE SEA	GEO-MORPHOLOGY	AVERAGE TIDAL RANGE (m) #	KEY DETERMINING FACTOR OF MAXIMUM WATER LEVEL	TYPICAL SALINITY RANGE	MIXING PROCESS	SEDIMENT STABILITY	MEAN ANNUAL RUNOFF ($x10^6 m^3$) *
Estuarine Lake	> 800	Variable	Circular with constricted inlet channel	0.1- 0.15	Mouth State	0 - 35	Wind/ riverine	Stable	20 - 650*
Estuarine Bay	> 1,000	100	Circular with unrestricted inlet	1.5 - 2.0	Tides	30 - 35 Average: 35	Tidal	Stable	40 - 80
Estuarine Lagoon	> 5,000	100	Circular with unrestricted inlet	1.5 - 2.0	Tides	35 - 36 Average: 35	Tidal	Stable	0
Predominantly Open	10 – 7,500	90 - 100	Linear with restricted inlet	0.75 - 1.5	Tides/ Mouth State	0 - 40	Tidal/riverine	Mobile (reset by large floods)	10 – 1 790
Large Temporarily Closed	> 15	> 50	Linear /funnel with highly restricted inlet	0.25 - 0.5	Mouth State	0 - 60	Tidal/ riverine/ wind/seepage	Mobile (breaching and floods)	1 - 280
Small Temporarily Closed	< 15	< 50	Linear/funnel with highly unrestricted inlet	0.15 - 0.3	Mouth State	0 - 30	Riverine/ wind/seepage	Mobile (breaching and floods)	0.1 - 70
Large Fluvially Dominated	100 - 3,700	> 90	Linear with highly restricted inlet	0.5 - 1.0	Mouth State	0 - 10	Riverine	Highly mobile (reset annually)	370 – 10 830
Small Fluvially Dominated	< 15	100	Linear with highly restricted inlet	0.5 - 1.5	Mouth State	0 - 5	Riverine	Highly mobile (reset annually)	20 - 50
Arid Predominantly Closed	10 - 500	<5	Linear/funnel with highly restricted inlet	0 (over-wash & breaching)	Mouth State	0 - 200 Average: Hypersaline	Evaporation/ seepage/wind	Stable, but reset on decadal-scales during floods	0.2 - 10

#Tidal ranges are indicative of what is normally experienced, but some deviations are expected, e.g. after breaching or post-flood
**Langebaan, uMgobezeleni and Kosi are groundwater dependent systems*

2.2.3 Estuary Ecosystem types

South Africa's 22 Estuarine Ecosystem Types are derived from an intersection of four biogeographical zones with the nine estuary functional types (Van Niekerk et al. 2019a; Van Niekerk et al. 2020a). Table 2.2 illustrates this interplay and lists the number of estuaries that occur within each ecosystem types, biogeographical region and /or estuary functional type. Figure 2.3 shows the distribution of the estuary functional type within the biogeographical regions.

Table 1.2: Distribution of estuary functional types across four biogeographical regions (Van Niekerk et al. 2020a)

ESTUARY FUNCTIONAL TYPE	BIOGEOGRAPHICAL REGIONS				# ESTUARIES PER FUNCTIONAL TYPE
	COOL TEMPERATE	WARM TEMPERATE	SUBTROPICAL	TROPICAL	
Estuarine Lake	4	3	2[1]	2	11
Estuarine Bay		1	2[1]		3
Estuarine Lagoon	1				1
Predominantly Open	3	25	17[1]		45
Large Temporarily Closed	9	40	45		94
Small Temporarily Closed	8	48	60		116
Large Fluvially Dominated	1	1	5		7
Small Fluvially Dominated	1	6			7
Arid Predominantly Closed	6				6
# ESTUARIES PER REGION	**33**	**124**	**131[1]**	**2**	**290**

[1]uMhlathuze was an Estuarine Lake but was subdivided into an Estuarine Bay (Richards Bay Estuary) and Predominantly Open System (uMhlathuze Sanctuary) in 1970 through port development

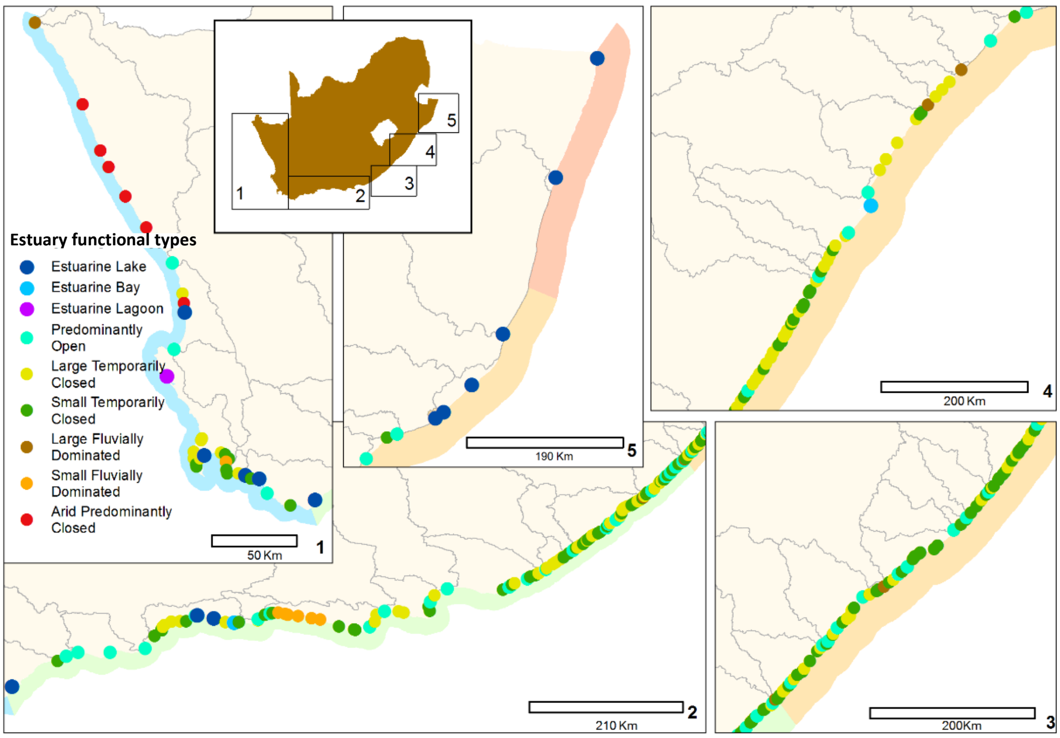


Figure 1.4: Location of functional types across four biogeographical regions (1: Cool Temperate; 2= Warm Temperate; 3 & 4 = Subtropical; 5 = Tropical) (Source: Van Niekerk et al. 2019a, 2020a)

2.3 Estuarine Functional Zone

By nature, estuaries are constantly changing both temporally and spatially, and as a consequence they do not have permanent or static habitat structures. While the total habitat area occupied by various biotic and abiotic habitat types within an estuary tends to remain more or less constant over long time scales, the actual location of these habitats is likely to be highly variable between resetting events (e.g. larger floods on decadal scales).

The Estuary Functional Zone (EFZ) is defined as the area that not only covers the estuary water body, but also areas that support physical and biological processes and habitats necessary for estuarine function and condition. The latter includes areas influenced by long-term estuarine sedimentary processes (i.e. sediment stored or eroded during floods), changes in channel configuration, aeolian transport processes, and changes due to coastal storms. The EFZ also encompasses flood plain ecotones and estuarine vegetation that contribute detritus to the base of the estuarine food chain and provide refuge to estuarine biota during high flow events from strong currents.

A fundamental constraint associated with the assessment and management of estuaries is defining their spatial extent (i.e. the smallest management unit or boundary) (van Niekerk and Taljaard 2003) owing to the dynamic nature of estuarine habitats. Biodiversity protection and the wise use of our estuarine resources require not only the protection of estuarine habitat and biota, but also the protection of the physical processes that sustain ecological and evolutionary processes. To do this, it is important to define the 'space' within which estuaries function over long time scales to safeguard the present and future health – the so-called 'estuarine functional zone' (EFZ) (van Niekerk et al. 2013, Van Niekerk et al. 2012).

The delineation of the EFZ needs to be done in a consistent but cost-effective manner, to be inclusive of all estuarine physical and biological processes so that it can be used to protect estuarine habitats. South Africa's method for the determination of the EFZ is described in detail in the NBA 2018 (Van Niekerk et al. 2019a). Key aspects that were considered included:

- The EFZs were mapped to their maximum historical extents (based on available data such as the Google Earth time slider tool, aerial photography and satellite imagery). For example, the EFZ included the maximum ranges of the estuary mouth (inlet) or the historical floodplain.
- Upstream boundaries of the EFZ were determined as the limits of tidal variation, back flooding when closed or salinity penetration; whichever penetrates furthest in alignment with recent scientific studies and the administrative definition of an estuary (e.g. DWAF 2008). This boundary was derived from the available literature, expert judgment or field observations. Where no data were available the boundary was assumed to be the DRDLR:NGI 1:10,000 +5m MSL topographical contour (bearing in mind that the tidal range in South Africa is microtidal [< 2 m] and sand bars across mouths can build up as high as +4.5 m MSL during closed periods).
- The default lateral boundary was also taken as the DRDLR: NGI 1:10,000 +5m MSL topographical contour. However, for the small, incised estuaries with relative high river flow, the +10 m MSL contour or a combination of the +5 m and +10 m MSL contours, was used to accommodate mapping uncertainty and flood processes (e.g. inundation levels and lateral scouring of the riparian area). For systems where no topographic information was available the SRTM 4.1 90 Digital Elevation Model was used to generate +5 m and +10 m MSL contour intervals for delineation of the upstream boundaries. Also included in the EFZ was contiguous habitat that is principally (more than 75% of feature) surrounded by estuarine habitat or processes (for example 's-bends' and 'islands' of high-lying ground, which could potentially be eroded in future resetting flood events). Small areas of freshwater ecosystems, identified as contiguous to estuaries (e.g. seeps and springs), were also amalgamated in EFZs.

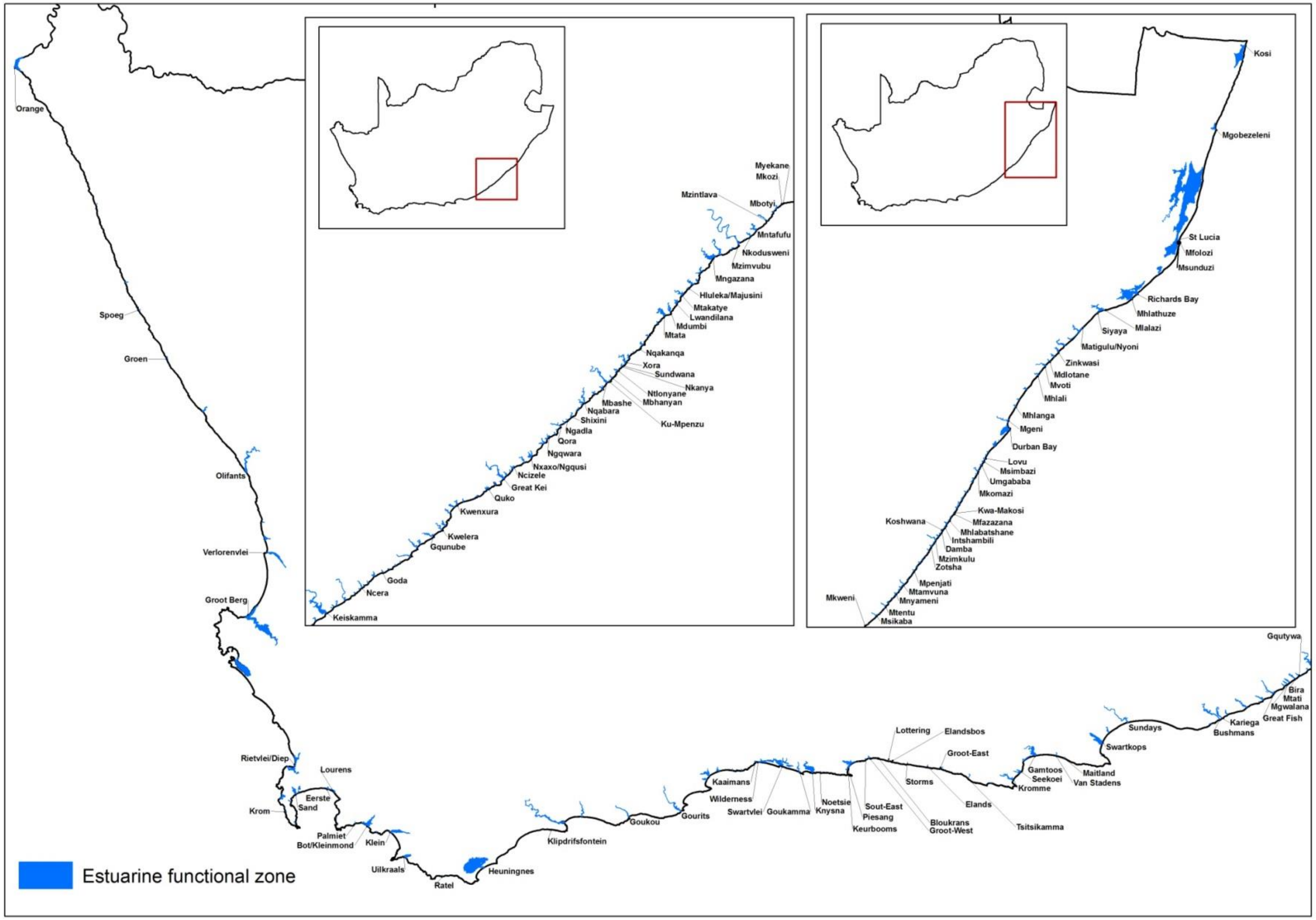


Figure 1.5: Estuarine Functional Zone delineation of South Africa estuaries – note the relative small size except for the Greater St Lucia Lake system (upper right)

- The alongshore extent was delineated as the known variability in estuary mouth position along the shore-based on the available data sources for each. Freshwater inputs (via an open mouth or seepage through the berm) change the physicochemical nature of coastal waters directly adjacent to estuaries, and are important for estuarine function. Surf zones off estuaries are essentially estuarine extensions during floods and under normal flow conditions are aggregation areas for recruiting estuarine biota. Estuarine fishes and invertebrates use riverine and estuarine signals as cues for locating and recruiting into estuaries (Van Niekerk et al. 2019).

The EFZs effectively delineate the Ecosystem Accounting Area (EAA) for Estuarine Ecosystems Accounting in South Africa (Table 2.3). Individual estuaries are delineated by the Estuary Functional Zone (EFZ) which serves as the primary unit of assessment within the ecosystem accounting area (Figure 2.4). The total extent of the mapped EFZ in South Africa is 200,730 ha. The EFZs can be grouped in various ways according to South Africa's estuary classification system. More than half of South Africa's estuarine extent is in the Subtropical region (55%) followed by the Warm Temperate (22%), Cool Temperate (19%) and the Tropical biogeographical (4%) regions. Estuarine Lakes comprise 56% of estuarine extent, while Predominantly Open estuaries comprise about 20% of extent. Estuarine Bays and Lagoons make out less than 3% of the total extent. Large Temporarily Closed and Fluvially Dominated types comprise about 8% and 7% respectively. Small Temporarily Closed systems only comprise about 2% of the total extent, while Arid Predominantly Closed and Small Fluvially Dominated contribute less than 1% to total extent (Van Niekerk et al. 2019a).

Overall, estuary size varies greatly with the Greater St Lucia/uMfolozi Lake system (in the Subtropical biogeographical region) representing more than half of South Africa's estuarine surface area, while over 70% of the countries estuaries are < 50 ha in size (van Niekerk et al 2013).

Table 1.3: Summary of EFZ areas across Biogeographical regions and Estuary type

BIOGEOGRAPHICAL REGION	**EFZ (ha)**
Cool Temperate	37,680
Warm Temperate	44,500
Subtropical	110,390
Tropical	8,170
ESTUARY TYPE	**EFZ (ha)**
Estuarine Lake	111,657
Estuarine Bay	5,826
Estuarine Lagoon	6,016
Predominantly Open	40,924
Large Temporarily Closed	16,161
Small Temporarily Closed	4,224
Large Fluvially Dominated	14,358
Small Fluvially Dominated	126
Arid Predominantly Closed	1,442
TOTAL AREA	**200,730**

The hectare is considered the most appropriate area unit to reflect the change in estuary extent and ecosystem services accounts (e.g. carbon sequestration). Given that the Small Fluvially Dominated' type estuaries, have a total area of only 126 ha, area units are not rounded up to reflect changes coverage, in even the smaller estuary functional types. The South African Estuarine Ecosystem Accounts are partially to fully spatial, but as a result of their relative small size (see Figure 2.4) not visually represented in maps in this report.

2.4 Estuarine Biodiversity

Owing to the diversity in biogeographical regions and estuary functional types around the South African coast, habitat and species diversity in estuaries is also high. For example, there are 176 estuarine-associated plant species, grouped into six vegetation habitat types - submerged macrophytes, salt marsh, mangroves, reeds and sedges, swamp forests and macroalgae (Adams et al. 2016, Van Niekerk et al. 2019a) (Table 2.4). On a biogeographic regional scale, supratidal salt marsh dominate in the Cool Temperate region and Warm Temperate region, reeds and sedges in the Subtropical region (10,800 ha), and swamp forest in the Tropical region. St Lucia, Groot Berg and Knysna constitute the largest biotic habitat extent. The number of macrophyte species per estuary varies from 1 to 54 (the latter recorded at Kosi). Macrophyte species richness in the Cool and Warm Temperate regions is higher than in the Subtropical and Tropical regions. Macrophyte species are distributed across 58 families with the dominant contributors being *Cyperaceae* (23), *Chenopodiaceae* (18), *Mesembryanthemaceae* (14) and *Asteraceae* (11), whilst the other 33 families have only one representative species. Only *Juncus kraussii* and *Phragmites australis* are widespread, occurring in more than half of the estuaries, with only 66 plant species occurring in five or more estuaries.

Table 1.4: Key vegetation habitat types in South African estuaries (Source: Adams et al. 2016)

TYPE	DESCRIPTION
Submerged macrophytes	 Plants that are rooted in both soft subtidal and low intertidal substrate and whose leaves and stems are completely submerged for most states of the tide. Submerged macrophytes tend to occur in abundance in permanently open estuaries, particularly eelgrass (*Zostera capensis*) whereas *Ruppia cirrhosa* prefers the less saline and sheltered conditions of Estuarine lakes and temporarily open/closed estuaries. *Stuckenia pectinata* (ribbon weed, fennel pondweed) prefers fresher conditions (salinities below 10) and therefore occurs in closed systems or in the upper reaches of estuaries. Submerged macrophytes are important primary producers in estuaries providing a source of food, refugia and nursery for invertebrates and fish. They play an important role in biogeochemical processes including oxygenating the water column during the growing season through photosynthesis, improving water clarity, nutrient trapping and recycling. The distribution and abundance of submerged macrophytes is threatened by a decline in water quality and smothering from macroalgal blooms and invasive aquatic plants.
Salt marsh	 A suite of herbaceous vascular plants that are adapted to endure the extremes of salinity, desiccation and tidal flooding characterizes salt marshes. Common genera are *Sarcocornia, Salicornia, Triglochin, Limonium* and *Juncus*. Halophytic grasses such as *Sporobolus virginicus* and *Paspalum* spp. are common. Salt marsh plants show distinct zonation patterns along tidal inundation and salinity gradients. Zonation is well developed in estuaries with a large tidal range e.g. Berg, Knysna and Swartkops estuaries. Intertidal salt marsh occurs below mean high water spring and supratidal salt marsh above this. *Sarcocornia pillansii* is common in the supratidal zone and large stands can occur in estuaries such as the Olifants. Salt marsh vegetation stabilizes the sediment protecting the banks of an estuary from eroding. They are important filters of sediment and pollutants as well as zones of nutrient production and retention.
Mangroves	 Mangroves are trees that establish in the intertidal zone in permanently open estuaries along the east coast of South Africa north of East London where water temperature is usually above 20 °C. The white mangrove *Avicennia marina* is the most abundant, followed by *Bruguiera gymnorrhiza* and then *Rhizophora mucronata*. Mangrove forests protect the coastline acting as buffers against severe weather. They are extremely productive habitats that are home to a diversity of fish and invertebrate species. Mangroves are also important for filtering and improving water quality. They also have a high recreational, cultural and tourism value. More recently the value of mangrove forests as a carbon sink has been recognized. Mangroves are threatened by overutilization such as the harvesting of mangrove wood for building material, and for removal for aquaculture and slash and burn cultivation.

TYPE	DESCRIPTION
Reeds and sedges	Reeds, sedges and rushes are important in the freshwater and brackish zones of estuaries. Because they are often associated with freshwater input they can be used to identify freshwater seepage sites along estuaries. The dominant species are the common reed *Phragmites australis*, *Schoenoplectus scirpoides* and *Bolboschoenus maritimus.* Like salt marsh, reeds and sedges protection the banks of estuaries from erosion. They also provide an important habitat for birds, invertebrates, fish and food for detritivores. Due to their high productivity *Phragmites*-dominated marshes are widely used in artificial wetlands for the treatment of polluted water. 
Swamp forests	Swamp forests are freshwater ecosystems associated with estuaries in the Subtropical and Tropical regions, including species such as *Barringtonia racemosa, Hibiscus tiliaceous, Ficus trichopoda* and *Syzigium cordatum.* In systems with little submerged macrophytes they play an important role in detritus input in the form of leaf litter. This habitat plays an important role in riparian erosion control and flood attenuation. 
Macroalgae	These can be free-floating or attached to rocks and other substrates. Filamentous macroalgae often form algal mats and increase in response to nutrient enrichment or calm sheltered conditions when the mouth of an estuary is closed. Typical genera include *Ulva* and *Cladophora*. Many marine species can get washed into an estuary and providing the salinity is high enough, can proliferate. These include *Codium, Caulerpa, Gracilaria* and *Polysiphonia.* Increased nutrient loads due to agricultural runoff and wastewater input have resulted in increased incidences of macroalgal blooms. 

Approximately 50 of the 150 estuarine-associated fish species that regularly occur in estuaries are endemic to southern Africa, with 20 exclusively found in South African waters. In fact, some species are confined to only a few systems. For example, the iconic Knysna seahorse only occurs in three estuaries (Knysna, Swartvlei, Keurbooms), the Bot River klipvis in two (Bot/Kleinmond and Klein) and the Estuarine pipefish in five systems - but only confirmed extant in Bushmans, Kariega, and Kasouga.

Important 'bait' invertebrate species, namely Sandprawn (*Kraussillichirus kraussi*), Mud Prawn (*Upogebia africana*) and *Macrobrachium petersii* also are southern African endemics, with the freshwater Sand-shrimp (*Palaemon capensis*) being endemic to South Africa. The importance of South Africa's estuaries for resident and migratory water birds has long been recognised. A total of 35 bird species are considered highly dependent on estuaries with more than 15% of their regional population is found in coastal lagoons and estuaries. The 118 water bird species found in South African estuaries belong to eight orders, 25 families and 73 genera.

2.5 Estuary Ecosystem Condition

'Ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics' (SEEA EEA 2.35). The measurement of ecosystem condition is a central aspect of ecosystem accounting since it provides information on the capacity of ecosystems to provide ecosystem services into the future. South Africa has a well-established system for assessing the ecological condition of estuaries, based on a conceptual model of the functioning of estuarine ecosystems. The approach has been commonly used to evaluate the change in estuary productivity and condition, for example in water resource classification and ecological flow requirements under the National Water Act (No. 24 of 1998) (e.g. DWA 2008) and in national biodiversity assessments under the National Environmental Management: Biodiversity Act (No. 10 of 2004) (e.g. Niekerk et al. 2019a). The index is also widely used in estuarine management planning, from water resource classification and biodiversity assessments, to estuarine management planning (under the National Environmental Management: Integrated Coastal Management Act [No. 26 of 2008]) and estuary conservation planning (under the National Environmental Management: Protected Areas Act [No. 57 of 2003]). More background on the context and development of this index is provided below.

2.5.1 International perspective

Globally, estuarine ecosystem health is described based on diversity, ecosystem organisation (structure), productivity, biomass, resilience to stress and stability (Sherman 2000; Costanza 1992; Costanza and Mageau 1999) Estuary health is defined as the 'maintenance of ecosystem structure and function, including natural variability and resilience on a landscape-scale' (Cairns and Niederlehner 1992). It is critical for ecological condition assessments to couple physical, chemical, geographic/climatic factors, where functionality is defined as the capacity of an estuary to support biotic and abiotic processes and the provision of ecosystem services (Borja et al. 2011). These should also be integrated with anthropogenic impacts were relevant, evaluating ecological integrity using all relevant information (Borja et al. 2004, 2008 and 2009a). Including only biotic indicator and excluding abiotic indicators) makes it difficult to relate ecological status to particular pressures causing estuarine deterioration, for example as a result of flow modification, habitat degradation, over-exploitation of living resources, or pollutant stress (Borja et al. 2009b). Information on pressures causing deterioration is essential to direct appropriate remedial measures (Borja et al. 2011). Indexes should integrate multivariate data into a single site-specific numeric value within a good-versus-bad gradient that can be interpreted by a non-specialist (Borja et al. 2011). Example of national or regional level condition indexes include the United States of America National Coastal Condition Report (USEPA, 2005), Australia's National Land and Water Resources Audit (NLWRA 2002) and Spain's Integrated Estuarine Ecological Status Assessment (Borja et al. 2004 & 2009b). Commonalities include using a range of abiotic (e.g. hydrology, tidal regimes, flood plain) and biotic (e.g. phytoplankton, macroalgae, macroinvertebrates and fishes) Estuary Ecosystem Condition Indicators; the focus on qualifying the impact of pressures (e.g. biological invasions and pollution); and the use of expert panels to address data gaps and access condition.

One of the key challenges in developing estuarine ecosystem integrity indices is the need to reflect the change in dynamic estuarine ecosystems in a data-limited environment, largely framing the selection of representative indicators and the calculation and weightings of indicators in the index to be functional in both data-rich and data-poor systems. Once-off measurements of abiotic or biotic aspects of estuaries should be interpreted in the context of medium to long-term dynamics, able to recognise the difference between dynamic and unidirectional change. Severe degradation of an estuary may involve a shift from dynamic change to dominantly unidirectional change. The loss of dynamic function per se may thus constitute an important measure of degradation in estuarine health.

2.5.2 Estuary Health Index of South Africa

In the South African approach, the term 'estuary health' is used to describe an estuary's condition - measured as the degree to which the present condition of an estuary deviates from its pristine condition (DWAF 2008, Turpie et al. 2012). The index that is currently applied in South Africa was preceded by various other approaches. The first index for estuarine health that was developed, - the so-called 'Community Degradation Index' compared the observed fish community (species richness) with that which would have occurred prior to degradation (Ramm 1988, 1990). However, it was found that while the fish community might reflect estuarine health to a certain extent, there are also other aspects, such as water quality and aesthetics, which might not be reflected in fish communities (Cooper et al. 1994). As a result, the approach was adapted to include three separate indices, namely a Biological Health Index (largely based on the original Community Degradation Index), a Water Quality Index, and Aesthetic Quality Index. The Biological Health Index required a reference list of fish related to each group of estuaries obtained from available records and pooling the species list for estuaries of the same physical character (Cooper et. al 1994). The Water Quality Index comprised six water quality variables (dissolved oxygen, oxygen absorbed, ammonia nitrogen, *E. coli*, nitrate nitrogen, ortho-phosphate and chlorophyll-a), while the Aesthetic Quality Index comprised weighting of parameters such as floodplain land-use, the naturalness of channel margins, smell, water turbidity or oil sheen, exotic vegetation, solid waste, presence of algal blooms or invasive plants. In 1996, the estuarine community in South Africa (CERM 1996) developed the Conservation Importance Index including a Physical Health Index, which contained a measure of the degree of siltation, tidal exchange (mouth condition), water quality and hydrodynamics (salinity). This index used a multi-criteria decision analysis technique (i.e. conjoint scoring). Other historical methods include the Estuarine Habitat Integrity and Biological Integrity approach, based on a procedure described for rivers which were based on a site visit, as well as an assessment of past literature, aerial photographs and maps (Kleynhans 1995; Van Driel 1998). The latter evaluated aspects of flow reduction, tidal flow modification, estuary bed modification, river mouth stabilisation, alien invasive vegetation, disturbance of biota and migratory barriers and its scoring system combined a measure of extent and intensity of each impact. A Botanical Importance Rating index (Coetzee et al. 1996) was also developed, and although initially not designed as a health index, this approach sums areas of different habitat types, each weighted by their functional importance. The above-mentioned indices paved the way for the formulation of a robust Estuary Health Index of South Africa that is currently being used widely (Turpie et al. 1999).

Based on the definition of 'estuary health', the Estuary Health Index of South Africa reflects the overall change in condition relative to a natural condition, assessed separately for each of the selected index variables. The selection of the index variables, as well as their grouping and weighting to reflect 'health' was decided through a series of workshop sessions with estuarine experts where several potential variables were identified, together with reasoning on how they would indicate and vary with a change in ecosystem health, grouped into physical (or abiotic) variables and biotic variables. As the listed variables were likely to be correlated with one another, creating unnecessary complexity in the index, those that were closely correlated were assessed to decide on which to select depending on the ultimate focus (e.g. concentrate on biotic variables if biological health is the main issue), or which were the more reliable, stable or easily measured parameter.

Following this process, estuarine experts agreed on four abiotic and five biotic Estuary Ecosystem Condition Indicators for inclusion in the Estuarine Health Index to evaluate the change in estuary productivity and condition (Figure 2.5). The index includes both abiotic and biotic condition indicators (also called components) as the inter-relationships between these indicators are often not well defined, and also because biotic responses often lag abiotic responses - abiotic responses can offer an early warning on condition change (Whitfield et al. 2008; Van Niekerk et al 2013).

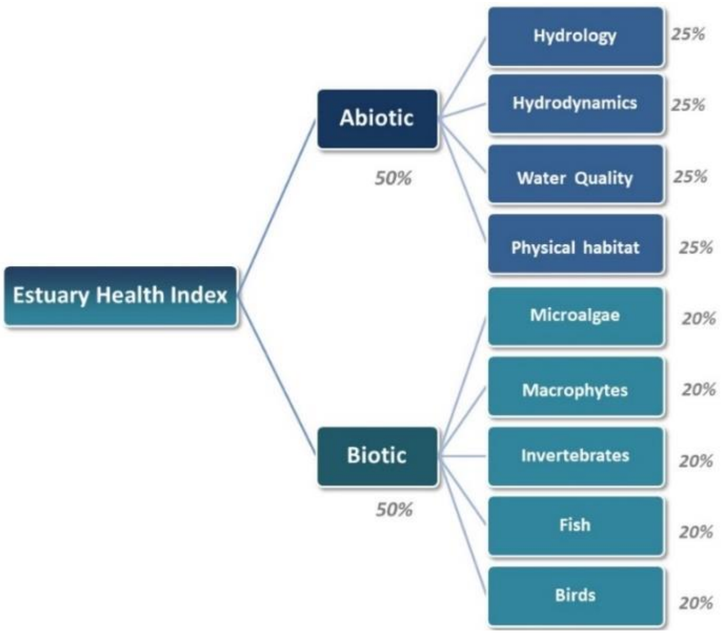


Figure 1.6: Illustration of the structure of the Estuary Health Index (DWAF 2008; Turpie et al. 2012)

The indicators form the primary input for the **Estuary Health Index developed to evaluate the condition of individual estuaries in South Africa** (DWAF 2008; Turpie et al. 2012). The **abiotic condition indicators** comprise:

- **Hydrology:** Assessing the hydrology helps to establish the extent to which modification in river inflow is responsible for the deviation of health from natural. Key elements include changes in wet and dry-season base flows and floods.

- **Hydrodynamics:** Assessing changes in water level, estuarine circulation and mixing processes, with a focus on connectivity to the sea (mouth state) and water level variation (in the case of temporarily open/closed systems).
- **Physical habitat:** Focussing on changes in the sedimentary processes in estuaries such as a change in the size and shape of systems, as well as the sediments structure and composition (e.g. muds, rocks, sands). The size and shape of an estuary determine many of its inherent physical features. Disturbance of the sediment erosion/deposition equilibrium in an estuary can lead to siltation, resulting in the estuary becoming shallower, or it can lead to the erosion of important estuarine habitats.
- **Water quality:** Assessing change in terms salinity and other water quality parameters (dissolved oxygen, suspended solids/turbidity, nutrients and toxic substances). Salinity distribution along the length of the estuary is treated separately from the other water quality parameters, as it also informs water exchange patterns.

The **biotic condition indicators** comprise:

- **Microalgae:** assessing phytoplankton and benthic microalgae which are important food sources for higher taxa.
- **Macrophytes:** assessing primary producers that are both habitat and food for many of the estuarine fauna (e.g. submerged macrophyte beds form important nursery areas for juvenile fish by providing food, shelter and protection from predators). Macrophytes also play an essential role in nutrient trapping and recycling, sediment stabilisation and bank protection.
- **Invertebrates:** assessing zooplankton, nektonic (swimming) invertebrates and benthic (bottom-dwelling) invertebrates that are all important food sources for fish and birds, as well as being an important resource used by people for food and bait. Invertebrates are also well-known habitat formers in estuaries and provide additional niches for other organisms thereby increasing the diversity and carrying capacity of estuarine systems.
- **Fish:** serving as an important food source for one another and birds, as well as being an important resource used by people for food. Fish are also highly mobile and thus respond rapidly to changes estuary condition.
- **Birds:** making an important contribution to the recreational and aesthetic value of estuaries, as well as contributing to the maintenance of estuarine processes through predation and nutrient inputs. Many birds are good indicators of estuarine conditions such as water quality, habitats and fish abundance.

In the estuarine ecosystem accounts, the above abiotic and biotic indicators (as applied in the Estuary Health Index), were also selected as Estuary Ecosystem Condition Indicators to ensure continuity and alignment with existing environmental planning and management applications. Both at the integrated Estuary Health Index level as applied to condition assessment of individual estuaries, and at the individual Estuarine Ecological Condition Indicator level (e.g. hydrodynamics, fish). Thus, the Estuary Health Index served as the primary data source for all condition accounts.

The 'reference condition' in the Estuarine Health Index of South Africa refers to the natural state of an estuary, around 1750, before subjected to major anthropogenic change

The Estuarine Health Index of South Africa reflects change as a percentage similarity (0 – 100%) to a defined natural state (referred to as the 'Reference Condition') which is calculated for both abiotic and biotic indicators derived from various data and information sources. Ratings for indicators are weighted (25% for each abiotic and 20% for each biotic component) and aggregated (50:50) to provide an overall percentage deviation from natural (van Niekerk et al. 2013). These percentage values are then translated into six ecological condition categories, ranging from natural (A) to critically modified (F) (Table 2.5). For the ecosystem accounting purposes, categories E and F were aggregated, resulting in five ecological condition categories, ranging from a natural to severely/critically modified state. These categories also represent declining functionality in process and pattern, from natural to little remaining.

Table 1.5: The Estuary Health Index translated to ecological condition and groupings proposed for ecosystem accounting categories (modified from Van Niekerk et al. 2013)

Condition (% of natural)	≥91%	90-75	75 - 61	60 - 41	40-21	≤20
Ecological condition Category	A Natural	B Largely natural / few changes	C Moderately modified	D Largely modified	E Highly degraded	F Extremely degraded
Ecological State	NATURAL	NEAR NATURAL	MODERATE	HEAVILY	SEVERE/CRITICAL	
Functionality	Retain Process & Pattern (Representation)		Some loss of Process & Pattern	Significant loss of Process & Pattern	Little remaining Process & Pattern	

Category	Description
A	**Unmodified, approximates natural condition.** The natural abiotic processes should not be modified. The characteristics of the resource should be determined by unmodifed natural disturbance regimes. There should be no human induced risks to the abiotic and biotic processes and function.
B	**Near natural with few modifications**. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged.
C	**Moderately modified**. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	**Heavily modified**. A large shift natural processes and ecosystem functions and/or loss of habitat, biota have occurred.
E F	**Severely modified**. The loss of natural habitat, biota and basic ecosystem functions is extensive. **Critically modified**. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural abiotic processes and associated biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

3. APPROACH AND METHODS

The approach and methods posed in this chapter relate to the **ecosystem extent and condition accounts** for estuarine ecosystems (organised in terms of biogeographical regions and functional types). It also introduces the concept of **ecosystem pressure accounting** that considers the change in anthropogenic pressures on estuaries. The latter serve well as proxies of condition where ecological information (e.g. monitoring surveys) to populate the ecosystem condition accounts is lacking. Also, pressure accounts are useful for reporting on sector-based resource utilisation (e.g. water, fisheries) and associated societal benefits. Preliminary investigation of **ecosystem service accounts** is also explored focussing on three important estuarine ecosystem services, namely carbon sequestration, nursery function for important fisheries, and habitat and refugia for rare endemic estuarine species.

Unless otherwise indicated, the opening stock is an estimate of natural circumstances (~1750) before significant anthropogenic induced change in the landscape, while the closing stock reflects the situation in 2018.

3.1 Extent Accounting

The estuary ecosystem accounts use the South African Estuarine Classification System as a basis (van Niekerk et al. 2020a). There are clear conceptual similarities between the South African classification system and the International Union for Conservation of Nature’s (IUCN) Global Ecosystem Typology (GET) for the Freshwater-Marine Realm (Level 1) and Transitional Waters Biome (Level 2) (Keith et al., 2020). Both systems use a functional grouping of estuarine ecosystems and then a biogeographical grouping (Figure 3.1), unsurprisingly the South African classification system is more detailed than the global system, resulting in a higher number of functional groups and biogeographical groups than the global system (Section 2.2).

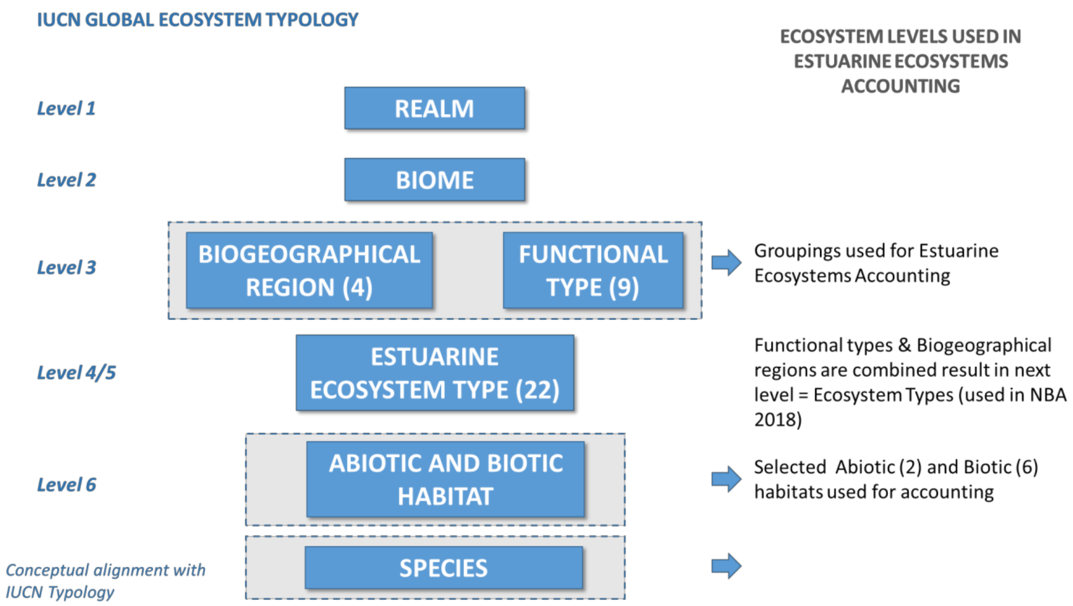


Figure 3.1: Ecosystem levels evaluated in Estuarine Ecosystem Accounting and the conceptual aliment with the IUCN Global Ecosystem Typology

Two parallel groupings were considered appropriate and useful for structuring the national-level estuary accounts, namely functional groups and biogeographic ecotypes. For ecosystem assessment, these groupings are combined to produce Ecosystem Types at the next level down in the classification hierarchy. While it is possible to disaggregate data further to the estuarine ecosystem type level (similar to IUCN GET biogeographic ecotypes - Level 4) it was deemed more appropriate at this stage of method development to apply the proposed approach at higher levels of aggregation to reduce repetitive results and test approach. Given South Africa's diverse climatic and oceanic conditions, biogeographical ecotypes/regions were presented as the higher organisation level in this report to accommodate South Africa's ecosystem typology as follows:

- Biogeographical regions (similar to IUCN GET biogeographic ecotypes); and
- Estuary functional types (similar to IUCN GET functional groups).

Estuarine habitat accounts aim to provide an overview of the intactness of key abiotic and biotic habitats within estuaries, with a focus on habitats that supports the provision of ecosystem services (and needed to quantitatively assess the delivery of these services). To reflect on the intactness of **estuarine abiotic habitat**, proxies are:

- Aquatic habitat (here defined as 'average open water area'); and
- Floodplain (here defined as EFZ area minus 'average open water area').

In the case of **estuarine biotic habitat**, an important proxy is:

- Estuarine vegetation types (here defined as estuarine macrophytes).

3.1.1 Extent accounts by biogeographical region and estuary functional type

For extent accounts by biogeographical region and functional type, the 'estuary' is used as the smallest unit (see Section 2.3 for more detail). The extent accounts record national-level shifts in the extent of estuaries (either expressed in the number of estuaries or as EFZ area [in ha]). For the accounts by biogeographical region, data were assessed in relation to the four **biogeographical regions** (Cool Temperate, Warm Temperate, Subtropical and Tropical) (Table 2.1). For accounts by **estuary functional types** data were further organised in terms of the nine functional types within each of the regions (Table 2.2). These accounts provide useful, transparent means of monitoring shifts in biodiversity against pre-set biodiversity targets, or to track trends over time.

The key data requirements necessary for national-level extent accounting are listed in Table 3.1 (specific data sources applied in this study is detailed in Appendix A).

Table 3.1: Important data requirements for extent accounts by biogeographical region and estuary functional type

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY/ ORGANISATION
Estuarine Functional Zone (EFZ)	Spatial demarcation of the functional zones of South African estuaries encapsulating all abiotic and biotic processes, or future updates thereof (area unit = ha) ((Van Niekerk et al., 2019a; Source: https://bgis.sanbi.org/))	SANBI (supported by CSIR)
Estuary Biogeographical zone and type	Estuary functional types as reflected in National Ecosystem Classification of South Africa, or future updates thereof (Van Niekerk et al., 2020a; Source: https://bgis.sanbi.org/))	
Land cover change	National Land Cover, or future updates thereof. (Source: https://bgis.sanbi.org/; GeoTerra Image 2015). Date is captured as raster data with minimum two time points (1990, 2014).	DEFF

3.1.2 Extent accounts for estuarine habitats

The habitat extent accounts used a range of proxies for **estuarine abiotic and biotic habitats** as is illustrated in Figure 3.2. Key data requirements are listed in Table 3.2 (specific data sources applied in this study are detailed in Appendix A).

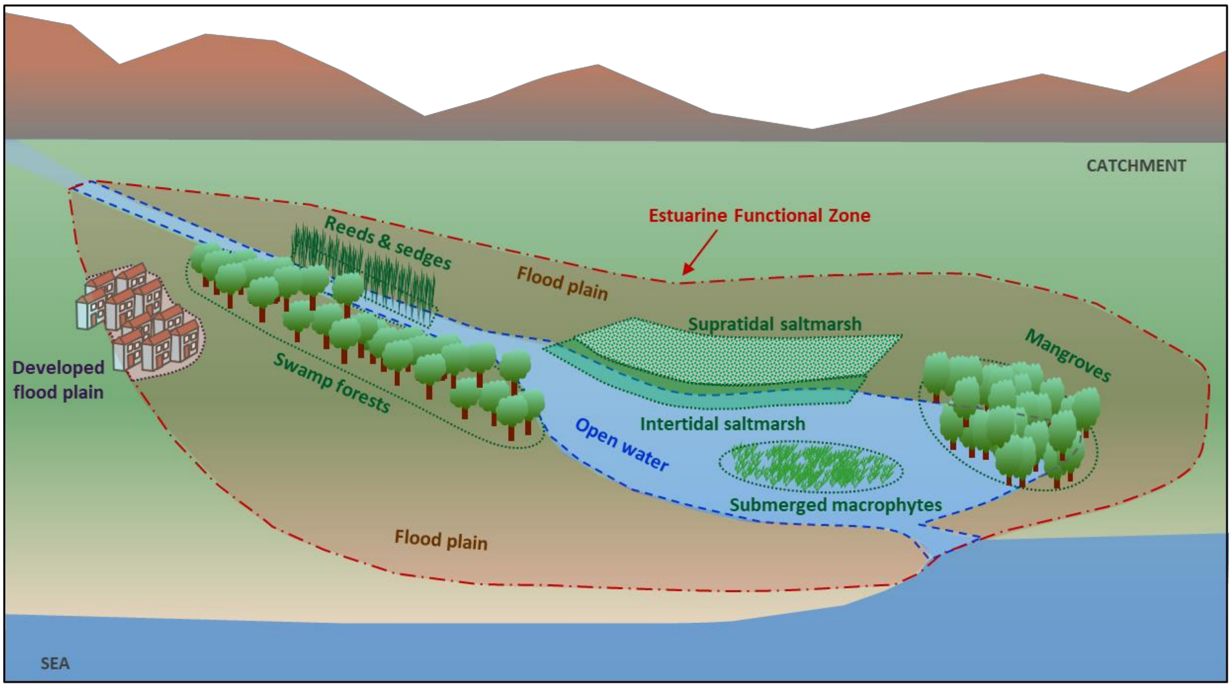


Figure 3.2: Schematic of the relationship between abiotic and biotic estuarine habitats in South African estuaries

The **abiotic estuarine habitat** comprises aquatic habitat (open water) and floodplain (which includes developed areas that are still subjected to abiotic processes). These were primarily selected on data availability, and practicalities of acquiring data in future (the sum of abiotic habitat types comprises the total EFZ area of an estuary). In South Africa, with its large number of systems that close from time to time, 'average open water area' (a proxy for aquatic habitat) is highly dynamic/ephemeral depending on numerous factors such as mouth state, river inflow conditions and state of the tide. Ideally, it should therefore be determined from a range of high-resolution imagery over an extended period (> 10 years). Currently, such data sets do not exist, but given the importance of aquatic habitat, this study attempts to estimate the baseline extent of such habitat using available data from the NBA 2018 (Van Niekerk et al. 2019a).

Floodplain habitat should include all dynamic areas influenced by long-term estuarine sedimentary processes, as captured by the EFZ. Floodplain habitat encompasses physical habitat (e.g. mud flats and sand banks) and all botanical habitat (e.g. mangroves, salt marshes and terrestrial vegetation). The extent of historical floodplain habitat has not been quantified for South Africa's estuaries, but it can be assumed that the floodplain extent comprises the EFZ minus open water area. (Development and agriculture within the EFZ are captured in the pressure account as land-use [see Section 3.3]).

Table 3.2: Key data requirements for estuarine habitat extent accounting

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY/ ORGANISATION
Estuarine Functional Zone (EFZ)	Spatial demarcation of the functional zones of South African estuaries, or future updates thereof (area unit = ha) (Source: https://bgis.sanbi.org/)	SANBI (supported by CSIR)
Average open water area	Spatial extent (area=ha) of average estuarine open water area (e.g. calculated from series of aerial images within a particular period)	CSIR
Estuarine Vegetation types	Spatial extent (area=ha) of selected key vegetation types (as captured in NMU's National Estuarine Botanical Database)	NMU

Estuarine Biotic habitats are represented by the six key estuarine vegetation habitat types as defined in by Adams et al. (2016) and updated in the NBA 2018 (Van Niekerk et al. 2019a) (Figure 3.2 and Table 2.4). Unlike estuarine abiotic habitats, biotic habitats do not occur contiguously within the EFZ. Rather they are a mosaic of biotic habitat 'superimposed' onto abiotic habitats, and as a result total biotic habitat area does not add up to total EFZ area. Historical aerial photographs were used to map change in the extent of the key biotic habitats, where possible.

Changes in the historical extent of biotic habitat are not available for all estuaries, as yet. Where it was available baseline datasets are only from the 1920/1930s onwards.

3.2 Condition Accounting

Over the past decade, the assessment of estuary condition in South Africa has progressed from a limited integrative index (Harrison et al., 2000) used for a snapshot country-wide survey (based on only geomorphology, ichthyofauna, water quality and aesthetics), to the more comprehensive Estuary Health Index used as part of Ecological Flow Requirement studies (previously called Resource Directed Measures [RDM]) (DWAF, 1999; Adams et al. 2002). The Estuary Health Index is also translated into a set of ecological condition categories (see Figure 2.3 in Section 2.5) which are widely used in estuarine resource management.

Ecosystem condition accounts for estuaries are presented at different levels of aggregation of the outputs derived from applying the Estuary Health Index to all 290 estuaries in the country. A single-value high-level perspective of the overall condition of South Africa's estuaries is represented by:

- National Estuarine Ecosystem Condition Index.

Similar to the estuary extent accounts, estuary condition can also be organised in terms of:

- Biogeographical regions; and
- Estuary functional type.

Condition accounts for biogeographical region are further disaggregated into abiotic and biotic Estuary Ecosystem Condition Indicators, such as water quality or birds (see Figure 3.3), to provide resolution on the condition of specific estuarine resources. The status of the individual Estuary Ecosystem Condition Indicators was not disaggregated to the functional type level as the objective of this indicator is to provide a high-level overview of the different components of the ecosystem.

Figure 3.3 illustrates the incremental aggregation applied in condition accounting, from *abiotic and biotic Estuary Ecosystem Condition Indicators* to condition per estuary, which can then be combined to report ecosystem condition accounts aggregated by *biogeographical* region or by *estuary functional type*, and finally into an overall National Estuarine Ecosystem Condition Index.

Finally, the accounts focus on the condition of habitats in estuaries, as represented by:

- Abiotic habitat (aquatic and floodplain); and
- Biotic habitat (estuarine vegetation).

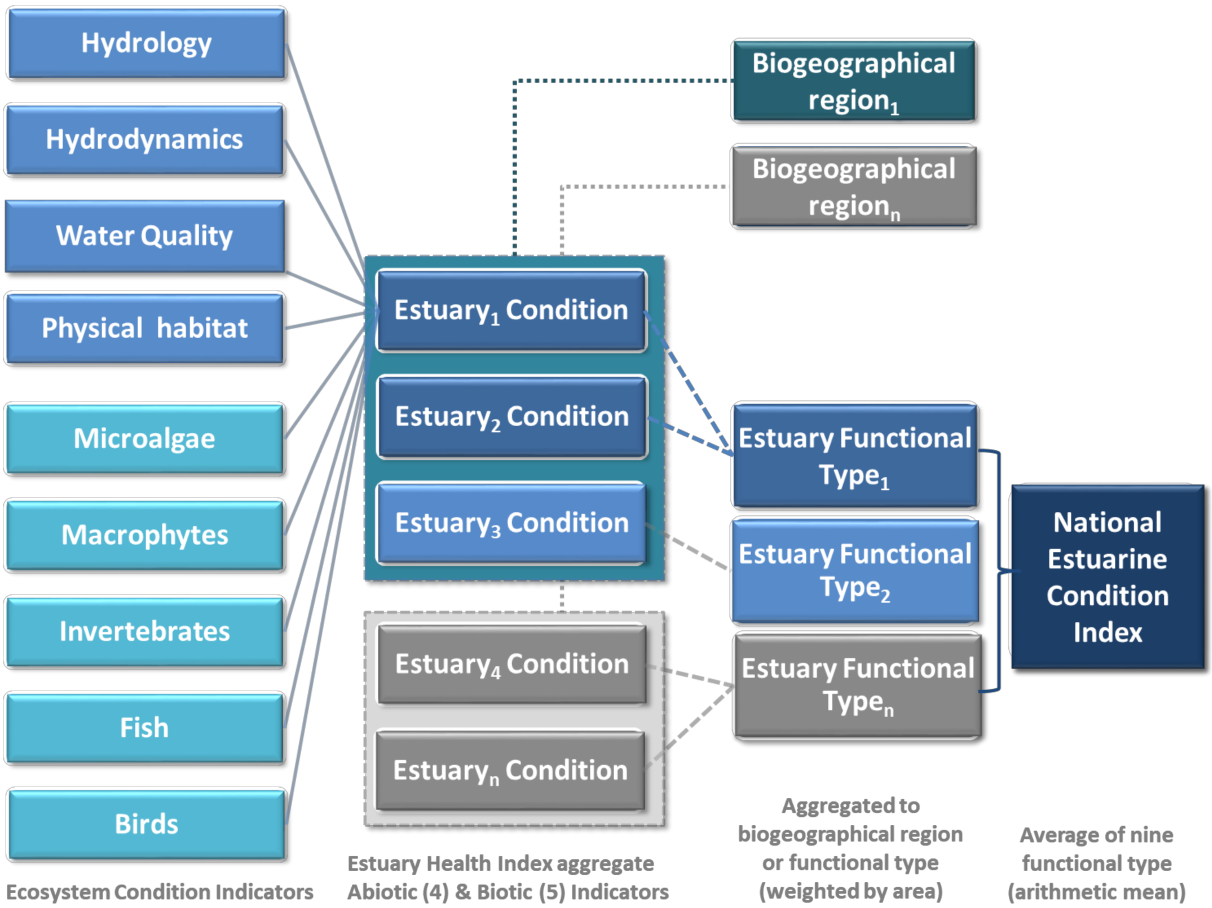


Figure 3.3: ***Increasing levels of aggregation of estuarine ecosystem condition - from biotic and abiotic Estuary Ecosystem Condition Indicators, to condition per estuary, to condition per biogeographical region or estuary functional type, and ultimately to National Estuarine Ecosystem Condition Index***

The key data requirements necessary for condition accounting are stipulated in Table 3.3. The conditions accounts used the NBA 2018 estuary condition data (using the Estuary Health Index) to ensure alignment with methods applied in 'Water Resource Classification' (National Water Act) and '*Ecosystem Threat Status'* and *Ecosystem Protection Level* assessments' (Biodiversity Act) (Van Niekerk et al. 2019a).

Table 3.3: ***Key data requirements for estuarine ecosystem condition accounting***

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY/ ORGANISATION
Estuarine Functional zone (EFZ)	Spatial demarcation of the functional zones of South African estuaries, or future updates thereof (area unit = ha) (Source: https://bgis.sanbi.org/)	SANBI (supported by CSIR)
Estuary Ecosystem map	Estuary Ecosystem types as reflected in National Ecosystem Classification of South Africa, or future updates thereof (Van Niekerk et al. 2020; Source: https://bgis.sanbi.org/)	
Estuary Condition	Aggregated condition for estuaries (including the condition of individual abiotic and biotic indicators as capture in National Biodiversity Assessment: Estuarine Realm, or future updates thereof. (Van Niekerk et al. 2020; Source: https://bgis.sanbi.org/))	
Land cover change	National Land cover, or future updates thereof. (Source: https://bgis.sanbi.org/; GeoTerra Image 2015). Data are captured as raster data with a minimum of two time points (1990, 2014)	DEFF

3.2.1 National Estuarine Ecosystem Condition Index

The primary aim of the high-level **National Estuarine Ecosystem Condition Index** is to provide information at the country-level at its simplest form. This indicator can, in turn, be evaluated with other national-level indicators, such as the **River Ecosystem Condition Index** (Nel and Driver 2015), to provide national government with a 'dashboard-type' overview of progress made towards sustainable natural resource use and protection.

For the overall National Estuarine Ecosystem Condition Index data were first weighted by area and aggregated to estuary functional type, and then averaged across estuary functional types (n=9) to derive at the overall country-level condition (see Figure 3.2). This was done to remove the biases posed by very large estuaries such as the St Lucia Estuarine Lake system that comprises more than 50% of South Africa's estuarine area. Overall weighting the index by estuary functional type (9 types), ensures that changes in smaller estuary functional types are also reflected in the overall National Estuarine Ecosystem Condition Index.

The authors tested the index responsiveness to a range of weightings, i.e. the number of estuaries, overall estuarine area, and 22 ecosystem types. Weighting by the nine estuary functional types resulted in a representative index that is not excessively influenced by either the large number of small estuaries in very good condition, or the small number of very large systems in poor condition (Table 3.4). This weighting also still retains index sensitivity to changes in individual types which is not the case if there is a high number of index components (i.e. weight by 22 ecosystem types).

Table 3.4: Approaches to testing the overall National Estuarine Ecosystem Condition Index sensitivity

POSSIBLE APPROACH		COMMENT
Calculate average condition based on the total number of SA estuaries (n=290) (weighted by number)	74.2	Sensitive to the high number of small estuaries in good condition. Not sensitive to the condition of the St Lucia Lake System.
Calculate average condition based on the total estuarine area of SA estuaries (n=200 736) (weighted by area)	58.9	Largely reflect the condition of the St Lucia Lake system and not sensitive to shifts in the condition of smaller systems
Σ Estuary Ecosystem condition weighted by area **/** **Σ** Ecosystems types (n=22) (weighted by Estuary Ecosystem types)	66.6	Relative insensitive to changes in specific types, needs two to three types to shift condition before reflecting the overall change. Not sensitive to changes in St Lucia Lake System condition.
National Estuarine Ecosystems Condition Index Σ Estuary Functional Type condition weighted by total area / Σ functional types (n=9) (weighted by Estuary Functional types)	**63.7**	**Moderately sensitive to a St Lucia Lake System condition ('St Lucia effect'), but also reflect changes in other types across the spectrum regardless of estuary size.**

Weighting by the number of estuaries resulted in an index value (=74.2) that was sensitive to the large number of good condition small estuaries in South Africa, but insensitive to the condition of important systems like St Lucia Lake System. However, weighting by area had the opposite result, in that the index (58.7) would largely only reflect the condition of larger estuaries like the St Lucia Lake System, but be completely insensitive to significant changes in the smaller estuaries or even functional types. To remove some of this bias, condition results were also weighted by area and aggregated to the 22 ecosystem types (Section 2.23) and then averaged (n=22). However, this approach (=66.6) proved to be relatively insensitive to changes in individual types, with two to three types needing to shift in condition before reflecting overall change the index value. This approach was also not sensitive to changes in the condition of important estuaries like the St Lucia Lake System.

Overall the best results were achieved by calculating the area-weighted condition of each of the nine functional types and then averaging the result to produce an index that is sensitive to change in all types of estuaries.

3.2.2 Ecosystem condition accounts by biogeographical region and estuary functional type

To produce the condition accounts by biogeographical region, the estuary condition within each of the four biogeographical regions were aggregated and organised into 'degree of modification' categories, the results were expressed as either number (#) of estuaries or percentage (%) of EFZ area in biogeographical region in a state. For the condition accounts by estuary functional types, estuaries were subdivided into nine types, and then organised into 'degree of modification' categories, expressed as number (#) of estuaries or percentage (%) of EFZ area within each estuary functional type.

To provide further resolution on the ecological condition of specific abiotic and biotic indicators, the individual abiotic and biotic component scores of the Estuary Health Index was organised into 'degree of modification' categories and the results expressed as number (#) of estuaries or percentage (%) of EFZ area within the biogeographical region. Estuary Ecosystem Condition Indicators were not disaggregated to a high level of detail (only to biogeographical level) as aquatic resources are inter-connected, and the intent here is to focus attention on indicators that are as a whole in rapid decline, showing marked recovery, or remain relative stable overtime.

Ecosystem condition accounts, reported by biogeographical region and estuary functional type, are intended to inform regional or district level estuary management and resource use, while the condition accounts for the ecosystem indicators reflect the status of estuary resources at the component level.

3.2.3 Estuarine habitat accounts

Detailed information on the condition of individual **abiotic habitats** (e.g. aquatic and floodplain) is not readily available for South Africa's estuaries. However, the Estuary Health Index does provide an overall 'abiotic condition' (Figure3.2) that integrates condition across the four abiotic Estuary Ecosystem Condition Indicators. Therefore, in the absence of data for the individual abiotic habitats, the abiotic Estuary Health Index scores allocated to estuaries are used as proxies for the condition in the abiotic habitat condition accounts (Van Niekerk et al. 2019a).

Similarly, currently there is no information available on the condition of specific vegetation types, representing **biotic habitat**, in South Africa's estuaries. However, the Estuary Health Index provides a health score for 'macrophytes' (Figure 3.2), largely representative of the condition of the selected estuarine vegetation types (Table 3.3).

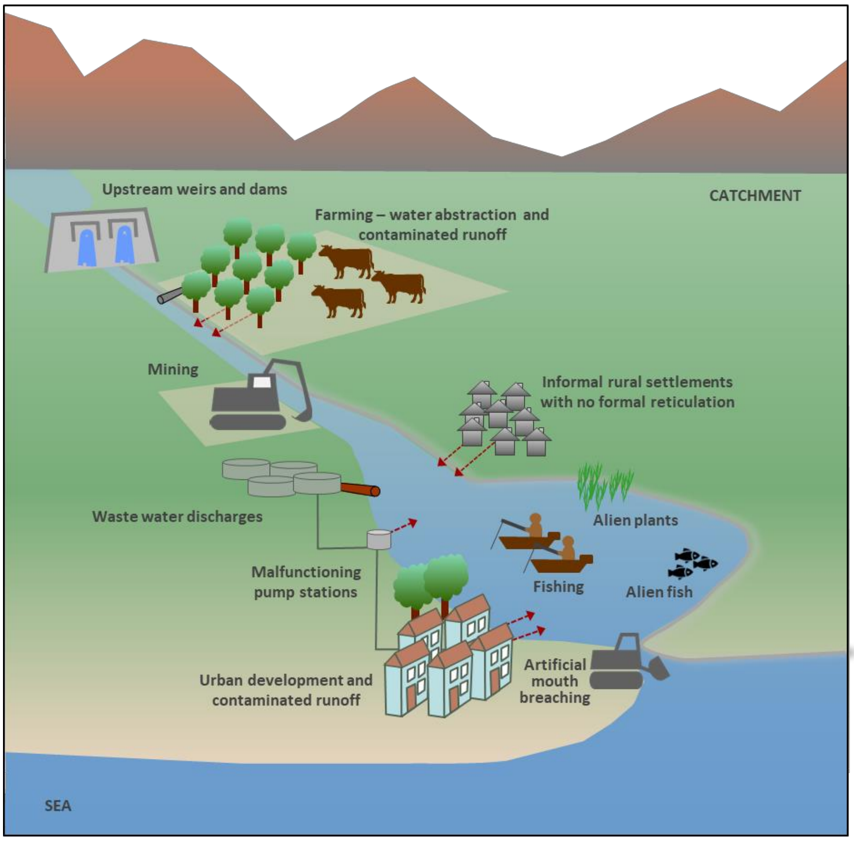
Therefore, in the absence of vegetation-specific condition data the Estuary Health Index macrophyte scores allocated to estuaries are were used a proxy for the condition in the biotic habitat condition accounts (Van Niekerk et al. 2019a).

3.3 Pressure Accounting

Anthropogenic (human) activities, both direct and indirect, are increasingly impacting on estuaries and their ability to sustain productivity and associated ecosystem services (Borja et al. 2016). Managing, and potentially reducing human impacts on these ecosystems, requires a scientific basis drawing on spatial and temporal trends in ecosystem health (Andersen et al. 2015). Thus, to secure optimum use of estuarine resources in a changing world, it is critically important to also understand the extent of anthropogenic pressures on estuaries and concomitant response in the condition of these systems, also referred to as ecosystem disservices (UN 2017).

A pressure in the context of estuary ecosystems accounting refers to anthropogenic activities that is drivers of change and quantification thereof.

The information captured in the pressure accounts should also be used to inform the development of 'Ecosystem Services Supply and Use 'accounts for estuaries.



Direct anthropogenic (human) pressures can be grouped broadly into six major categories that have been identified namely (i) water resource use, (ii) land-use, (iii) exploitation of living resources, (iv) pollution and (v) artificial breaching (manipulation of estuary mouths) (see Figure 3.4). Indirect pressures largely relate to another serious issue facing South Africa's estuaries, namely biological invasions, for example by plants and fish. The key data requirements necessary for national-level estuary pressure accounting are stipulated in Table 3.5, while the specific sources used for this assessment are detailed in Appendix A.

Figure 3.4: Illustration of some of the key pressures on estuaries that need to be quantified in estuarine ecosystem accounting approaches

3.3.1 Anthropogenic activities (direct pressures)

Pressure accounts are an example of a thematic account need to manage estuaries at the national level. Focusing on accounting for direct anthropogenic pressures a range of methods was applied (see detail below). In all instances, the data that were fed into the Estuary Health Index, as published in the NBA 2018 (Van Niekerk et al. 2019a), were used in the preparation of estuary pressure accounts (see Appendix A for more detail on data sources). Pressures were rated from 'low' to 'very high' depending on the magnitude of the pressure and the degree of impact it was having on the resource, with 'low' pressure rating associated with processes and/or biota remaining in a largely natural state and 'very high' associated with severely or critically modified processes and/or biotic responses. Given that the range of functional types in South Africa, with varying levels of sensitivity to pressures, the results of the Estuary Health Index were used as a guide to evaluating estuary specific sensitivity to a specific pressure on that estuary and then aggregated to biogeographical region or functional type level.

Water Resource Use: Historically, the assessment of water resource use in South Africa mostly relied on a macro-scale water resource planning model (WASM), providing annual summaries on the availability, supply and utilisation of water resources at regional and catchment scales for present and projected future situations (Schultz and Watson 2002; Van Niekerk et al. 2013). More recently simulated data on natural and current mean annual runoff (MAR) inflow to estuaries became available through regional-level water resources and flow requirement studies, and through regional-level desktop studies (e.g. Van Niekerk et al. 2015). Reduction in MAR was therefore used to quantify the extent of this pressure. To estimate the impact of this pressure on estuaries, the 'hydrology' score in the Estuary Health Index is used as a proxy (Figure 3.2). This score considers change in low flows (60%) and floods (40%) or overall percentage reduction in MAR. The Estuary Health Index rates condition indicator 'hydrology' as similarity to natural out of 100, with the pressure rated as 'low' if > 75% similar to natural (Categories A - B), 'medium' 75 - 60 % (Category C), 'high' 60 – 40 % (Category D), 'very high' < 40% (Categories E – F).

Table 3.5: Key data requirements for national-level estuary pressure accounting

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY
River inflow	Natural and current mean annual runoff into estuaries (unit= x10^6m^3 /a)	National water department
Land-use	National land cover change (unit=m^2)	DEFF
Wastewater volumes	Wastewater volumes entering estuaries and/or river reaches just upstream of estuaries (unit= M/L)	National, regional water departments, local authorities
Fish catches	Estimates of landed fish (legal or illegal) catches per estuary (unit =t)	National fisheries department
Artificial breaching	Records of estuary mouth manipulations (as captured in provincial approved maintenance management plans or recorded as illegal by compliance management)	Conservation agencies and provincial departments of environmental affairs
Alien invasive	Field observations of extent (unit=ha) and type of biological invasions per estuary.	NMU National Department of Agriculture (Land-use and Soil Management)
Extralimital species	Field observations of type and extent (abundance and no species) of biological invasions per estuary.	National fisheries department, SANBI
Estuarine condition	Condition of hydrology, hydrodynamics, physical habitat, water quality (disaggregated), macrophyte and fish indicators using the Estuary Health Index, as capture in NBA 2018, or updates thereof.	SANBI (supported by CSIR)

Land-use: The pressure was derived from visually examining Google Earth© and Landsat imagery by assessing the extent of **anthropogenic alteration** (e.g. canalisation, riparian infrastructure, infilling) in the EFZ of estuaries by a team of experts in a workshop environment. These observations were validated with field observations and available data captured in the NMU National Botanical Database (Adams et al. 2016). To provide a spatial estimate of the degree of intactness of the EFZ, the 2014 SANBI land-cover data (GeoTerraImage 2015) was disaggregated into natural and modified classes (artificial water bodies, urban (built-up) areas, mining, plantations and agriculture (croplands). The natural class also includes secondary natural, i.e. land that has been fallow for decades and is in the process of recovering (i.e. now supporting estuarine associated vegetation). The extent of this pressure was therefore estimated based on transformation in EFZ. To estimate the extent to which this pressure impacted estuaries, the 'physical habitat' condition indicator score in the Estuary Health Index is used as a proxy (Figure 3.2), where 'low' > 75% similar to natural (Categories A - B), 'medium' 75 - 60 % (Category C), 'high' 60 – 40 % (Category D), 'very high' < 40% (Categories E – F).

Exploitation of living resources: This pressure assessment focused on **fishing**, using available information on catch (tonnes) per estuary (Van Niekerk and Turpie, 2012; Lamberth and Turpie, 2003) and updating these with more recent data records on illegal catches ((e.g. sourced from DEFF and KZN-Wildlife) (Van Niekerk et al. 2019a) to estimate extent of pressure. The impact of this pressure on estuaries is partially derived from the Estuary Health Index score for 'fish' (Figure 3.2), but the fishing effort (e.g. number of fishers, gillnets versus fishing rods), catch composition and size, the age distribution of fish in sample data sets were also considered. 'very high' is associated with gillnetting or fish traps. 'high' generally indicates high recreational or subsistence exploitation. 'medium' similarly indicates a medium level of recreational or subsistence exploitation. While 'low' indicate little fishing pressure, all estuaries do reflect the impact of beach and nearshore fishing. A few systems were rated as 'None' as there were no fish in them (e.g. hypersaline estuaries).

Pollution: This pressure arises from numerous sources, including municipal and industrial wastewater disposal, urban stormwater runoff and agricultural return-flow. However, very little quantitative data available at the national-level being largely limited to volumes of municipal and industrial wastewater discharges. For this reason, the extent of pollution pressures focuses on **wastewater discharges.** To estimate the extent of this pressure, the annual volumes discharged to estuaries, or in the river reach just upstream of estuaries was used (Van Niekerk et al. 2019a), while the 'water quality' condition indicator (excluding salinity) in the Estuary Health Index was used as a proxy to estimate the degree of impact on affected estuaries (Van Niekerk et al. 2019a), where 'low' > 75% similar to natural (Categories A - B), 'medium' = 75 - 60 % (Category C), 'high' 60 – 40 % (Category D), 'very high' < 40% (Categories E – F).

Artificial beaching: Estuaries where inlets (or mouths) are artificially manipulated, were identified through various sources, including field observations, social media posts, literature, interactions with national and provincial authorities and NBA 2018 data (Van Niekerk et al. 2019a). The number of estuaries where artificial mouth manipulation was practised was used to estimate the extent of this pressure. To assess the impact of this pressure the Condition Indicator 'hydrodynamic' score in the Estuary Health Index (Figure 3.2) in affected systems were used as a proxy, where 'low' > 75% similar to natural (Categories A - B), 'medium' 75 - 60 % (Category C), 'high' 60 – 40 % (Category D), 'very high' < 40% (Categories E – F).

3.3.2 Biological Invasions (indirect pressures)

Invasive alien species pose a significant threat to estuaries causing both ecological and economic damage. For example, alien species can exert significant pressure on community structure and functions of indigenous specie, by modifying spatial and food chain resources, with direct or indirect effects on the occurrence of indigenous species (Drake et al. 1989; Leppäkoski et al. 2002; Elton 1958). Economic concerns include, for example, burrowing activities that can result in damage to banks (causing embankment erosion), clogging of water intake filters of industrial cooling water and drinking water plants, and alien species preying heavily upon native species of economic importance. In recent years, national and international environmental policy and legislation have begun to reflect these threats and respond accordingly (e.g. CBD 1992; IMO 2004; European Commission 2008).

The biological invasion account focuses on two key pressures, namely **invasive plants** and **alien/extralimital (translocated) fish.** For alien invasive plant species, the extent of invasion is estimated along estuaries (lower, middle and upper reaches) (Van Niekerk et al. 2019a). The degree of impact is estimated on a three-tier scale, with 'low' alien coverage < 5% of EFZ; 'medium' alien coverage 5-15% of EFZ, 'high' alien coverage > 15% of total EFZ area (available data on microalgal and macroalgal blooms was also recorded using the same method)

For **alien or extralimital (translocated) fish** the extent was estimated from species lists in estuaries, grouped into to 1) egg and larvae eaters, 2) habitat altering species and 3) predatory species (Van Niekerk et al. 2019a). The estimated degree of impact on estuaries was derived from the number and type of fish species present in each estuary, where 'low' 1-2 species, 'medium' 3-4 species, 'high' 5-6 species OR 1-2 predatory species OR Sharptooth catfish *Clarias gariepinus* present (if translocated), 'very High' >7 species OR 3- 4 predatory species.

3.4 Ecosystem Services Accounting

Ecosystem accounting aims to provide natural resource managers and policy makers with an overview of how changes in ecosystem extent and condition affect economic outputs and human welfare to ultimately reflect on sectoral and national monetary levels. In ecosystem accounting, ecosystem services are defined as the 'contributions that ecosystems make to **benefits** used in economic and other human activity (i.e. **they are contributions that ecosystems make to human wellbeing**, UN 2017). Of particular relevance is determining how changes in the supply of ecosystem services affect human wellbeing, and to understand this, it is necessary to understand the underlying links between ecosystem structure and function and the supply of ecosystem services as well as their demand.

In this preliminary exploration of physical accounting of ecosystem services, three benefits humans derive from estuaries are considered:

- Carbon sequestration for the mitigation of climate change (regulating services);
- Nursery function for important fisheries (provisioning services); and
- Habitat and refugia for rare endemic estuarine species (supporting services).

3.4.1 Carbon sequestration

'Blue carbon' refers to the carbon found in three biotic habitats: mangroves, seagrasses, and salt marshes (Adams et *al.* 2020). In addition, carbon is also stored in swamp forest, reeds and sedges – what is generally referred to as 'Mg' associated with freshwater wetland habitats. These habitats sequester carbon from the atmosphere and lock it into the soil. These habitats are unique in that the carbon that they sequester during photosynthesis is often moved from the short-term carbon cycle (10-100 years) to the long term carbon cycle (1000 years) and is continuously buried as slowly decaying biomass (Barbier et al. 2011). Blue carbon habitats thus have a much higher projected sequestration potential than terrestrial habitats. In addition to 'blue carbon', South Africa also supports swamp forests, reeds and sedges which are generally seen habitats which sequester 'teal carbon' as carbon captured in freshwater inland wetlands. However, these estuarine habitats are under pressure, thereby reducing their capacity to provide this ecosystem service. When these habitats are degraded they emit large amounts of CO_2 into the atmosphere contributing to global climate change with impacts on biodiversity, water supply, drought and floods, agriculture and human health. Reflecting on the above, the key data requirements for the physical accounting of carbon sequestration are listed in Table 3.6, while the key parameters applied in these accounts are described in Table 3.7.

Table 3.6: Key data requirements for physical accounting of carbon sequestration

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY
Extent of macrophyte habitat	Spatial extent (area=ha) of selected macrophyte estuarine habitats (National Estuarine Botanical Database).	NMU
Condition of macrophyte habitat	Condition of biotic indicator ('macrophytes') as capture in National Biodiversity Assessment: Estuarine Realm, or future updates thereof [Van Niekerk et al., 2020; Source: https://bgis.sanbi.org/])	SANBI (supported by CSIR)

Table 3.7: Description of parameters applied in physical accounting of carbon sequestration

PARAMETER	DESCRIPTION
Carbon stocks	Global average estimates for carbon stocks (to 1 m depth) are estimated at 386 Mg/ha for mangroves, 255 Mg/ha for salt marshes and 108 Mg/ha for seagrasses (Howard et al. 2014). Average estimates for swamp forest was not readily available are highly varied, thus for this study and average of 300 Mg/ha were used, while reeds and sedges were estimated at a much lower value of 100 Mg/ha (Adame et al 2015).
Macrophyte coverage	Adams et al. (2016) presented total area coverage and species composition for most South African estuaries.

3.4.2 Nursery function for important fisheries

Lamberth and Turpie (2003) showed that more than half of South Africa's estuarine-associated fish species are utilised in fisheries (subsistence, recreational and commercial). At least 60% of these species are considered entirely or partially dependent on estuaries. The total landed catch of fish taken directly from estuaries (3 700 tonnes per annum) is considerably lower than the total estimated catch of inshore marine fisheries (28 000 tonnes per annum). However, depending on the biogeographical region and fishery sector, more than 80% of the catch by inshore fisheries may comprise estuary-associated species. Thus, probably the most important value of estuaries to various fisheries species relates to the provision of sheltered nursery environments (Costanza et al. 1997; Cooper et al. 2003, Whitfield 1994).

Five key estuarine-dependent fish species important for food security and of commercial and / or recreational importance were selected as a case study, namely, Dusky kob *Argyrosomus japonicus,* White steenbras *Lithognathus lithognathus,* Spotter grunter *Pomadasys commersonnii,* Mullet *Chelon richardsonii,* Leervis *Lichia amia and* Elf *Pomatomus saltatrix.* The approach adopted here was to align, as far as possible, to existing assessment tools such as the NBA 2018, species red-listing under the SANBI Marine Programme and the National Status of Resources Report produced by DEFF Fisheries Research and Development (Van Niekerk et al. 2019a; Sink et al. 2019) to share and jointly improve data and information sourcing (Table 3.8).

Table 3.8: Key data requirements for physical accounting of nursery function for important fisheries and habitat and refugia for rare endemic species

DATA	DATA REQUIREMENT	RESPONSIBLE AUTHORITY
Estuary condition	Aggregated condition for estuaries (including the condition of individual abiotic and biotic indicators as captured in the National Biodiversity Assessment: Estuarine Realm, or future updates thereof [Van Niekerk et al. 2020; Source: https://bgis.sanbi.org/])	SANBI/DEFF (supported by CSIR)
Important nursery estuaries	Identified important nursery estuaries (Van Niekerk et al. 2015)	DEFF
National stock status assessments	Key estuarine fish stocks listed per level of exploitation	DEFF
IUCN red listing of species	The IUCN Red List is a species threat assessment and amongst others provides information about the range, population size, habitat and ecology, use and trade (Source: https://www.iucnredlist.org/)	SANBI/IUCN

Reflecting on the above, key parameters considered in the physical accounting of support to important fisheries by estuaries are listed in Table 3.9. To account for the extent of estuarine nursery areas, the number of estuaries considered important nurseries for selected fisheries species was used (as described in the NBA 2018 – Van Niekerk et al. 2019a).

Table 3.9: Description of key parameters applied in physical accounting of nursery function for important fisheries species

ASPECT	PARAMETER	DESCRIPTION
Status of estuarine nursery areas	Distribution of fisheries	Biogeographical regions within which fisheries for selected species are found
	Nursery systems	Number of estuaries acting as nursery areas for selected fisheries species
	Recruitment signal	Freshwater recruitment signals (i.e. assisting fish to 'find' estuaries) using the percentage of remaining (natural) MAR still reaching estuaries as a proxy.
	Good condition estuary nurseries	Percentage EFZ areas of important nursery estuaries where overall estuarine condition (as per Estuary Health Index) is still within near-natural to moderate condition
	Nursery area under high fishing pressure	Percentage EFZ areas of important nursery estuaries where very high/high fishing pressure has been observed
Status of fisheries	National stock status	Status of fisheries stocks as assessed and provided by the Department responsible for Fisheries and environment. Thresholds are proportion of pristine remaining; critical <2%, collapsed (<25%), over-exploited (<40%), optimum (40%-60%), under-exploited (>60%)
	Pristine biomass (%)	Parameters assessed are spawner biomass (breeding potential or biomass of reproductive adults), trends in catch per unit effort (CPUE) and current vs historical catch composition.
	IUCN threat status	Species threat status as determined by the IUCN (Critically endangered, endangered, vulnerable, least concern)

To gauge the condition of estuarine nursery areas, four parameters were considered namely, number of nursery systems, recruitment signal, good condition nursery areas remaining and nursery areas exposed to high fishing pressure. With specific reference to the extent of specific fisheries, distribution across biogeographical regions was used. To establish changes in fisheries condition, two parameters were applied, namely national stock status and IUCN threat status.

Estuarine fish-nursery contribution to estuarine and nearshore marine fisheries was categorised as 'high', 'medium', and 'low' based on the size of the estuaries and recruitment, diversity and abundance of exploited species in individual estuaries (Van Niekerk et al. 2015). Estuaries of low to medium-low importance were not evaluated as part of this study.

3.4.3 Habitat and refugia for rare endemic estuarine species

South African estuaries support several rare endemic estuarine species with very narrow distribution ranges, for example, the Bot river klipvis *Clinus spatulatus*, Knysna seahorse *Hippocampus capensis*, Estuarine pipefish *Syngnathus watermeyeri* (Van Niekerk et al. 2019a). These iconic species are not only of intrinsic value, but also often hold cultural significance for local residents and economies. In addition, South African estuaries also used to support two sawfish species, the Green sawfish *Pristis zijsron* and the Largetooth sawfish *Pristis pristis*, both of which are now extinct in South Africa.

The approach adopted here was to align as far as possible with existing assessment tools such as the NBA 2018 and the IUCN Red Listing of species of the SANBI Marine Programme (Van Niekerk et al. 2019a) to improve data sharing and information sourcing. Table 3.10 summarises parameters for consideration in the accounting for estuarine iconic species.

Table 3.10: Description of parameters applied in physical accounting of habitat and refugia for rare endemic estuarine species

ASPECT	PARAMETER	DESCRIPTION
Status of estuarine habitat	Regional extent	Biogeographical regions within which iconic estuarine species are found
	Genetic exchange mechanism	Connectivity of systems to the sea (i.e. open mouth conditions) and thereby to adjacent estuaries influences gene flow (exchange) between populations. Because freshwater flow is a key mechanism determining connectivity to the sea, the percentage of remaining (natural) MAR still reaching estuaries were used as a proxy for this parameter
	Good condition estuaries	Percentage EFZ areas of important nursery estuaries where overall estuarine condition (as per Estuary Health Index) is still within near-natural to moderate condition
	Nursery area under high fishing pressure	Percentage EFZ areas of important nursery estuaries where very high/high fishing pressure has been observed
Status of iconic species	IUCN threat status	Species threat status as determined by IUCN Red Listing (Critically endangered, endangered, vulnerable, least concern)

To account for the extent of estuarine nursery area, the number of estuaries considered key nurseries for each of the fisheries species was used to gauge the condition of estuarine nursery areas. Four parameters are considered namely, number of nursery systems, recruitment signal, good condition nursery areas remaining and nursery areas exposed to high fishing pressure. With specific reference to the extent of individual fisheries, the distribution across various biogeographical regions was used (as described in the NBA 2018 – Van Niekerk et al. 2019a). IUCN Red Listing threat status was used to reflect the conservation status of iconic species.

3.5 Data Availability and Confidence

The ecosystems accounts presented in this document were derived from available data and information sources (refer to Appendix A for details). An overview of data availability, as well as the confidence in such data, is provided below.

3.5.1 Extent accounting

Estuarine Functional Zones: The 'estuary space' as demarcated by the EFZ is used as the smallest unit in extent accounting by biogeographical regions and functional types. The EFZs of estuaries were mapped at a ~1:10,000 scale using a range of topographical maps (e.g. old DRDLR:NGI 1:10,000 black and white orthographic maps from the 1970s and DRDLR:NGI 1:10,000 +5m MSL topographical maps) as well as Google Earth imagery. However, at this scale many small inconsistencies were detected in the 'base maps', mainly relating to steep slopes in the confined, upper reaches of the numerous small rural estuaries (>50 ha in size). In many of these cases (e.g. less well documented Wild Coast estuaries), steep cliff faces resulted in permanent shadows making it impossible to see the actual edge of the flood plain and thus casting doubt on the accuracy of available topographical contours (i.e. contour displacement errors observed in rectified satellite imagery and Google Earth images). The exact limited of tidal penetration is also not known for several systems (landwards boundary estimated from 5 m contour). In addition, the historical delineation of some of the highly transformed estuaries (e.g. Diep/Rietvlei, Sout, Zeekoei) should be refined through more detailed 'historical ecology' studies.

Mapping error is estimated at <5% of total EFZ area at the national scale. It is recommending that a fine-scale mapping exercise (1:3,000 - similar to coastal ecosystem map) be undertaken to improve the resolution of the estuary ecosystem map as captured in the EFZs. This should be supported by ground-truthing of the lesser-known, more remote rural systems and a refined delineation of the natural state for severely/critically modified systems.

Open water area: 'Average open water area' (a proxy for aquatic habitat) is highly dynamic and relative ephemeral - depending on mouth state, river inflow conditions and state of the tide. Open water area should be determined from a range of high-resolution imagery over an extended period (> 10 years) representative of both open and closed condition. Currently, such data sets do not exist. Historical maps/datasets often also fall short of mapping the full tidal extent as they mostly only mapped the extent of salinity penetration, often resulting in only the lower half or third of estuaries being mapped. Given that 70% of South Africa's estuaries area < 5 ha automated remote sensing has not yet provided an accurate substitute for detailed 'manual' mapping of estuarine habitats.

In 2009 the open water area of South Africa's estuaries was once-off mapped at a 1: 10,000 scale, based on a satellite composite image of that year. This national standardise dataset was used as a baseline in the open water extent accounts, but it is recommended that more iterations of this mapping exercise be undertaken in future to generate a more representative baseline over time. Mapping error is estimated at 5-10% of total open water area at the national scale, but can > 30% for some of the very small estuaries.

Biotic habitat: Adams *et al.* (2016) presented the total area coverage and species composition of South African estuary habitats associated with different estuary types and bioclimatic regions. The paper published an estuary botanical database summarising data from literature and field studies on the coverage and species composition of macrophyte habitats in the country. The habitat cover worksheet contains each estuary name, coordinates, estuary type, biogeographic zone, habitat area and human pressures such as the extent of development. The species worksheet lists the presence of macrophyte species noted during field surveys. Details about the different vegetation maps were also included such as who mapped the estuary, what aerial photographs were used, and if the system was ground-truthed. Since that work (Adams *et al*. 2016), additional ground-truthing and vegetation mapping has been completed, mainly along the West Coast. Mangrove and salt marsh habitat extent was updated through mapping efforts in Google Earth. Polygons were drawn around these habitats, distinguished by colour, height and position in the estuary. Mapping was carried out by the same person to ensure consistency. The available vegetation maps were standardized and converted to meet SANBI specifications (available online at www.bgis.com). This resulted in some area changes as older maps were not based on the Estuarine Functional Zone (EFZ) and therefore required adjustment. Different projections have been used and topological errors were corrected (i.e. overlaps or slivers). Mapping error is estimated at 1 to 10% at the habitat scale, depending on the size of the estuary and type of habitat. For example, real-world mapping of a mosaic or ecotone of mangrove and salt marsh habitats in small estuaries involves expert judgment on habitat boundaries.

Currently, GIS vegetation maps are for 122 estuaries, with 41 mapped before the EFZ delineation (i.e. incomplete open water and flood plain areas) and only particular habitats such as mangrove distribution mapped for some estuaries. The geodatabase containing these shapefiles is available on request from the Botany Department at Nelson Mandela

University. The geodatabase contains the distribution and area covered by the different macrophyte habitats in South African estuaries. The associated metadata provide necessary details about the method followed.

3.5.2 Condition accounting

A significant constraint to change detection in estuaries is the lack of long-term measured data on South African estuaries. One of the challenges that led to this situation is the existence of a range of mandated departments involved in estuary management and therefore monitoring. An analysis of current monitoring initiatives shows that that up-to-date national scale field surveys of the abiotic (topography, bathymetry and sediment structure) and biotic components (plants, inverts fish and bird) are urgently needed (Van Niekerk et al. 2019a). National surveys were last carried out in early 1980 and 1990s. These surveys urgently need to be repeated in a once-off effort that is comparable with the earlier surveys. Towards this, it is recommended that DEFF expands its current fish (and invertebrate) monitoring surveys to also include a representative sample of small and large estuary types across biogeographical regions (where no such datasets presently exist, e.g. in protected areas).

To address possible data gaps the Estuary Health Index requires that a multidisciplinary group of estuarine scientists assesses the condition of each estuary in a workshop setting and a final assessment is based on their collective conceptual understanding of likely impacts affecting that system (DWAF 1999). The available information and expert knowledge is used to build a ‘conceptual picture’ of the probable natural state of each estuary and the changes that have occurred under current conditions. To develop a clear understanding of the status of estuarine health within South Africa, large complex systems such as the uMhlathuze Estuary / Richard’s Bay Harbour and uMfolozi/St Lucia were evaluated separately. Consequently, the health assessment was conducted for a total of 290 estuaries.

Condition data were available for all the estuaries of South Africa, but at varying levels of assessment resulting in different levels of confidence, with 7 % of estuaries being evaluated at the Comprehensive/Intermediate level, 12% at the Rapid level and 81% at a Desktop level. Small adjustments were made to individual Estuary Ecosystem Condition Indicators of historical condition assessments (in a moderating workshop environment) if pressure data indicated significant increase in resource use, e.g. increase in illegal gillnetting along Subtropical and Tropical coasts or construction of a new dam in the catchment.

4. EXTENT ACCOUNTS

4.1 Extent Accounts for Estuaries by Biogeographical Region and Estuary Functional Type

Extent accounts for estuary ecosystems are organised per estuary functional type and across the four biogeographical regions in South Africa. These are presented in Tables 4.1 (expressed in the number of estuaries) and in Table 4.2 (expressed as total EFZ area). The opening stock is an estimate of natural circumstances (~1750,) while the closing stock reflects the situation in 2018. Noteworthy, is the change in Subtropical region, where in the 1970, an estuarine lake (uMhlathuze) was subdivided to create an estuarine bay (Richards Bay Estuary) and a predominantly open system (uMhlathuze Sanctuary) to accommodate a port development. This resulted in a change in the number of estuaries in South Africa (from 289 to 290), as well as a redistribution of numbers in the affected in estuary type categories (Table 4.1).

Table 4.1: Extent account for estuaries by biogeographical region and estuary functional type (expressed as the number of estuaries)

		BIOGEOGRAPHICAL REGION			
		COOL TEMPERATE	WARM TEMPERATE	SUBTROPICAL	TROPICAL
Opening stock (~1750):	**289**	**33**	**124**	**130**	**2**
Estuarine Lake	12	4	3	3	2
Estuarine Bay	2	0	1	1	0
Estuarine Lagoon	1	1	0	0	0
Predominantly Open	44	3	25	16	0
Large Temporarily Closed	94	9	40	45	0
Small Temporarily Closed	116	8	48	60	0
Large Fluvially Dominated	7	1	1	5	0
Small Fluvially Dominated	7	1	6	0	0
Arid Predominantly Closed	6	6	0	0	0
Natural expansion/regression:	*-*	*-*	*-*	*-*	*-*
Managed expansion/regression:	***+1***	***0***	***0***	***+1***	*0*
Estuarine Lake	*-1*	*0*	*0*	*-1*	*0*
Estuarine Bay	*+1*	*0*	*0*	*+1*	*0*
Estuarine Lagoon	*0*	*0*	*0*	*0*	*0*
Predominantly Open	*+1*	*0*	*0*	*+1*	*0*
Large Temporarily Closed	*0*	*0*	*0*	*0*	*0*
Small Temporarily Closed	*0*	*0*	*0*	*0*	*0*
Reclassifications (+/-):	*-*	*-*	*-*	*-*	*-*
Reappraisals (+/-):	*-*	*-*	*-*	*-*	*-*
Closing stock (2018):	**290**	**33**	**124**	**131**	**2**
Estuarine Lake	11[1]	4	3	2	2
Estuarine Bay	3[1]	0	1	2	0
Estuarine Lagoon	1	1	0	0	0
Predominantly Open	45[1]	3	25	17	0
Large Temporarily Closed	94	9	40	45	0
Small Temporarily Closed	116	8	48	60	0
Large Fluvially Dominated	7	1	1	5	0
Small Fluvially Dominated	7	1	6	0	0
Arid Predominantly Closed	6	6	0	0	0

[1]uMhlathuze was an Estuarine Lake but was subdivided into an Estuarine Bay (Richards Bay Estuary) and Predominantly Open System (uMhlathuze Sanctuary) in 1970 through port development

This change is also reflected in the total EFZ area in the estuary functional types of the Subtropical region (Table 4.2). Therefore, while there has been a change in the number of estuaries, and shifts between estuary functional types, the total EFZ area of estuaries in South Africa (and the Subtropical region) has not changed markedly.

Table 4.2: Extent account for estuaries by biogeographical region and estuary functional type (expressed as EFZ extent in hectares)

		BIOGEOGRAPHICAL REGION			
		COOL TEMPERATE	WARM TEMPERATE	SUBTROPICAL	TROPICAL
Opening stock (~1750):	**200,736**	**37,677**	**44,501**	**110,392**	**8,166**
Estuarine Lake	111,657	7,238	14,389	81,864	8,166
Estuarine Bay	5,826	0	3,011	2,815	0
Estuarine Lagoon	6,016	6,016	0	0	0
Predominantly Open	40,924	15,455	17,782	7,687	0
Large Temporarily Closed	16,161	3,949	7,002	5,211	0
Small Temporarily Closed	4,224	553	1,623	2,048	0
Large Fluvially Dominated	14,358	3,020	573	10,766	0
Small Fluvially Dominated	126	4	122	0	0
Arid Predominantly Closed	1,442	1,442	0	0	0
Natural expansion/regression	-	-	-	-	-
Managed expansion/regression:	***0***	***0***	***0***	***0***	***0***
Estuarine Lake	*-11,996*	*0*	*0*	*-11,996*	*0*
Net change as % of opening	*-10.8%*	*0*	*0*	*-14.7%*	*0*
Estuarine Bay	*+6,354*	*0*	*0*	*+6,354*	*0*
Net change as % of opening	*+109.2%*	*0*	*0*	*+225.7%*	*0*
Estuarine Lagoon	*0*	*0*	*0*	*0*	*0*
Predominantly Open	*+5,642*	*0*	*0*	*+5,642*	*0*
Net change as % of opening	*+13.9%*	*0*	*0*	*+73.4%*	*0*
Large Temporarily Closed	*0*	*0*	*0*	*0*	*0*
Small Temporarily Closed	*0*	*0*	*0*	*0*	*0*
Large Fluvially Dominated	*0*	*0*	*0*	*0*	*0*
Small Fluvially Dominated	*0*	*0*	*0*	*0*	*0*
Arid Predominantly Closed	*0*	*0*	*0*	*0*	*0*
Reclassifications (+/-):	-	-	-	-	-
Reappraisals (+/-):	-	-	-	-	-
Closing stock (2018):	**200,736**	**37,677**	**44,501**	**110,392**	**8,166**
Estuarine Lake	99,661	7,238	14,389	69,868	8,166
Estuarine Bay	12,180	0	3,011	9,169	0
Estuarine Lagoon	6,016	6,016	0	0	0
Predominantly Open	46,566	15,455	17,782	13,329	0
Large Temporarily Closed	16,161	3,949	7,002	5,211	0
Small Temporarily Closed	4,224	553	1,623	2,048	0
Large Fluvially Dominated	14,358	3,020	573	10,766	0
Small Fluvially Dominated	126	4	122	0	0
Arid Predominantly Closed	1,442	1,442	0	0	0

The above physical extent accounts for estuaries demonstrate how, for different categories of estuary, increases and decreases in extent can be reflected, that is natural expansion/regression, managed expansion/regression, reclassifications (+/-) and reappraisals (+/). To provide a more concise summary the focus will mostly be on managed expansion/regression, but accounts can readily be refined to include more categories in future where and if the resolution in data becomes available.

4.2 Extent Accounts for Estuarine Habitat

For national-level accounting, estuarine habitat is grouped into abiotic habitat and biotic habitat, where aquatic (open water area), floodplain and developed flood plain comprise the key abiotic habitat types; and the key estuarine vegetation type (see Table 2.5) comprise the biotic habitat.

Table 4.3, provides the extent account for the abiotic habitat across the four biogeographical regions. Given the limitations in historical data and confidence in current data sets, these accounts could not be disaggregated into the finer functional groups. South Africa has incomplete data on the natural states (~1750) to populate opening stocks for abiotic habitats. Therefore, only the closing stocks (2018) are provided which will become the baseline for future accounts. In 2018, the total the aquatic habitat (open water area) comprised 58,994 ha (29% of EFZ extent), while floodplain habitat comprised 141,742 ha (71% of EFZ extent). The ratio between aquatic; floodplain habitat in the Cool and Warm Temperate regions is relatively low (1:3 and 1:4 respectively) compared with the distribution in the Subtropical and Tropical regions (1:2 and 1:1 respectively). This is indicative of the extensive flood plain areas typical of the Temperate regions, with more even distribution between abiotic habitats in the Tropical/Subtropical regions. Nearly 30,339 ha of the abiotic floodplain area is under some form of altered land-use, but still largely subject to physical processes like inundation by floods and erosion. High-resolution information was not available to identify 'developed floodplain' areas armoured against these natural physical processes (e.g. sea walls and high levees) (e.g. representative of a managed regression of physical habitat).

Table 4.3: Extent account for abiotic estuarine habitat by biogeographical region (expressed as habitat in hectares)

		BIOGEOGRAPHICAL REGION			
		COOL TEMPERATE	WARM TEMPERATE	SUBTROPICAL	TROPICAL
Opening stock (~1750):	..	..	..	..	..
Aquatic (open water) habitat	..	Incomplete historical data			
Floodplain	..				
*Floodplain (developed)	..				
Natural expansion/regression	-	-	-	-	-
Managed expansion/regression:	-	-	-	-	-
Reclassifications (+/-):	-	-	-	-	-
Reappraisals (+/-):	-	-	-	-	-
Closing stock (2018):	**200,736**	**37,677**	**44,501**	**110,392**	**8,166**
Aquatic (open water) habitat	58,994	9,529	8,474	37,544	3,447
Floodplain	111,403	22,122	26,997	57,688	4,546
Floodplain (developed)	30,339	6,026	9,030	15,160	123

** Developed floodplain may still be subject to natural physical processes such as floods (note that any biodiversity losses are accounted for in biotic habitat accounts)*

The extent account for biotic habitat across the four biogeographical regions, as represented by key estuarine vegetation types amounts to 39,772 ha (Table 4.4). In this account available data from the 1920s/30s (albeit only for total habitat area) constitute the opening stock and data from 2018 the closing stock. Climatic conditions (biogeography) restrict mangroves to the Warm Temperate, Subtropical and Tropical regions. Although salt marsh vegetation spans all biogeographic regions, it is most dominant in the Cool and Warm Temperate regions. Only 20% of estuaries (70) support submerged aquatic macrophytes as these species are sensitive to changes to water level, turbidity, nutrients and salinity. Reeds and sedges occur in brackish conditions throughout South Africa, while swamp forests are mostly restricted to the Subtropical and Tropical regions (Adams et al. 2016).

Table 4.4: Extent account for biotic estuarine habitat by biogeographical region (expressed habitat in hectares)

		BIOGEOGRAPHICAL REGION			
		COOL TEMPERATE	**WARM TEMPERATE**	**SUBTROPICAL**	**TROPICAL**
Opening stock (~1750):	**22,920**	-	-	-	-
Mangroves	**1,576**	Incomplete historical data			
Intertidal salt marsh	**5,354**				
Supratidal salt marsh	**15,051**				
Submerged macrophytes	**2,515**				
Reeds & sedges	**..**				
Swamp forests	**..**				
Natural expansion/regression	-	-	-	-	-
Managed expansion/regression:	*-5,631*	..	..	..	..
Mangroves	*+97*	..	..	..	..
Net change as % of opening	*+6.2%*				
Intertidal salt marsh	*-568*	..	..	..	..
Net change as % of opening	*-10.6%*				
Supratidal salt marsh	*-4,979*	..	..	..	..
Net change as % of opening	*-33.1%*				
Submerged macrophytes	*-180*	..	..	..	..
Net change as % of opening	*+7.2%*				
Reeds & sedges	..	..	..	..	..
Swamp forests	..	..	..	..	..
Reclassifications (+/-):	-	-	-	-	-
Reappraisals (+/-):	-	-	-	-	-
Closing stock (2018):	**39,772**	**13,061**	**8,197**	**15,951**	**2,563**
Mangroves	1,673	0	25	1,577	71
Intertidal salt marsh	4,786	2,339	1,887	502	58
Supratidal salt marsh	10,072	6,302	2,704	837	229
Submerged macrophytes	2,695	593	939	488	675
Reeds & sedges	17,184	3,827	2,641	10,472	244
Swamp forests	3,362	0	1	2,075	1,286

Evident from the extent account for biotic habitats is that the greatest loss in habitat between 1920/30s (baseline) and 2018, occurred in supratidal salt marsh habitats (Supratidal -4,979 ha and Subtidal -568 ha) primarily as a result of urban and agricultural intensive land-use development (Table 4.4). Supratidal salt marsh typically occurs up to the 2.5 m contour, most removed from the open water, sometimes the ecotone between intertidal salt marsh and terrestrial vegetation and, therefore it is the most likely habitat to be affected by intensive land-use (Adams et al. 2016). Intertidal salt marsh has been lost from several estuaries, mainly as a result of the construction of bridges, causeways and jetties. Although the area covered by mangroves in South Africa is small they form an important ecological component providing numerous ecosystem services. It is estimated that nearly 300 ha of mangrove habitat has been lost over time due to development, resource utilisation, grazing and changes in mouth condition. The most significant loss in mangroves is estuaries occurred as a result of port development in Durban Bay (Begg 1978; Forbes and Demetriades 2009). However, overall mangrove area in the country increased due to marked expansion of this habitat in the Subtropical region (uMhlathuze Estuary), associated with Richard's Bay port development where the deepening of the mouth and altering of the river alignment resulted in a larger intertidal habitat (Bedin 2001). These intertidal areas were rapidly colonised by white mangrove *Avicennia marina* thus increasing its extent by about 97 ha since the 1920/30s. Submerged macrophyte coverage declined by 180 ha due to declining water quality. However, the inter-annual coverage of submerged macrophytes can vary greatly as they are strongly influenced by flood events and changing mouth states (Adams 2016).

5. CONDITION ACCOUNTS

5.1 National Estuarine Ecosystem Condition Index

The **National Estuarine Ecosystem Condition Index** provides a high-level overview of the condition of estuaries in South Africa (Table 5.1), comprising **a single value aggregate** of the average condition of the nine estuary functional types (see Section 2.2). Each estuary functional type in the index has an equal weighing to ensure sensitivity to changes in condition regardless of average estuary size in a type. In other words, each estuary functional type is equally weighted in the overall national index, regardless of its total EFZ area to allow for sensitivity to change in smaller functional types.

Table 5.1: National Estuarine Ecosystem Condition Index based on the arithmetic mean of the estuary functional types (equal weighting of estuary functional types)

ESTUARY FUNCTIONAL TYPE	EFZ AREA (ha)	ESTUARY FUNCTIONAL TYPE CONDITION	
		Opening (~1750)	Closing (2018)
Arid Predominantly Closed	1,442	100	44.9
Estuarine Bay	12,180	100	48.3
Estuarine Lagoon	6,016	100	84.6
Estuarine Lake	86,348	100	54.2
Large Fluvially Dominated	14,358	100	56.3
Large Temporarily Closed	16,475	100	64.6
Predominantly Open	57,768	100	64.2
Small Fluvially Dominated	126	100	92.8
Small Temporarily Closed	6,022	100	63.6
NATIONAL ESTUARINE ECOSYSTEMS CONDITION INDEX RATING (arithmetic mean of nine functional types)	**200,736**	**100**	**63.7**

The **National Estuarine Ecosystem Condition Index for South Africa is 63.7** (out of 100) (Figure 5.1), indicating that there has been a significant decline in overall estuary condition in South Africa from natural. The degradation of Arid Predominantly Closed systems (with only 45% of processes and functioning still intact) show the largest decline in condition, while Small Fluvially Dominated systems (93% largely natural) show the least decline.

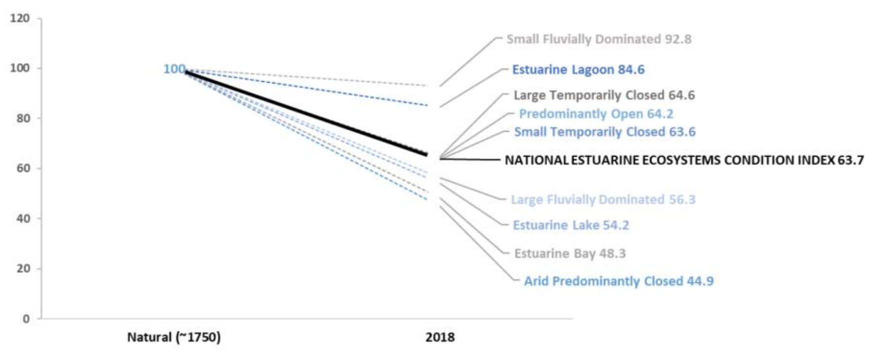


Figure 5.1: National Estuarine Ecosystem Condition Index aggregated from the nine estuary functional types overall condition

In support of the **National Estuarine Ecosystem Condition Index**, Figures 5.2 and 5.3 depict the condition of all 290 estuaries in relation to geographical location and estuary size, in Figure 5.2 estuary condition reflected on the vertical axis (estuaries higher on the graph are in better condition) and grouped into six size categories (larger bubbles represent larger estuaries). Results are plotted from west to east as the distance from the Orange Estuary (situated on the western boundary).

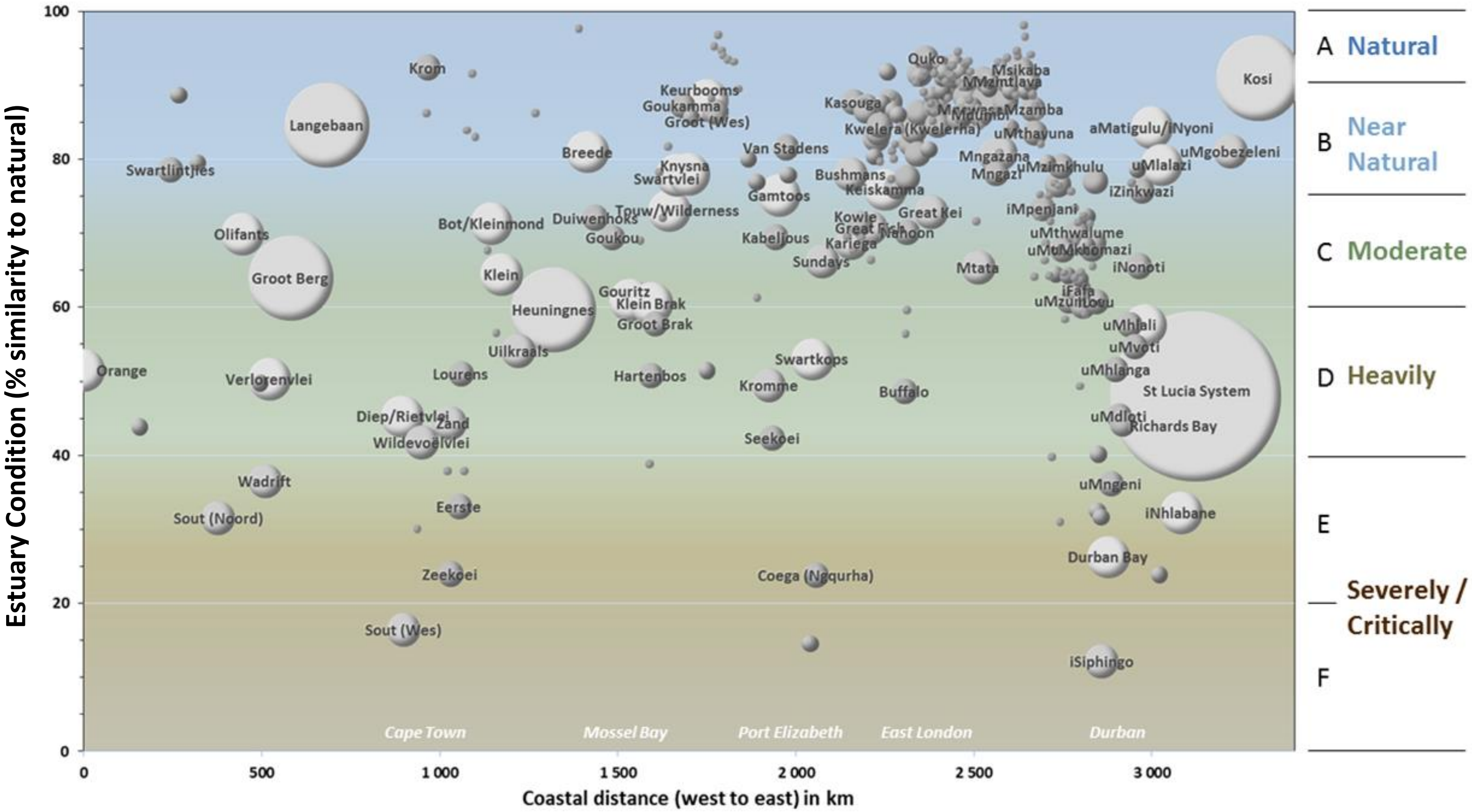


Figure 5.2: Bubble plot of South African estuaries arranged from west to east along the coast showing estuary condition (as % similarity to natural) (left axis), ecological condition category (A-F) (right axis) and relative size (represented by the size of bubble). (Size of EFZ grouped into six categories: Very Large: > 10 000 ha, Large: 5 000 – 10 000 ha, Medium – Large: 1 000 – 5 000 ha, Medium: 500 -1 000 ha, Small: 100 – 500 ha, Very small: < 50 ha). (Source: Van Niekerk et al. 2019a)

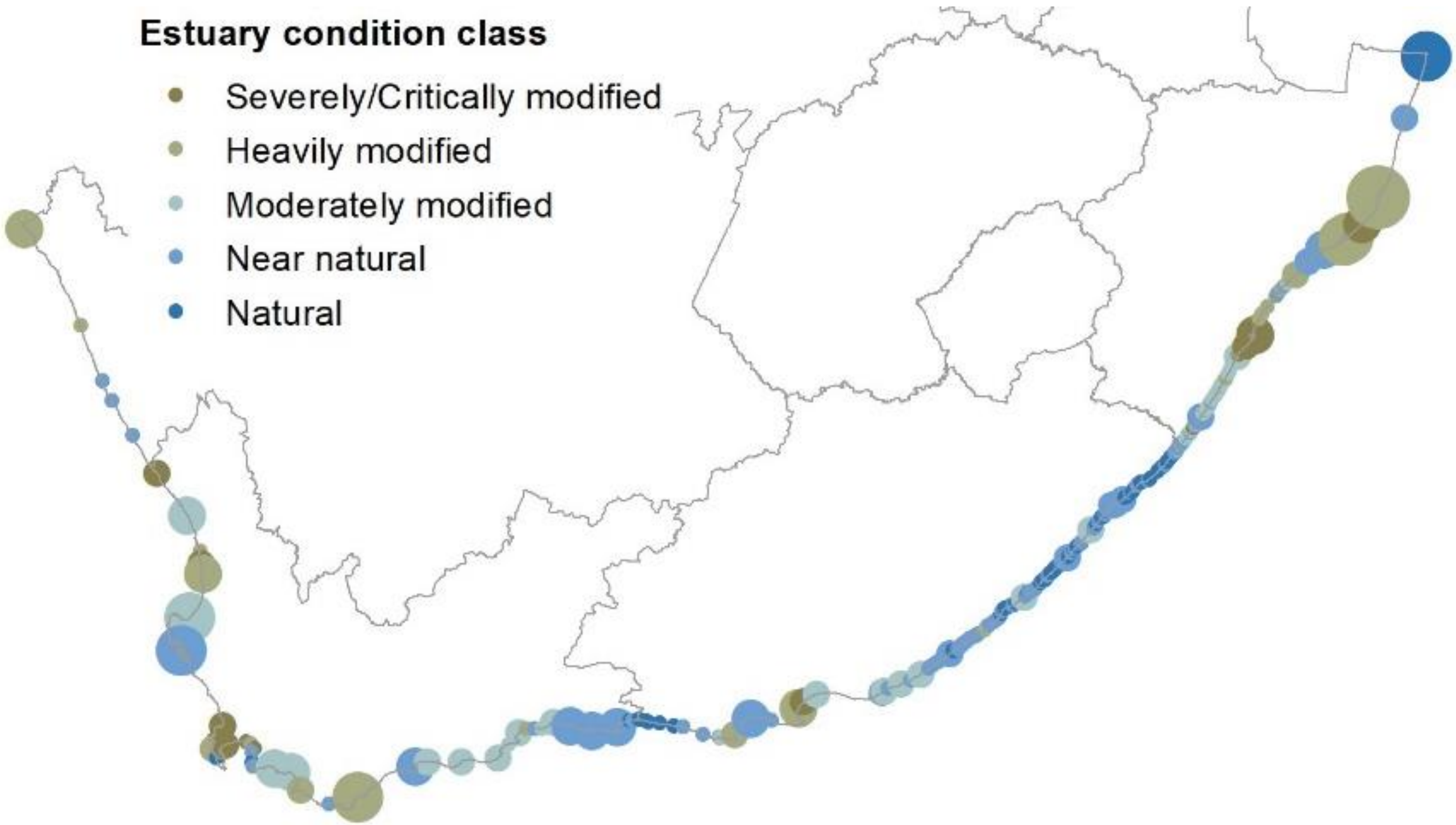


Figure 5.3: Estuary Condition grouped into five categories with bubbles displaying relative size and location of estuaries (Source: Van Niekerk et al. 2019a)

5.2 Condition Account by Biogeographical Region

Tables 5.2 and 5.3 present the estuarine condition accounts organised per biographical region, expressed as a percentage of estuaries and a percentage of EFZ area, respectively. Accounts consider a reference condition (around 1750) as opening account, where all estuaries would have been in pristine (natural) condition. The difference in the total number of estuaries between opening (natural) and closing (2018) stocks also reflects the subdivision of the estuarine lake into two systems in the Subtropical region.

Table 5.2: Condition account by biogeographical region (expressed as a percentage of estuaries per ecological condition category)

	# ESTUARIES	ECOLOGICAL CONDITION CATEGORY (% ESTUARIES)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):	**289**	**100.0**	**0**	**0**	**0**	**0**
Cool Temperate	**33**	100.0	0	0	0	0
Warm Temperate	**124**	100.0	0	0	0	0
Subtropical	**130**	100.0	0	0	0	0
Tropical	**2**	100.0	0	0	0	0
Increase/Decrease:		***-79.3***	***+39.7***	***+20.3***	***+11.7***	***+7.6***
Cool Temperate		*-93.9*	*+24.2*	*+15.2*	*+30.3*	*+24.2*
Warm Temperate		*-75.0*	*+47.6*	*+15.3*	*+8.1*	*+4.0*
Subtropical		*-80.2*	*+35.9*	*+26.7*	*+10.7*	*+6.9*
Tropical		*-50.0*	*+50.0*	*0.0*	*0.0*	*0.0*
Closing stock (2018):	**290[1]**	**20.7**	**39.7**	**20.3**	**11.7**	**7.6**
Cool Temperate	**33**	6.1	24.2	15.2	30.3	24.2
Warm Temperate	**124**	25.0	47.6	15.3	8.1	4.0
Subtropical	**131[1]**	19.8	35.9	26.7	10.7	6.9
Tropical	**2**	50.0	50.0	0.0	0.0	0.0

[1]uMhlathuze was an Estuarine Lake (Subtropical) but was subdivided into an Estuarine Bay (Richards Bay Estuary) and Predominantly Open System (uMhlathuze Sanctuary) in 1970 through port development

Based on the condition account expressed as the number of estuaries (Table 5.2), in 2018 only 60 of South Africa's estuaries were still in a natural state, mostly represented by systems in the Warm Temperate (31) and Subtropical regions (26). However, almost half of the modified systems still are in a near-natural state (115), again dominated by systems in the Warm Temperate (59) and Subtropical regions (47). Proportionally, estuaries in the Cool Temperate region have been subject to the highest levels of degradation with 23 of the region's 33 estuaries falling into heavily and severely/critically modified categories, mainly located near coastal urban centres (e.g. Cape Town). Converting these numbers to percentages (Figure 5.3), the 2018 results reveal that only 21% of South Africa's estuaries are still in a natural state (A category), with 40% in a near-natural state (B category), 20% in a moderately modified state (C category), 12% in a heavily modified state (D category), and 7% in a severely/critically modified state. Estuaries in natural and near-natural states are mainly located in the Tropical (100%), Warm Temperate (73% of systems in the region) and Subtropical (50% of systems in the region) regions, while the estuaries in the Cool Temperate region were characterised by heavily to Severely/Critically modified systems (55% of systems in the region).

A different picture, however, emerges when condition distribution is expressed in terms percentage of EFZ area (Table 5.3 and Figure 5.4). Only 5.3% and 17.3% of EFZ still remain in a natural or near-natural state, mostly located in the Warm Temperate and Tropical regions. More than 57% of the estuarine functional area is already in a heavily modified state (partly an artefact of the largest estuary in South Africa (the St Lucia /uMfolozi system) falling within this category), and an additional 4.5% already critically modified.

Table 5.3: Condition account by biogeographical region (expressed as a percentage of EFZ area per ecological condition category)

	EFZ AREA (ha)	ECOLOGICAL CONDITION CATEGORY (% EFZ area) NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):	**200,736**	**200,736**	**0**	**0**	**0**	**0**
Cool Temperate	37,677	100.0	0	0	0	0
Warm Temperate	44,501	100.0	0	0	0	0
Subtropical	110,392	100.0	0	0	0	0
Tropical	8,166	100.0	0	0	0	0
Increase/Decrease in stock:		*-94.7*	*+17.3*	*+15.2*	*+57.6*	*+4.5*
Cool Temperate		*-99.6%*	*+17.1%*	*+50.7%*	*+25.5%*	*+6.3%*
Warm Temperate		*-96.1%*	*+41.2%*	*+17.9%*	*+35.7%*	*+1.3%*
Subtropical		*-98.7%*	*+8.3%*	*+3.1%*	*+81.7%*	*+5.5%*
Tropical		*-10.2%*	*+10.2%*	*0*	*0*	*0*
Closing stock (2018):	**200,736**	**5.3**	**17.3**	**15.2**	**57.6**	**4.5**
Cool Temperate	37,677	0.4	17.1	50.7	25.5	6.3
Warm Temperate	44,501	3.9	41.2	17.9	35.7	1.3
Subtropical	110,392	1.3	8.3	3.1	81.7	5.5
Tropical	8,166	89.8	10.2	0.0	0.0	0.0

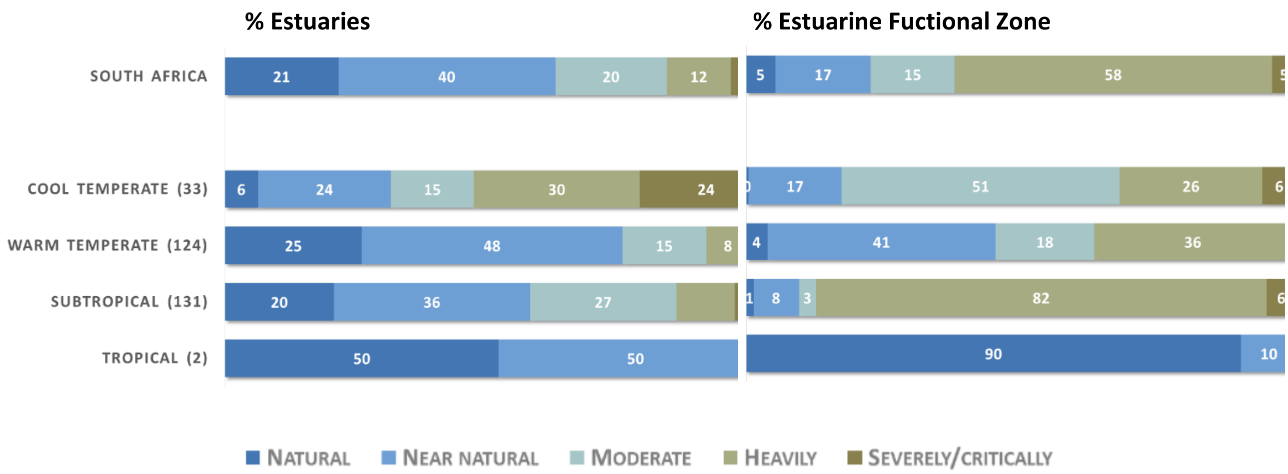


Figure 5.4: Relative distribution of ecological condition categories across biogeographical regions (2018) - expressed as a percentage of the [number of] estuaries per region (left) and a percentage of total EFZ area per region (right)

The different results for 'estuary numbers' and 'estuarine functional area', indicates that smaller estuaries tend to be in better condition. This is unsurprising as these systems are not subject to the same level of human pressures compared with the larger, more productive systems. Typically, larger estuaries are more heavily affected by catchment and direct development pressures, resulting in their overall poorer condition. However, larger systems are more resilient to human pressures compared with the smaller systems, the former generally having larger assimilative capacities and stronger flushing mechanisms (e.g. tidal exchange).

To provide resolution on the condition of specific estuarine ecosystem indicators, Tables 5.4 and 5.5 present the condition accounts across the biogeographical region for abiotic and biotic indicators, respectively.

Table 5.4: Condition account for abiotic Estuary Ecosystem Condition Indicators by biogeographical region (expressed as a percentage of EFZ area per ecological condition category)

	EFZ AREA (ha)	ECOLOGICAL CONDITION CATEGORY (% of EFZ area)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):						
HYDROLOGY	**200,736**	100.0	0	0	0	0
HYDRODYNAMICS	**200,736**	100.0	0	0	0	0
SALINITY	**200,736**	100.0	0	0	0	0
WATER QUALITY	**200,736**	100.0	0	0	0	0
PHYSICAL HABITAT	**200,736**	100.0	0	0	0	0
Increase/Decrease:						
HYDROLOGY		*-89.8*	*+52.9*	*+22.1*	*+8.5*	*+6.4*
HYDRODYNAMICS		*-77.4*	*+12.8*	*+12.2*	*+13.3*	*+39.1*
SALINITY		*-84.6*	*+13.4*	*+14.3*	*+17.9*	*+39.0*
WATER QUALITY		*-90.4*	*+10.1*	*+46.7*	*+10.2*	*+23.4*
PHYSICAL HABITAT		*-91.6*	*+18.2*	*+47.2*	*+14.3*	*+11.8*
Closing stock (2018):						
HYDROLOGY	**200,736**	**10.2**	**52.9**	**22.1**	**8.5**	**6.4**
Cool Temperate	37,677	18.5	7.4	50.8	9.2	14.2
Warm Temperate	44,501	17.6	20.3	41.5	6.9	13.7
Subtropical	110,392	5.2	78.0	6.1	9.5	1.2
Tropical	8,166	0.0	100.0	0.0	0.0	0.0
HYDRODYNAMICS	**200,736**	**22.6**	**12.8**	**12.2**	**13.3**	**39.1**
Cool Temperate	37,677	23.8	36.1	23.6	6.4	10.1
Warm Temperate	44,501	46.6	15.7	9.3	26.3	2.1
Subtropical	110,392	7.6	4.7	9.7	11.4	66.7
Tropical	8,166	89.8	0.0	10.2	0.0	0.0
SALINITY	**200,736**	**15.4**	**13.4**	**14.3**	**17.9**	**39.0**
Cool Temperate	37,677	22.4	14.0	34.0	21.4	8.2
Warm Temperate	44,501	19.6	32.0	12.4	32.3	3.7
Subtropical	110,392	5.9	6.7	8.6	12.1	66.7
Tropical	8,166	89.8	0.0	10.2	0.0	0.0
WATER QUALITY	**200,736**	**9.6**	**10.1**	**46.7**	**10.2**	**23.4**
Cool Temperate	37,677	16.4	2.4	0.2	29.1	51.9
Warm Temperate	44,501	4.3	30.8	43.5	10.2	11.2
Subtropical	110,392	2.8	5.1	67.3	4.5	20.3
Tropical	8,166	100.0	0.0	0.0	0.0	0.0
PHYSICAL HABITAT	**200,736**	**8.4**	**18.2**	**47.2**	**14.3**	**11.8**
Cool Temperate	37,677	16.7	22.6	14.6	33.4	12.8
Warm Temperate	44,501	1.6	43.4	39.9	12.8	2.3
Subtropical	110,392	2.3	7.1	64.9	9.5	16.3
Tropical	8,166	89.8	10.2	0.0	0.0	0.0

Considering the condition of the Estuary Ecosystem Indicator ‘hydrology’ (Table 5.4), results show that Tropical and Subtropical estuaries are in a relatively intact state with 100% and 83% of extent in a natural or near-natural condition, while the Cool and Warm Temperate estuaries are largely in a moderately to severely/critically modified state, with 51% and 41% respectively, in a moderately modified state and an additional 23% and 20% in heavily to severely/critically modified condition. The condition indicator ‘hydrodynamics’ reveals most Cool Temperate, Warm Temperate and Tropical estuaries are in a relatively good state with 60%, 63% and 90% of extent in a natural or near-natural condition, respectively. However, 66% of the estuarine extent in the Subtropical region is in severely/critically modified.

The condition indicator ‘Salinity’ shows that while 90% of estuarine extent in the Tropical region is in a natural or near-natural state, only 36% and 52% of Cool Temperate and Warm Temperate estuaries is in similar condition. About 78%

of Subtropical estuaries are in a heavily to severely/critically modified state. Of concern is the condition of indicator 'Water quality' where 52% of estuarine extent in the Cool Temperate region is in a severely/critically modified state, with an addition 29% in heavily modified state. In contrast, 35% and 100% of Warm Temperate and Tropical regions are in a natural to near-natural condition. In the Subtropical region 67% of estuarine extent also is moderately modified state. Results on the 'Physical habitat' indicator are more encouraging with 40%, 43% and 100% of Cool Temperate, Warm Temperate and Subtropical regions still in natural or near-natural condition, while 65% of Subtropical estuarine area is in a moderately modified state.

Table 5.5: Account for abiotic Estuary Ecosystem Condition Indicators by biogeographical region (expressed as a percentage of EFZ per ecological condition category)

	EFZ AREA (ha)	ECOLOGICAL CONDITION CATEGORY (% of EFZ area)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):						
MICROALGAE	**200,736**	100	0	0	0	0
MACROPHYTES	**200,736**	100	0	0	0	0
INVERTEBRATES	**200,736**	100	0	0	0	0
FISH	**200,736**	100	0	0	0	0
BIRDS	**200,736**	100	0	0	0	0
Increase/Decrease:						
MICROALGAE		*-94.6*	*+14.7*	*+24.6*	*+14.1*	*+41.2*
MACROPHYTES		*-98.8*	*+17.6*	*+41.6*	*+21.2*	*+18.5*
INVERTEBRATES		*-98.3*	*+13.8*	*+12.8*	*+25.7*	*+46.0*
FISH		*-99.6*	*+4.4*	*+13.3*	*+60.8*	*+21.2*
BIRDS		*-93.3*	*+18.8*	*+15.7*	*+43.7*	*+15.1*
Closing stock (2018):						
MICROALGAE	**200,736**	**5.4**	**14.7**	**24.6**	**14.1**	**41.2**
Cool Temperate	37,677	0.1	17.4	50.7	9.4	22.4
Warm Temperate	44,501	3.1	29.0	49.2	14.2	4.6
Subtropical	110,392	1.9	8.3	7.6	16.8	65.4
Tropical	8,166	89.8	10.2	0.0	0.0	0.0
MACROPHYTES	**200,736**	**1.2**	**17.6**	**41.6**	**21.2**	**18.5**
Cool Temperate	37,677	0.6	22.8	6.2	57.4	13.0
Warm Temperate	44,501	2.2	28.1	19.3	38.6	11.7
Subtropical	110,392	1.0	5.5	65.7	3.3	24.4
Tropical	8,166	0.0	100.0	0.0	0.0	0.0
INVERTEBRATES	**200,736**	**1.7**	**13.8**	**12.8**	**25.7**	**46.0**
Cool Temperate	37,677	0.7	22.5	15.9	48.7	12.3
Warm Temperate	44,501	5.7	28.5	19.0	36.6	10.2
Subtropical	110,392	0.5	5.2	3.6	15.4	75.3
Tropical	8,166	0.0	10.2	89.8	0.0	0.0
FISH	**200,736**	**0.4**	**4.4**	**13.3**	**60.8**	**21.2**
Cool Temperate	37,677	0.6	1.0	0.0	73.0	25.4
Warm Temperate	44,501	0.8	12.5	31.9	43.9	11.0
Subtropical	110,392	0.1	2.6	4.7	67.2	25.4
Tropical	8,166	0.0	0.0	89.8	10.2	0.0
BIRDS	**200,736**	**6.7**	**18.8**	**15.7**	**43.7**	**15.1**
Cool Temperate	37,677	8.0	38.4	12.8	21.3	19.5
Warm Temperate	44,501	3.8	35.6	51.3	4.7	4.6
Subtropical	110,392	0.6	6.7	3.4	70.4	18.8
Tropical	8,166	100.0	0.0	0.0	0.0	0.0

In the biotic Estuary Ecosystem Condition Indicator account (Table 5.5), results show that the condition of 'Microalgae' in the Cool and Warm Temperate estuaries is largely in a moderately to severely/critically modified state, with 51% and

49% of extent respectively in a moderately modified state and an additional 31% and 19% in heavily to severely/critically modified condition. The condition of in the Subtropical estuaries reflects the impact of nutrient enrichment at 65% of extent in a severely/critically modified state, while Tropical estuaries are largely in a pristine condition with 90% of extent in a natural condition. Results for condition indicator 'Macrophytes' show that most Cool and Warm Temperate estuaries have been a highly modified with 57% and 39% of extent in a heavily modified state, respectively with an additional 13% and 12% in a severely/critically modified state. In contrast, Subtropical estuaries about 66% are still in a moderately modified state, with 100% of the estuarine area in the Tropical region in a near-natural state.

The condition of 'Invertebrates' indicator also shows that most Cool and Warm Temperate estuaries are in a highly modified condition at 49% and 37% of extent in a heavily modified state, respectively with an additional 12% and 10% in a severely/critically modified state. Further, 75% of the Subtropical estuaries are a severely/critically modified state, while 90% of Tropical Estuaries is in a moderately modified state. Of grave concern is the condition of Fish highlighting that most Cool Temperate, Warm Temperate and Subtropical estuaries are in a severely degraded condition with 73%, 44% and 67% of extent, respectively is in a heavily modified state, with an additional 25%, 11% and 25% in a severely/critically modified state. Tropical estuaries, however, still reflect 90% in a moderately modified state. The condition of the 'Birds' indicator shows that nearly 46% and 40%, respectively of Cool and Warm Temperate estuaries in a natural or near-natural state, while an additional 13% and 51% is in a moderately modified state respectively. Subtropical estuaries are 70% in a heavily modified state, with 100 % of Tropical estuaries still in a largely natural state.

Figure 5.5 represents the overall national-level condition distribution of various abiotic and biotic components, as represented by associated Ecosystem Condition Indicators. The national overview of the abiotic condition indicators shows that in terms of Hydrology, estuaries representing about 63% of total EFZ area in South Africa still are in relatively good condition (natural/near-natural condition). However, in terms of hydrodynamics only 36% of EFZ area is still in good condition, primarily the result of artificial mouth manipulation in many of the country's systems. Similarly, salinity distribution patterns and water quality has been markedly altered, with only 28% and 20% of EFZ areas, respectively, still remaining in good condition, primarily associated with flow modifications and pollution. Physical habitat (benthic substrate) also have been markedly modified with only 26% of EFZ area still being in a good condition, mostly as a result of alterations in flood regimes and inappropriate land-use in the EFZ.

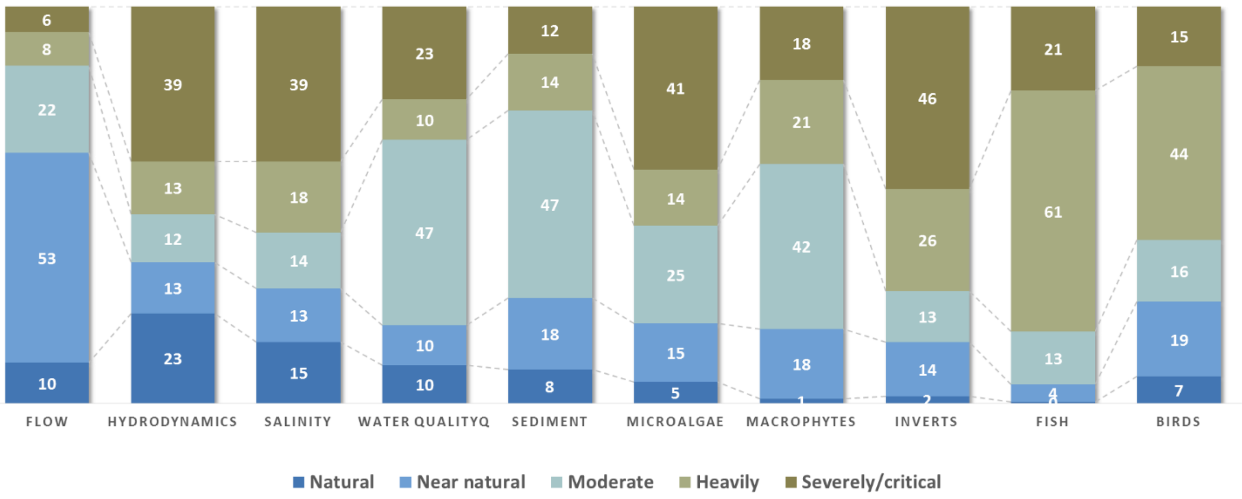


Figure 5.5: ***Comparison of Ecological condition across abiotic and biotic ecosystem indicators in South African estuaries (2018) (expressed as a percentage of EFZ area)***

Reflecting on the overall condition of biotic ecosystem condition indicators (Figure 5.5), there is a steady decline in health along the trophic scale from microalgae (20%), to macrophytes (19%), through to invertebrates (16%), and ultimately to the fish (4%) components, showing the cumulative effects of human pressures encountered in higher trophic levels, e.g. bait collection and fishing. In contrast, birds show less of a decline, with 26% still in good condition, highlighting the robustness of bird communities to anthropogenic pressures.

5.3 Condition Account by Estuary Functional Type

An alternative way in which to reflect estuary condition at the national-level is to show change across estuary functional types as is presented in Table 5.6 (expressed as a percentage of estuaries) and Table 5.7 (expressed as percentage EFZ area).

Table 5.6: Condition account by estuary functional type (expressed as a percentage of estuaries per ecological condition category)

	# ESTUARIES	ESTUARY CONDITION CATEGORY (% ESTUARIES)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):	**289**	**100.0**	**0**	**0**	**0**	**0**
Estuarine Lake	12	100.0	0	0	0	0
Estuarine Bay	2	100.0	0	0	0	0
Estuarine Lagoon	1	100.0	0	0	0	0
Predominantly Open	44	100.0	0	0	0	0
Large Temporarily Closed	94	100.0	0	0	0	0
Small Temporarily Closed	116	100.0	0	0	0	0
Large Fluvially Dominated	7	100.0	0	0	0	0
Small Fluvially Dominated	7	100.0	0	0	0	0
Arid Predominantly Closed	6	100.0	0	0	0	0
Increase/Decrease:		***-79.3***	***+39.7***	***+20.3***	***+11.7***	***+7.6***
Estuarine Lake		*-92.3*	*+15.4*	*+23.1*	*+38.5*	*+15.4*
Estuarine Bay		*-100.0*	*+50.0*			*+50.0*
Estuarine Lagoon		*-100.0*	*100.0*			
Predominantly Open		*-86.4*	*+45.5*	*+27.3*	*+9.1*	*+4.5*
Large Temporarily Closed		*-85.1*	*+40.4*	*+23.4*	*+14.9*	*+6.4*
Small Temporarily Closed		*-70.7*	*+39.7*	*+18.1*	*+5.2*	*+7.8*
Large Fluvially Dominated		*-100.0*	*+28.6*	*+14.3*	*+57.1*	
Small Fluvially Dominated		*-28.6*	*+28.6*			
Arid Predominantly Closed		*-100.0*	*+50.0*		*+16.7*	*+33.3*
Closing stock (2018):	**290**	**20.7**	**39.7**	**20.3**	**11.7**	**7.6**
Estuarine Lake	13	7.7	15.4	23.1	38.5	15.4
Estuarine Bay	2	0	50.0	0	0	50.0
Estuarine Lagoon	1	0	100.0	0	0	0
Predominantly Open	44	13.6	45.5	27.3	9.1	4.5
Large Temporarily Closed	94	14.9	40.4	23.4	14.9	6.4
Small Temporarily Closed	116	29.3	39.7	18.1	5.2	7.8
Large Fluvially Dominated	7	0	28.6	14.3	57.1	0
Small Fluvially Dominated	7	71.4	28.6	0	0	0
Arid Predominantly Closed	6	0	50.0	0	16.7	33.3

Comparing the condition in terms of estuary functional types, results show that four types, that is Estuarine Bays, Estuarine Lagoons, Large Fluvially Dominated and Arid Predominantly Closed systems no longer exist in a natural state (Table 5.7). Of the 12 estuarine lake systems, seven are already in heavily to critically modified states, while four out of the seven Large Fluvially Dominated systems have also been heavily modified. A significant proportion of the most common types, Large Temporarily Closed (94) and Small Temporarily Closed estuaries (116), are still in relatively good condition (natural/near-natural states), at 52 and 81 systems, respectively.

Table 5.7: Condition account by estuary functional type (expressed as a percentage of EFZ area per ecological condition category)

	EFZ AREA (ha)	CONDITION DISTRIBUTION (expressed as % EFZ area per type)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening (~1750):	**200,736**	**100.0**	**0**	**0**	**0**	**0**
Estuarine Lake	111,657	100.0	0	0	0	0
Estuarine Bay	5,826	100.0	0	0	0	0
Estuarine Lagoon	6,016	100.0	0	0	0	0
Predominantly Open	40,924	100.0	0	0	0	0
Large Temporarily Closed	16,161	100.0	0	0	0	0
Small Temporarily Closed	4,224	100.0	0	0	0	0
Large Fluvially Dominated	14,358	100.0	0	0	0	0
Small Fluvially Dominated	126	100.0	0	0	0	0
Arid Predominantly Closed	1,442	100.0	0	0	0	0
Increase/Decrease:						
Estuarine Lake		*-93.4*	*+2.7*	*+5.1*	*+83.6*	*+2.0*
Estuarine Bay		*-100.0*	*+51.7*	*0.0*	*0.0*	*+48.3*
Estuarine Lagoon		*-100.0*	*+100.0*	*0.0*	*0.0*	*0.0*
Predominantly Open		*-98.2*	*+35.1*	*+48.9*	*+11.5*	*+2.7*
Large Temporarily Closed		*-91.8*	*+31.8*	*+21.3*	*+29.7*	*+9.1*
Small Temporarily Closed		*-70.8*	*+37.4*	*+16.7*	*+8.3*	*+8.4*
Large Fluvially Dominated		*-100*	*+9.1*	*+4.0*	*+86.9*	*0.0*
Small Fluvially Dominated		*-27.1*	*+27.1*	*0.0*	*0.0*	*0.0*
Arid Predominantly Closed		*-100.0*	*+21.6*	*0.0*	*+6.2*	*+72.2*
Closing (2018):	**200,736**	**5.3**	**17.3**	**15.2**	**57.6**	**4.5**
Estuarine Lake	111,657	6.6	2.7	5.1	83.6	2.0
Estuarine Bay	5,826	0.0	51.7	0.0	0.0	48.3
Estuarine Lagoon	6,016	0.0	100.0	0.0	0.0	0.0
Predominantly Open	40,924	1.8	35.1	48.9	11.5	2.7
Large Temporarily Closed	16,161	8.2	31.8	21.3	29.7	9.1
Small Temporarily Closed	4,224	29.2	37.4	16.7	8.3	8.4
Large Fluvially Dominated	14,358	0.0	9.1	4.0	86.9	0.0
Small Fluvially Dominated	126	72.9	27.1	0.0	0.0	0.0
Arid Predominantly Closed	1,442	0.0	21.6	0.0	6.2	72.2

However, a different picture emerges when condition distribution is expressed as a percentage of EFZ area within each type (Figure 5.7). Only two estuary functional types, Estuarine lagoons and Small Fluvially Dominated systems are still all (100%) in a natural or near-natural condition, while Small Temporarily Closed and Estuarine Bay types also retain 66% and 52% respectively in a natural or near-natural condition. Predominantly Open estuaries are largely moderately modified at 49%, with an additional 12% heavily modified. Of special concern is that Estuarine Lakes retain only 10% in a natural or near-natural condition, while 84% is heavily modified and an additional 2% severely/critically modified. Large Fluvially Dominated systems are 87% heavily modified. Arid Predominantly Closed also presents a bleak picture, with 72% severely/critically modified.

Comparing results on percentage of estuaries versus percentage EFZ area, results reveal that proportionally Estuarine Bays, Estuarine Lakes, Large Fluvially Dominated and Arid Predominantly Closed systems are in the worst condition with 53%, 50%, 57% and 50% of systems within each of these type, respectively, being in heavily to critically modified states (Figure 5.6). The single Estuarine Lagoon (Langebaan) is still in a near-natural state (100%). Proportionally, Large and Small Temporarily Closed systems, and Small Fluvially Dominated systems are still in relatively good conditions, with 55%, 69% and 100% remaining in natural/near-natural condition.

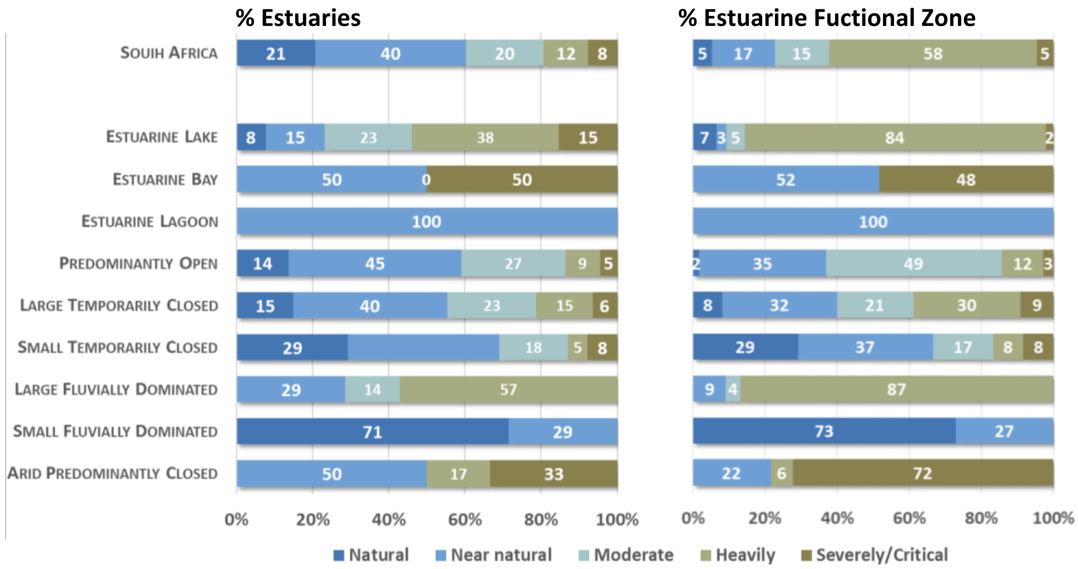


Figure 5.6 Comparison of estuarine condition across ecosystem functional types (2018) (expressed as a percentage of estuaries per type [left] and a percentage of total EFZ area per type [right])

5.4 Condition Accounts for Estuarine Habitat

Tables 5.8 and 5.9 present the condition accounts for abiotic and abiotic habitats, respectively. Given that detailed information on abiotic habitats (e.g. open water and floodplain) were not readily available for South Africa's estuaries the overall 'abiotic condition score' as per the Estuary Health Index of South Africa has been used as a proxy for the overall condition of abiotic habitat (Van Niekerk et al. 2019a) (Table 5.8). Results show that only 25% of total abiotic habitat are still in a natural or near-natural state, while 25% are moderately modified and an additional 45% are heavily modified, all linked to increasing human pressures.

Table 5.8: Condition account for abiotic estuarine habitat (expressed as a percentage of area per ecological condition category)

	TOTAL INTACT AREA (ha)	ECOLOGICAL CONDITION CATEGORY (% of habitat)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (~1750):	**200,736**	**100.0**	**0**	**0**	**0**	**0**
Aquatic habitat	**58,994**	100.0	0	0	0	0
Floodplain	**141 742**	100.0	0	0	0	0
Increase/Decrease:		*-90.1*	*+14.7*	*+25.4*	*+45.4*	*+4.7*
Aquatic habitat						
Floodplain						
Closing stock (2018):	**200,736**	**9.8**	**14.7**	**25.4**	**45.4**	**4.7**
Aquatic habitat	**58,994**	No detail condition data				
Floodplain	**141 742**					

With estuarine vegetation types being used to represent estuarine biotic habitat, the Estuary Health Index score for 'Macrophytes' was used as a proxy for biotic habitat condition (Table 5.9) (Van Niekerk et al. 2019a). Results show that only 19% of total biotic habitat is still in a natural or near-natural state, while 42% are moderately modified and an additional 21% are heavily modified. Overall 18% of biotic habitats are severely/critically modified.

Table 5.9: Condition account for biotic estuarine habitat (expressed as a percentage of area per ecological condition category)

	INTACT AREA (ha)	ECOLOGICAL CONDITION CATEGORY (% of habitat type)				
		NATURAL	NEAR-NATURAL	MODERATELY MODIFIED	HEAVILY MODIFIED	SEVERELY/ CRITICALLY
Opening stock (1930/40s):	**24,496**	**100**	**0**	**0**	**0**	**0**
Mangroves	**1,576**	**100**	0	0	0	0
Intertidal salt marsh	**5,354**	**100**	0	0	0	0
Supratidal salt marsh	**15,051**	**100**	0	0	0	0
Submerged macrophytes	**2,515**	**100**	0	0	0	0
Reeds & sedges	**..**	**100**	0	0	0	0
Swamp forests	**..**	**100**	0	0	0	0
Increase/Decrease:		*-98.8*	*+17.6*	*+41.6*	*+21.2*	*+18.5*
Mangroves						
Intertidal salt marsh						
Supratidal salt marsh						
Submerged macrophytes						
Reeds & sedges						
Swamp forests						
Closing stock (2018):	**36,409**	**1.2**	**17.6**	**41.6**	**21.2**	**18.5**
Mangroves	**1,672**	No data to distinguish across botanical habitat types				
Intertidal salt marsh	**4,786**					
Supratidal salt marsh	**10,072**					
Submerged macrophytes	**2,695**					
Reeds & sedges	**17,184**					
Swamp forests	**3,362**					

6. PRESSURE ACCOUNTS

6.1 Accounts for Anthropogenic Activities (direct pressures)

Table 6.1 presents the pressure account linked to anthropogenic activities directly impacting on estuaries for each of the six key pressure categories, reflecting the magnitude of the pressure, the number of affected estuaries, as well as an indication of the degree of impact on the affected estuaries across the four biogeographical regions.

Table 6.1: Pressure account for anthropogenic activities by biogeographical region (magnitude of pressure - expressed in a range of units; the number of affected estuaries; the degree of impact on affected estuaries - expressed as % of affected estuaries)

	MAGNITUDE OF PRESSURE	# OF AFFECTED ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES (expressed as % of affected estuaries)			
			LOW	MEDIUM	HIGH	VERY HIGH
Opening stock (~1750):						
WATER RESOURCE USE (x10^6 m^3/a)	0	0	0	0	0	0
LAND-USE IN EFZ (ha)	0	0	0	0	0	0
FISHING (t/a)	0	0	0	0	0	0
WASTEWATER DISPOSAL (m^3/d)	0	0	0	0	0	0
CATCHMENT WATER QUALITY	0	0	0	0	0	0
ARTIFICIAL BREACHING	0	0	0	0	0	0
Increase/Decrease:						
WATER RESOURCE USE (x 10^6 m^3/a)	*12,064*	*290*	*66.9*	*13.8*	*10.7*	*8.6*
LAND-USE IN EFZ (ha)	*30,339*	*290*	*54.1*	*16.9*	*16.2*	*12.8*
FISHING (t/a)	*3,728*	*283*	*59.7*	*18.7*	*15.5*	*6.0*
WASTEWATER DISPOSAL (m^3/d)	*839,837*	*42*	*11.9*	*11.9*	*26.2*	*50.0*
ARTIFICIAL BREACHING (ha)	*127,929*	*45*	*33.3*	*31.1*	*17.8*	*17.8*
Closing stock (2018):						
WATER RESOURCE USE (x10^6 m^3/a)	**-12,122**	**290**	**66.9**	**13.8**	**10.7**	**8.6**
Cool Temperate	-7,648	33	24.2	33.3	9.1	33.3
Warm Temperate	-1,942	124	66.9	13.7	12.9	6.5
Subtropical	-2,532	131	77.1	9.2	9.2	4.6
Tropical	0	2	100.0	0.0	0.0	0.0
LAND-USE IN EFZ (ha)	**30,339**	**290**	**54.1**	**16.9**	**16.2**	**12.8**
Cool Temperate	6,026	33	30.3	6.1	27.3	36.4
Warm Temperate	9,030	124	69.4	15.3	8.9	6.5
Subtropical	15,160	131	45.0	21.4	20.6	13.0
Tropical	123	2	100.0	0.0	0.0	0.0
FISHING (t/a)	**3,728**	**283**	**59.7**	**18.7**	**15.5**	**6.0**
Cool Temperate	1,035	27	70.4	11.1	0.0	18.5
Warm Temperate	1,167	123	69.9	12.2	17.9	0.0
Subtropical	1,172	131	48.9	26.7	16.0	8.4
Tropical	354	2	0.0	0.0	50.0	50.0
WASTEWATER DISPOSAL (m^3/d)	**839,837**	**42**	**11.9**	**11.9**	**26.2**	**50.0**
Cool Temperate	521,588	9	0.0	0.0	33.3	66.7
Warm Temperate	79,391	9	44.4	11.1	22.2	22.2
Subtropical	238,835	24	0.0	12.5	33.3	54.2
Tropical	0	0	0.0	0.0	0.0	0.0
ARTIFICIAL BREACHING	**127,929**	**45**	**33.3**	**31.1**	**17.8**	**17.8**
Cool Temperate	25,777	14	28.6	35.7	14.3	21.4
Warm Temperate	17,579	8	12.5	25.0	37.5	25.0
Subtropical	83,743	22	45.5	27.3	13.6	13.6
Tropical	829	1	0.0	100.0	0.0	0.0

The above pressure account can also be graphically illustrated as a percentage of total estuaries in a biogeographical region or affected estuaries (Figure 6.1). Colour coding is used to represent the degree of pressure: **Dark red** = very high pressure, **red** = high, **orange** = medium; **yellow** =- low, **grey** = none.

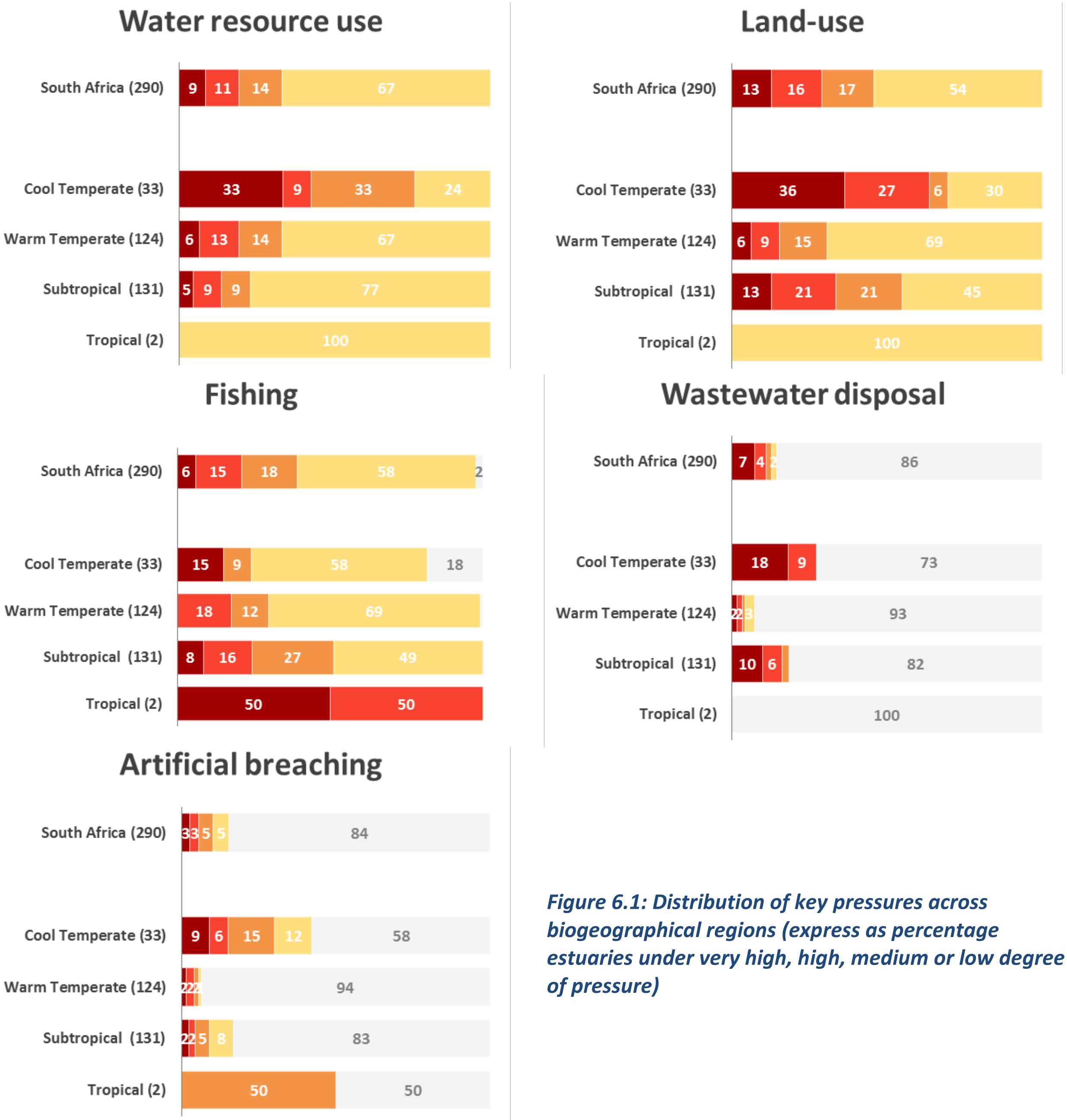


Figure 6.1: Distribution of key pressures across biogeographical regions (express as percentage estuaries under very high, high, medium or low degree of pressure)

Water resource use has reduced freshwater flows to estuaries by about 12,000 million cubic meters per annum (2018), with only about 67% of natural flows remaining (i.e. 24,800 million cubic meters per annum). Freshwater flows to most of the country's estuaries have been modified, albeit not to the same extent across bioregions. Flow reduction in the Cool Temperate region is highest (7,590 million cubic meters per annum), followed by the Subtropical region (2,530 million cubic meters per annum), and the Warm Temperate region (1,940 million cubic meters per annum). As a result, the extent of this pressure is already rated as 'high' to 'very high' in 14 of the 33 estuaries in the Cool Temperate region (42%), especially affecting the large permanently open systems (e.g. Orange, Great Berg and Olifants estuaries). Nationally, this pressure is ranked 'very high' in 24 systems (9%), 'high' in another 31 systems (11%) and 'medium' in 40 systems (14%). Primary consequences associated with flow modification include changes in frequency and duration of estuary-marine connectivity (in temporarily open/closed systems) and upstream penetration of saline waters (permanently open systems), with ripple effects into water quality and estuarine biota.

Land-use within EFZ has contributed significantly to deterioration in estuaries. Veldkornet et al. (2015) concluded that most estuaries are subject to some sort of altered land-use with only 28 estuaries considered to be in a near-pristine state. Urban development has areas occurred within 275 estuaries (covering an area of about 6,630 ha). Agricultural activities (cultivation) were evident in 168 estuaries, particularly sugar cane cultivation in KwaZulu-Natal. Overall, 29% of South African estuaries are subject to severe (high and very high) pressure from habitat modification and development, mostly in the Cool Temperate (63%) and Subtropical (34%) regions (Figure 6.2). To develop a spatial indicator that can report the degree of EFZ intactness per area, the 2014 SANBI land-cover data (GeoTerraImage 2015) was disaggregated into natural and modified classes (artificial water bodies, urban (built-up) areas, mining, plantations and agriculture (croplands). The data shows that overall about 84% of the EFZ have relative natural land cover, i.e. natural vegetation type still present. Agriculture (in the form of croplands) was responsible for about 10% of land cover change, while urban areas contribute about 4% of the land-use change. Mining, plantations and artificial water bodies contributed 0.8%, 0.6% and 0.2% of land cover change. However, especially the mining data was found to be of poor resolution and did not reflect the extent of ongoing mining (e.g. sand) activities in estuaries. This dataset also does not report on 'habitat condition' of natural habitat, as it only focuses on the change in the extent of natural vegetation cover, thus giving binary-type results (habitat is either near/natural or severely/critically modified).

Over 3,730 tonnes of fish are caught annually, with 21% of estuaries subjected to high or very high fishing pressure. Up until a decade ago, excessive fishing pressure (catch and effort) was confined to three large estuaries in the Cool Temperate region and one in the Tropical region. Since then, there's been a substantial increase in fishing effort, mostly illegal gillnetting, in estuaries elsewhere on the coast. Systems in the Subtropical and Tropical biogeographical regions have been particularly hard-hit, exacerbated by the effective collapse of fisheries compliance in KwaZulu-Natal allowing open- and uncontrolled access to fish resources. Highest fishing pressure occurs in the Subtropical and Warm Temperate region (1,170 tonnes per annum each), followed by the Cool Temperate region (1,040 tonnes per annum). Nationally, fishing pressures already are ranked 'high' to 'very high' in 61 estuaries (21%), which translates to 18% of systems in the Warm Temperate region (22 estuaries), 23% of systems in the Subtropical region (32 estuaries), and a 100% of systems in the Tropical region (2 estuaries). Less than 2% of estuaries are not under some fishing pressure as few have national, provincial or municipal protection or 'no-take' status. In addition, the integrity of estuarine protected areas is being eroded by both sanctioned and unlawful fishing in these areas.

It is estimated that about 840 million cubic metres of wastewater are being discharged daily either directly into estuaries, or to river reaches just upstream of estuaries, in 42 systems country-wide. Effluent is mostly derived from municipal wastewater treatment works (WWTW), but includes wastewater from fish factories (130 000 m^3/d) along the Cool Temperate region (Groot Berg Estuary). Nationally, the deterioration of estuarine water quality, associated with wastewater discharges, is ranked as 'high to 'very high' in at least 32 estuaries (11%), mainly in the large urban centres in the Cool Temperate region (Cape Town and surrounds) and Subtropical region (Durban and surrounds).

Artificial breaching of estuary mouths (also called inlet manipulation) is practised in at least 45 systems nationally. Although this amounts to only 15% of the total number of estuaries along the coast, the affected systems represent more than 60% of the total national estuarine habitat (Figure 6.5). In 17 of the 45 affected systems, pressure from this practice is ranked as 'high' to 'very high' spanning the Cool Temperate, Warm Temperate and Subtropical regions. Inappropriate breaching at too low water levels causes premature closure, reduces marine connectivity and results in the accumulation of marine sediments in the lower reaches of estuaries. Not only does this affect the productivity and important nursery function of estuaries, but it also increases flood risks to adjacent coastal communities in the long term.

Anthropogenic pressure accounts can also be assessed in terms of estuary type as presented in Table 6.2, while Figure6.2 graphically compares the percentage of total estuaries in an estuary type or affected estuaries for each of the key pressure categories. Colour coding is used to represent the degree of pressure: **Dark red** = very high pressure, **red** = high, **orange** = medium; **yellow** =- low, **grey** = none.

Table 6.2: Pressure account for anthropogenic activities by estuary functional type (magnitude of pressure - expressed in a range of units; Number of affected estuaries; Degree of impact on affected estuaries - expressed as a percentage of affected estuaries)

	MAGNITUDE OF PRESSURE	# OF AFFECTED ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES *(expressed as % of affected estuaries)*			
			LOW	MEDIUM	HIGH	VERY HIGH
Opening stock (~1750):						
WATER RESOURCE USE (x10^6 m^3/a)	0	0	0	0	0	0
LAND-USE IN EFZ (ha)	0	0	0	0	0	0
FISHING (t/a)	0	0	0	0	0	0
WASTEWATER DISPOSAL (m^3/d)	0	0	0	0	0	0
ARTIFICIAL BREACHING (ha)	0	0	0	0	0	0
Increase/Decrease:						
WATER RESOURCE USE (x 10^6 m^3/a)	***12,064***	***290***	***66.9***	***13.8***	***10.7***	***8.6***
LAND-USE IN EFZ (ha)	***30,339***	***290***	***54.1***	***16.9***	***16.2***	***12.8***
FISHING (t/a)	***3,728***	***283***	***59.7***	***18.7***	***15.5***	***6.0***
WASTEWATER DISPOSAL (m^3/d)	***839,837***	***42***	***11.9***	***11.9***	***26.2***	***50.0***
ARTIFICIAL BREACHING (ha)	***127,929***	***45***	***33.3***	***31.1***	***17.8***	***17.8***
Closing stock (2018):						
WATER RESOURCE USE (x10^6 m^3/a)	**12,122**	**290**	**66.9**	**13.8**	**10.7**	**8.6**
Estuarine Lake	-135	13	53.8	23.1	15.4	7.7
Estuarine Bay	+12	2	50.0	0.0	50.0	0.0
Estuarine Lagoon	-0	1	100.0	0.0	0.0	0.0
Predominantly Open	-3,369	44	54.5	20.5	6.8	18.2
Large Temporarily Closed	-305	94	61.7	21.3	12.8	4.3
Small Temporarily Closed	-52	116	80.2	4.3	10.3	5.2
Large Fluvially Dominated	-8,240	7	42.9	14.3	14.3	28.6
Small Fluvially Dominated	-27	7	85.7	0.0	0.0	14.3
Arid Predominantly Closed	-7	6	16.7	33.3	0.0	50.0
LAND-USE IN EFZ (ha)	**30,339**	**290**	**54.1**	**16.9**	**16.2**	**12.8**
Estuarine Lake	9,675	13	30.8	23.1	15.4	30.8
Estuarine Bay	2,132	2	50.0	0.0	0.0	50.0
Estuarine Lagoon	7	1	100.0	0.0	0.0	0.0
Predominantly Open	9,330	44	45.5	25.0	18.2	11.4
Large Temporarily Closed	3,675	94	46.8	14.9	25.5	12.8
Small Temporarily Closed	376	116	64.7	17.2	9.5	8.6
Large Fluvially Dominated	5,028	7	42.9	0.0	28.6	28.6
Small Fluvially Dominated	0	7	100.0	0.0	0.0	0.0
Arid Predominantly Closed	114	6	33.3	16.7	0.0	50.0
FISHING (t/a)	**3,728**	**283**	**59.7**	**18.7**	**15.5**	**6.0**
Estuarine Lake	1617	13	23.1	15.4	15.4	46.2
Estuarine Bay	166	2	0.0	0.0	50.0	50.0
Estuarine Lagoon	206	1	0.0	0.0	0.0	100.0
Predominantly Open	1267	43	9.3	14.0	65.1	11.6
Large Temporarily Closed	272	94	57.4	31.9	9.6	1.1
Small Temporarily Closed	45	114	85.1	13.2	1.8	0.0
Large Fluvially Dominated	153	7	28.6	0.0	28.6	42.9
Small Fluvially Dominated	2	7	100.0	0.0	0.0	0.0
Arid Predominantly Closed	0	2	100.0	0.0	0.0	0.0
WASTEWATER DISPOSAL (m^3/d)	**839,837**	**42**	**9.5**	**9.5**	**31.0**	**50.0**
Estuarine Lake	118,040	3	0.0	0.0	66.7	33.3
Estuarine Bay	22,380	2	0.0	50.0	50.0	0.0
Estuarine Lagoon	0	0	0.0	0.0	0.0	0.0
Predominantly Open	261,417	9	33.3	11.1	22.2	33.3
Large Temporarily Closed	346,566	17	0.0	11.8	17.6	70.6
Small Temporarily Closed	78,608	9	33.3	11.1	22.2	33.3
Large Fluvially Dominated	12,826	2	50.0	0.0	50.0	0.0
Small Fluvially Dominated	0	0	0.0	0.0	0.0	0.0
Arid Predominantly Closed	0	0	0.0	0.0	0.0	0.0

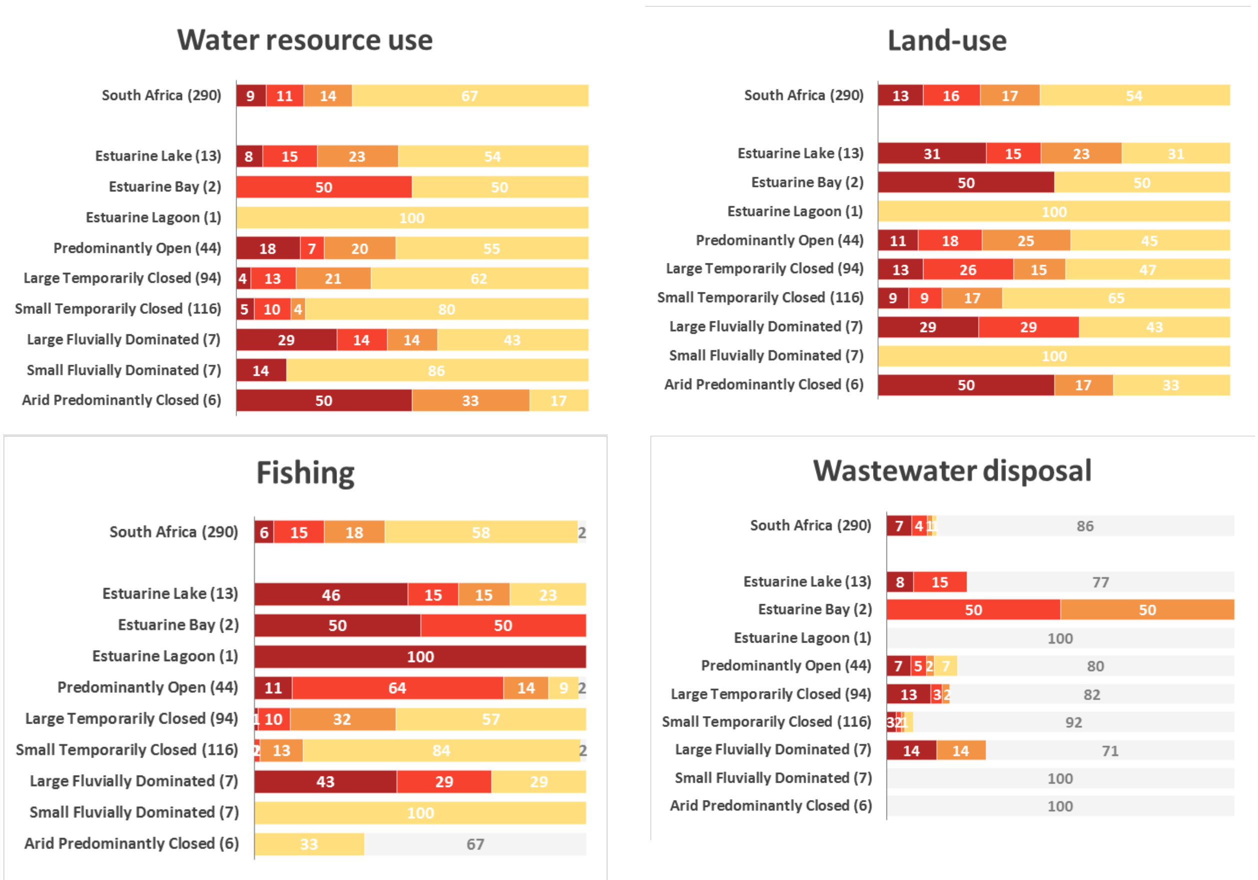
	MAGNITUDE OF PRESSURE	# OF AFFECTED ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES *(expressed as % of affected estuaries)*			
			LOW	MEDIUM	HIGH	VERY HIGH
ARTIFICIAL BREACHING (ha)	**127,929**	**45**	**33.3**	**31.1**	**17.8**	**17.8**
Estuarine Lake	90,448	9	0.0	55.6	22.2	22.2
Estuarine Bay	0	0	0.0	0.0	0.0	0.0
Estuarine Lagoon	0	0	0.0	0.0	0.0	0.0
Predominantly Open	19,357	8	75.0	12.5	0.0	12.5
Large Temporarily Closed	5,141	18	27.8	27.8	22.2	22.2
Small Temporarily Closed	421	5	60.0	0.0	20.0	20.0
Large Fluvially Dominated	12,473	4	25.0	75.0	0.0	0.0
Small Fluvially Dominated	0	0	0.0	0.0	0.0	0.0
Arid Predominantly Closed	89	1	0.0	0.0	100.0	0.0

Water resource use: From an estuary type perspective, Small Temporarily Closed (18 systems representing 16% of type), Large Temporarily Closed (16 systems representing 17%), Predominantly Open (11 systems representing 25%), Arid Predominantly Closed (3 systems representing 50%), Large Fluvially Dominated (3 systems representing 43%) and an Estuarine Bay (1 system representing 50%) are the subject to severe impact (very high and high severity) from flow modification. Also, a large number of Predominantly Open (20%) and Large Temporarily Closed (21%) systems are experiencing moderate impact from water resource use pressure. These results indicate that it is generally the larger estuary functional types, associated with larger catchments that are targeted for water resource use, and therefore suffer impacts from flow modification. Arid Predominantly Closed systems are also significantly affected, a consequence of both significant freshwater resource use and high sensitivity to flow modification in a hot, arid environment.

Land-use: Land-use pressure is relatively equally distributed across all estuary functional types, with a large number of estuaries subject to high or very high impacts. These systems are numerically dominated by Large temporarily closed (36 systems representing 38% within this type) followed by Small temporarily closed (21 systems representing 18%), Predominantly Open (13 systems representing 29%), Large Fluvially Dominated (4 system representing 57%), Arid Predominantly Closed (3 systems representing 50%), Estuarine Bays (1 system representing 50%), and Estuarine lakes (6 systems representing 46%). In fact, only two estuary functional types, namely Estuarine Lagoon and Small Fluvially Dominated systems, are experiencing low impact from development pressure. These estuaries are well-represented in formally protected areas.

Fishing pressure: Fishing effort is not equally distributed across all estuary functional types with larger types by-and-large being under much greater pressure than smaller types. Estuarine Lagoons (1) and Estuarine Bays (2), representing 100% of these types, are under severe impact from fishing pressure (High to very high). Not far behind are the Predominantly Open estuaries (33 systems representing 61% of type), Estuarine Lakes (8 systems representing 75%) and Large Fluvially Dominated systems (5 systems representing 71%), all under severe impact. Most of the smaller estuary functional types only experience low levels of fishing pressure, while the Arid Predominantly Closed type are not subject to fishing pressure as these systems are mostly hypersaline and support little or no fish resources.

Wastewater disposal: Functional estuary types most severely affected (high to very high) by pollution pressure are Large Temporarily Closed (15 systems representing 16% of this type), Small Temporarily Closed (5 systems representing 4%), Predominantly Open (5 systems representing 11%), Large Fluvially Dominated (1 system representing 14%) and an Estuarine Bay (1 system representing 50%). The large volumes of wastewater discharged into estuary functional types that close for periods of time, such as Estuarine lakes, Large and Small Temporarily Closed estuaries, are of key concern as these systems do not have the assimilative capacity (especially during the closed phases) to deal with pollutants (such as excessive nutrients and organic matter), increasing the risks of eutrophication, low oxygen events and fish (and invertebrate) kills.



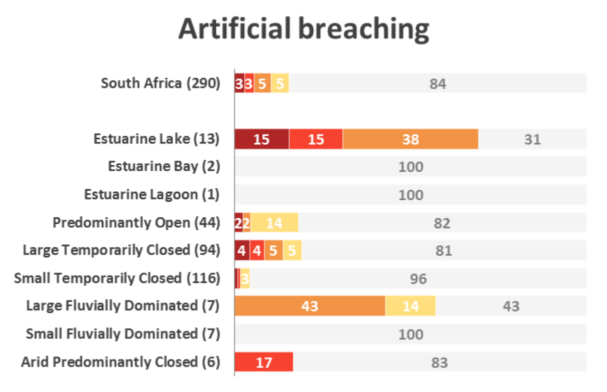


Figure 6.2: Distribution of key pressures across estuary functional types (express as percentage estuaries under a very high, high, medium or low degree of pressure)

Artificial breaching: While not numerically dominating in terms of the estuary functional types affected by this pressure, Estuarine lakes are the most at risk from artificial breaching. Nine lake systems (representing 69% of this type) are subject to artificial breaching, resulting in severe impacts (high to very high) in four systems (30%). This highlights most Estuarine lakes having a history of human interference in natural breaching patterns. More recently, significant effort has been made to reverse this trend in some systems (e.g. St Lucia Estuarine Lake system restoration programme). Arid Predominantly Closed estuaries (1 system representing 17% of type) also experience severe impact from this pressure, as do Large Temporarily Closed estuaries (8 systems representing 8%). Predominantly Open estuaries (8 systems representing 4%), which closes under extended low flow conditions are also affected, of which 1 system (1%) encounters severe impact. Large Fluvially Dominated estuaries (4 systems representing 57%) are also under pressure from breaching, as is a small number of Small Temporarily Closed estuaries (5 systems representing 4%).

6.2 Accounts for Biological Invasions (indirect pressures)

The pressure account for biological invasions across biogeographical regions (using alien or translocated plant and fish species) is presented in Table 6.3, while Figure 6.3 graphically compares the extent of biological invasions by biogeographical regions or affected estuaries. Colour coding is used to represent the degree of pressure: **dark red** = very high pressure, **red** = high, **orange** = medium; **yellow** =- low, **grey** = none.

For plants, the degree of impact is estimated on a three-tier scale, with 'Low' alien coverage < 5% of EFZ; 'Medium' alien coverage 5-15% of EFZ, 'High' alien coverage > 15% of total EFZ area (available data on microalgal and macroalgal blooms was also recorded using the same method). For invasive fish; 'Low' 1-2 species, 'Medium' 3-4 species, 'High' 5-6 species OR 1-2 predatory species OR Sharptooth catfish *Clarias gariepinus* present (if translocated), 'Very High' >7 species OR 3- 4 predatory species.

Table 6.3: Pressure account for biological invasions by biogeographical region (Number of affected estuaries; Degree of impact on affected estuaries - expressed as % of affected estuaries)

	TOTAL # OF ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES *(expressed as % of affected estuaries)*			
		LOW	MEDIUM	HIGH	VERY HIGH
Opening stock (~1750):					
VEGETATION	0	0	0	0	0
FISH	0	0	0	0	0
Increase/Decrease:					
VEGETATION	*+108*	*1.9*	*72.2*	*25.9*	*0.0*
FISH	*+73*	*73*	*17.8*	*2.7*	*57.5*
Closing stock (2018):					
VEGETATION	**108**	**1.9**	**72.2**	**25.9**	**0.0**
Cool Temperate	21	4.8	57.1	38.1	0.0
Warm Temperate	33	0.0	57.6	42.4	0.0
Subtropical	53	0.0	88.7	11.3	0.0
Tropical	1	100.0	0.0	0.0	0.0
FISH	**73**	**17.8**	**2.7**	**57.5**	**21.9**
Cool Temperate	18	16.7	5.6	50.0	27.8
Warm Temperate	34	14.7	2.9	61.8	20.6
Subtropical	21	23.8	0.0	57.1	19.0
Tropical	0	0.0	0.0	0.0	0.0

A third of estuaries have invasive terrestrial plants occurring within the EFZ, with aquatic plant invasive species also occurring in 23 estuaries, of these 28 (10%) experience a high degree of impact and 78 (27%) estuaries medium impact from this pressure. The Subtropical region has the highest number of estuaries under pressure (53 systems representing 41% of systems in the region), followed by the Warm Temperate (33 systems representing 26%) and the Cool Temperate region (21 systems representing 63%). Invasive *Acacia* species, particularly rooikrans *Acacia cyclops*, and *Eucalyptus* trees are most common in the Cool and Warm Temperate regions, with Kikuyu grass *Pennisetum clandestinum* also being prevalent. A greater diversity of invasive plants occurs within the Subtropical systems, especially in KwaZulu-Natal of which the dominant tree species include Brazilian pepper tree *Schinus terebinthifolius* Raddi*, Casuarina equisetifolia* and *Sesbania punicea.* Water hyacinth *Eichhornia crassipes* remains the worst aquatic weed in South African estuaries, displacing rare submerged macrophyte species.

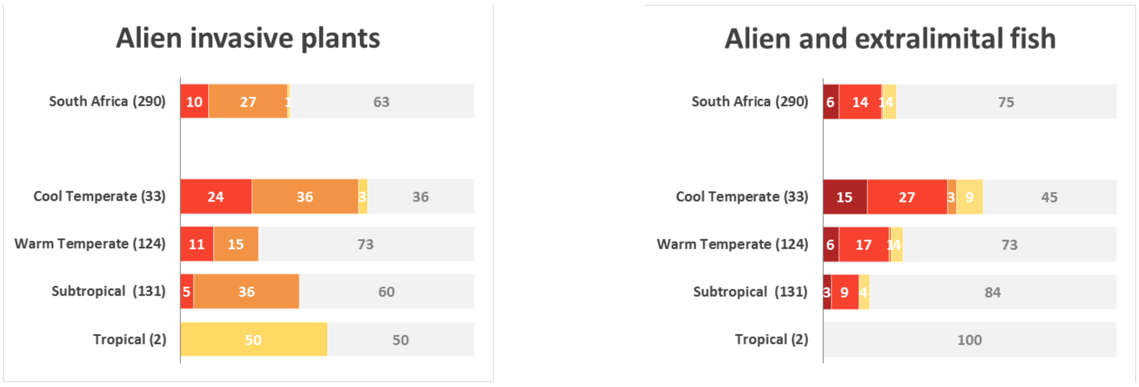


Figure 6.3: Distribution of alien biological invasions by biogeographical regions (expressed as a percentage of estuaries within region)

Alien and extralimital fish occur in 25 % of South Africa's estuaries, of these 16 (6%) and 42 (14%) estuaries experience severe (high to very high) impact from this pressure, respectively. The Warm Temperate region has the highest number with 34 (28%) of estuaries in this region under pressure, followed by the Subtropical with 21 (16%) and Warm Temperate 18 (54%) regions. There are 22 species of alien, extralimital or translocated fish recorded to date in South African estuaries with up to nine species reported in a single system. All are freshwater species with two, the Mozambique tilapia *Oreochromis mossambicus* and rainbow trout *Oncorhynchus mykiss* being euryhaline (tolerant of salt water). Most of these species are confined to the headwaters of estuaries. It's here that they may become a barrier to the upstream movement of eggs, larvae and juveniles of estuary-dependent fish and catadromous eels. Four of these species are predators of fish eggs and larvae of indigenous species, eight are predominantly piscivores and two habitat altering. Many of these alien, extralimital or translocated fish are also vectors of disease such as epizootic ulcerative syndrome (EUS). Further invasions can be dampened by stricter import controls, policing of illegal introductions and stocking and management of the aquarium trade and aquaculture industry. Barring poisoning, existing populations can be controlled by directed and innovative fishing to the benefit of local communities. The distribution of alien invasion across estuary functional types is demonstrated in Table 6.4.

Table 6.4: Pressure account for biological invasions by estuary functional type (Number of affected estuaries and Degree of impact on affected estuaries - expressed as % of affected estuaries)

PARAMETER	TOTAL # OF ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES *(expressed as % of affected estuaries)*			
		LOW	MEDIUM	HIGH	VERY HIGH
Opening stock (~1750):					
VEGETATION	**0**	0	0	0	0
INVERTEBRATES	0	0	0	0	0
FISH	**0**	0	0	0	0
Increase/Decrease:					
VEGETATION	*+108*	*1.9*	*72.2*	*25.9*	*0.0*
FISH	*+73*	*17.8*	*2.7*	*57.5*	*21.9*
Closing stock (2018):					
VEGETATION	**108**	**1.9**	**72.2**	**25.9**	**0.0**
Estuarine Lake	8	12.5	62.5	25.0	0.0
Estuarine Bay	0	0.0	0.0	0.0	0.0
Estuarine Lagoon	0	0.0	0.0	0.0	0.0
Predominantly Open	28	0.0	75.0	25.0	0.0
Large Temporarily Closed	39	0.0	71.8	28.2	0.0
Small Temporarily Closed	25	0.0	80.0	20.0	0.0
Large Fluvially Dominated	5	0.0	60.0	40.0	0.0
Small Fluvially Dominated	1	0.0	100.0	0.0	0.0
Arid Predominantly Closed	2	50.0	0.0	50.0	0.0
FISH	**73**	**17.8**	**2.7**	**57.5**	**21.9**

PARAMETER	TOTAL # OF ESTUARIES	DEGREE OF IMPACT ON AFFECTED ESTUARIES *(expressed as % of affected estuaries)*			
		LOW	MEDIUM	HIGH	VERY HIGH
Estuarine Lake	8	12.5	12.5	50.0	25.0
Estuarine Bay	2	50.0	0.0	50.0	0.0
Estuarine Lagoon	0	0.0	0.0	0.0	0.0
Predominantly Open	26	11.5	0.0	53.8	34.6
Large Temporarily Closed	21	19.0	0.0	76.2	4.8
Small Temporarily Closed	9	33.3	0.0	55.6	11.1
Large Fluvially Dominated	6	0.0	16.7	33.3	50.0
Small Fluvially Dominated	1	100.0	0.0	0.0	0.0
Arid Predominantly Closed	0	0.0	0.0	0.0	0.0

Figure 6.4 graphically compares extent of biological invasions across estuary functional types or affected estuaries. Colour coding is used to represent the degree of pressure: **dark red** = very high pressure, **red** = high, **orange** = medium; **yellow** =- low, **grey** = none.

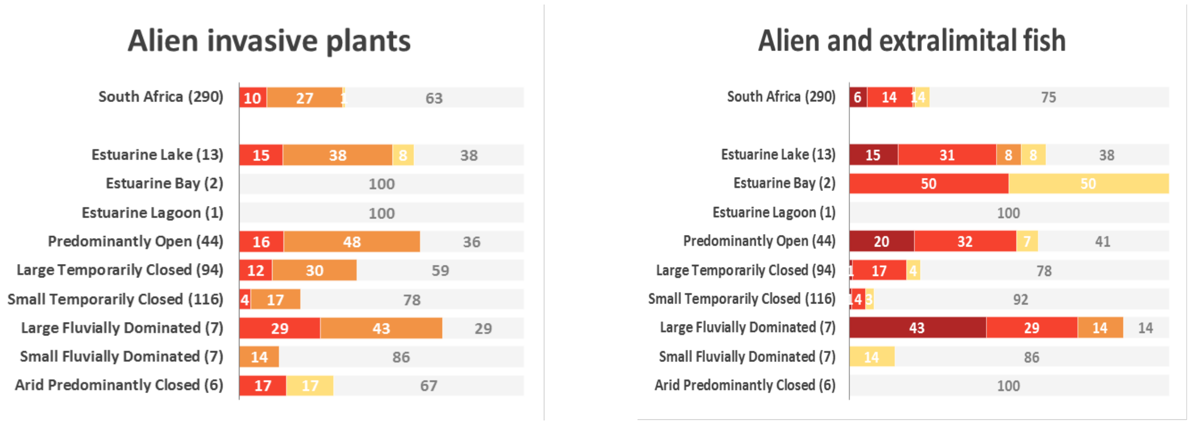


Figure 6.4: Distribution of alien biological invasions by estuary functional type (expressed as a percentage of estuaries within type)

Alien invasive plants: Interesting from the assessment of plant invasion across estuary functional types is that this pressure is not equally distributed across types. Large temporarily closed (39 systems representing 58% of this type), Predominantly open (28 system representing 59%), Small Temporarily Closed (25 systems representing 22%), Large Fluvially Dominated estuaries (5 systems representing 71%) and Estuarine Lakes (8 systems representing 61%) are under severe impact from pressure, mostly associated with larger catchments, serving as both a pathway for invasive species, or providing freshwater preferred by most invasive species. Therefore, reduced connectivity of Estuarine Lakes to the sea - resulting in a fresher environment – favours the establishment of alien species. In contrast, marine-dominated Estuarine Bays and Estuarine Lagoon systems are not experiencing great pressure from invasive alien plants.

Alien invasive or translocated fish species are generally confined to estuary functional types associated with large catchments such as Predominantly Open (26 systems representing 59% of this type), Large Temporarily Closed (21 systems representing 22%), and Large Fluvially Dominated (6 systems representing 86%) types. The high occurrence in Predominantly Open systems is as a result of the human introduction of alien or extralimital fish species in the past. Fish invasions are also proportionally more abundant in large estuary functional types such as Estuarine Lakes (8 systems representing 62%) and Estuarine Bays (2 systems representing 100%). In most of the above cases, impacts are severe (high and very high).

7. ECOSYSTEM SERVICES ACCOUNTS

For this experimental study, preliminary investigation on three important ecosystem services were also explored to demonstrate the construction of physical ecosystem services accounts of estuaries, namely:

- Carbon sequestration for the mitigation of climate change;
- Nursery function for important fisheries;
- Habitat and refugia for rare endemic estuarine species.

7.1 Carbon Sequestration

Table 7.1 presents the ecosystem services physical account for carbon sequestration potential of estuaries based on important vegetation types. Results show that overall there have been a **nett loss of 1,365,323 Mg in carbon sequestration potential** largely related to the large loss of intertidal salt marsh (-568 ha) and subtidal salt marsh (-4 979 ha) habitat which translates to a loss of 144,840 Mg and 1,269,645Mg in carbon sequestration potential respectively. This is only partially offset by natural and artificial gains in mangrove (+97 ha) and seagrass (+180 ha) habitat which can store about 29,722 Mg and 19,440 Mg carbon based on global values for these habitats.

Table 7.1: Ecosystem services account: Carbon sequestration (expressed in Mg)

	TOTAL	BIOTIC HABITAT/CARBON STORAGE					
		MANGROVE	INTERTIDAL SALT MARSH	SUBTIDAL SALT MARSH	SEA-GRASS	REEDS & SEDGES	SWAMP FOREST
Baseline stock (1930/40s):						-	-
HABITAT COVERAGE (ha)	**45,042**	**1,576**	**5,354**	**15,051**	**2,515**	**-**	**-**
Storage per unit area (Mg/ha)		386	255	255	108	-	-
CARBON STORAGE (Mg)	**8,810,231**	**608,336**	**1,365,270**	**3,838,005**	**271,620**	**-**	**-**
Managed Gains/Losses:							
NET HABITAT COVERAGE (ha)	*-5,290*	*+97*	*-568*	*-4,979*	*+180*	-	-
Net change as % of opening	*-11.7%*	*+4.9%*	*-10.6%*	*-33.1%*	*+7.2%*	-	-
CARBON STORAGE (Mg)	*-1,365,323*	*+29,722*	*-144,840*	*-1,269,645*	*+19,440*	**-**	**-**
Net change as % of opening	*-15.5%*	*+4.9%*	*-10.6%*	*-33.1%*	*+7.2%*	**-**	**-**
Closing stock (2019):							
HABITAT COVERAGE (ha)	**39,752**	**1,653**	**4,786**	**10,072**	**2,695**	**17,184**	**3,362**
Cool Temperate	9,463	0	2,339	2,704	593	3,827	0
Warm Temperate	6,330	25	1,887	837	939	2,641	1
Subtropical	15,323	1,557	502	229	488	10,472	2,075
Tropical	8,636	71	58	6,302	675	244	1,286
CARBON STORAGE (Mg)	**7,444,908**	**638,058**	**1,220,430**	**2,568,360**	**291,060**	**1,718,400**	**1,008,600**
Cool Temperate	1,732,709	0	596,445	689,520	64,044	382,700	0
Warm Temperate	1,070,082	9,650	481,185	213,435	101,412	264,100	300
Subtropical	2,509,811	601,002	128,010	58,395	52,704	104,7200	622,500
Tropical	2,132,306	27,406	14,790	1,607,010	72,900	24,400	385,800

Looking at biotic habitats and comparing across biogeographical regions, the Subtropical and Tropical region supports the highest amounts of carbon storage potential at 2,509,811 Mg and 2,132,306 Mg respectively, largely attributable to mangrove, reeds and sedges and swamp forest habitats. The Cool Temperate region supports 1,732,709 Mg carbon storage potential because of its extensive extent of salt marshes, followed by the Warm Temperate region at 1,070,082.

South Africa's 'blue carbon' habitat in estuaries comprises 1,672 ha of mangroves, 14,596 ha of salt marsh and 2,685 ha of submerged macrophytes (Adams 2016). So far only limited research has been done on South Africa soil carbon stocks at four estuaries. Results showed soil carbon stocks for mangroves at the Nahoon and Nxaxo estuaries were 110 Mg C ha^{-1} and 230 Mg C ha^{-1} respectively, 3–5 Mg C ha^{-1} for salt marshes at Nxaxo, Nahoon and Swartkops estuaries; and ranged from 2–220 Mg C ha^{-1} for seagrasses at Nxaxo, Swartkops and Knysna estuaries (Adams et al. 2020). These values are lower than globally reported figures, but due to the small sample size it was not deemed appropriate to extrapolate these figures to a national-level assessment as yet. In addition to 'blue carbon', South Africa also supports swamp forests, reeds and sedges which is generally seen as a 'teal carbon' as captured in freshwater inland wetlands. Very little data were available on the type of swamp forest in South Africa. Global average estimates for similar habitats varies significantly depending on the species composition of the swamp forest (Adame et al. 2015). Further research is needed to address this data deficiency.

Considering just the 'blue carbon' ecosystems value and using global figures of carbon stocks (Siikamäki et al. 2012), the total estuarine blue ecosystem carbon was estimated as 6.7 Tg C, which equates to approximately 24.6 Tg CO_2 (using molecular weight of CO_2/molecular weight of carbon; EPA 2016). Turpie and Letley (2019) estimate the avoided social cost of carbon associated with estuarine habitats in South Africa using a social cost of carbon of US$31.25 per ton of CO_2 (in 2010 US$; Nordhaus 2017) and the assumption that 3% of this would be borne in Africa (Nordhaus 2017). The cost to South Africa was assumed to be proportional to its GDP contribution to Africa, scaled by the level of vulnerability to climate change using the Notre Dame Global Adaptation Initiative (ND-GAIN) vulnerability index. Based on this index, it was estimated that South Africa is likely to bear only 0.35% of the global social cost of each ton of carbon emitted. Turpie and Letley (2019) estimate that the avoided degradation and loss of South Africa's estuary habitats represents avoided damages (or GDP losses) of R11.8 billion per annum at a global scale, and South Africa's share of this would be R42 million per annum. Adams et al. (2020) estimate a lower value for blue carbon habitats based on ongoing research at R1.2 to R10.6 billion per annum when carbon is traded at a high price and R120 to R150 million per annum when carbon is traded at lower prices.

7.2 Nursery Function for Important Fisheries

Lamberth and Turpie (2003) estimated the total value of estuarine fisheries and the contribution of estuarine fish to the inshore marine fisheries, as 700 to 1 000 million per annum (in 2019 ZAR) (Lamberth and Turpie 2003; Turpie et al. 2014a & b, updated Turpie et al. 2017). Values are highest along the southwestern Cape and eastern Cape coasts. Given that the capacity of estuaries to replenish marine fishery stocks has been lost due to freshwater starvation and recreational fishing pressure, this value represents only 58% of what it would be if all estuaries were in their natural condition. In other words, fishery values have been reduced by an estimated R700 million due to estuary degradation (Turpie et al. 2017). Physical accounting, therefore, had to capture changes in the extent and condition of estuarine nursery potential, as well as measuring the change in the extent and condition of exploited fish stocks.

Fish diversity and abundance differ between estuaries of different sizes and types, with higher biomass and species-richness associated with larger and permanently open systems (Lamberth and Turpie 2003) (Figure 7.1), such as the Great Berg and Breede estuaries. Freshwater flow influences estuarine biota, particularly the juveniles of marine organisms that use them as nursery grounds (Whitfield 1994; Strydom et al. 2003), either directly through recruitment signals, and habitat availability, or indirectly through the role of freshwater flow in system productivity (Gillsanders and Kingsford 2002). However, many estuaries have lost much of their nursery habitat and function because of freshwater starvation, pollution, development impacts and mouth manipulation. Furthermore, stocks of estuary-associated fish have been depleted through fishing, both legal and illegal, in estuaries and the sea throughout their range.

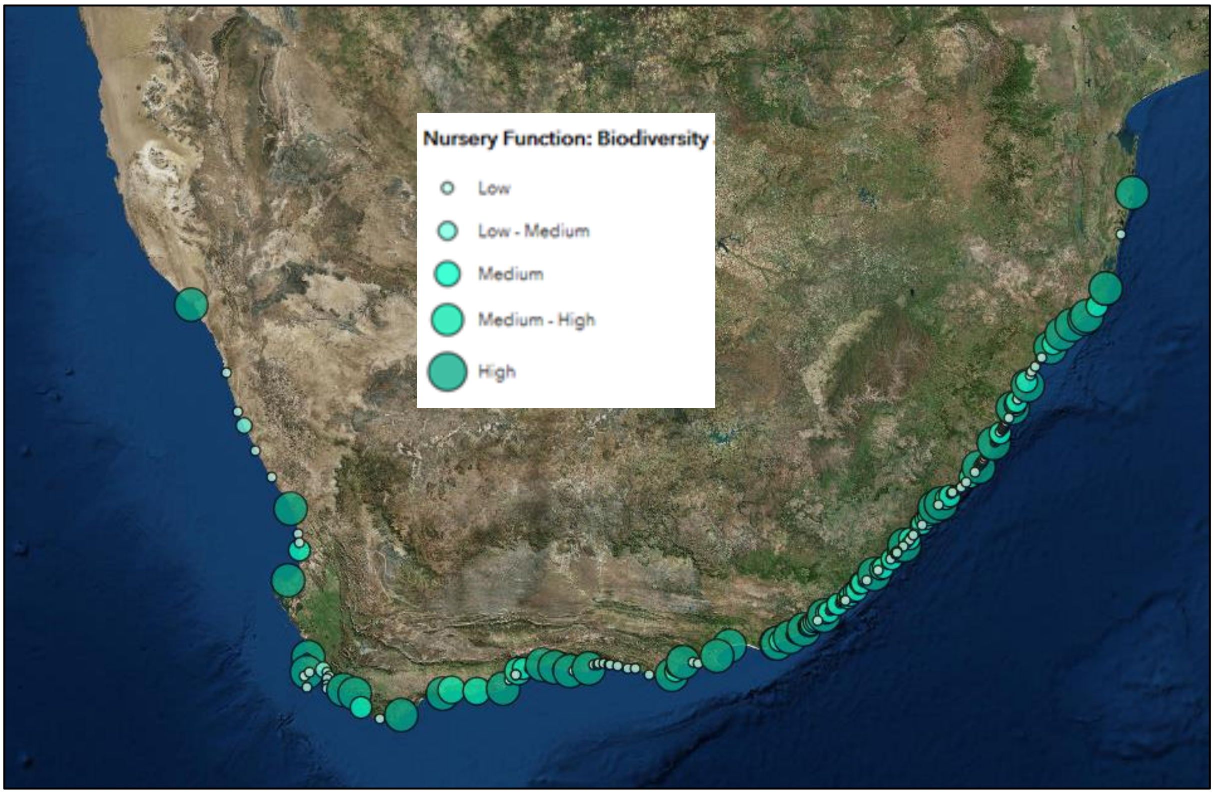
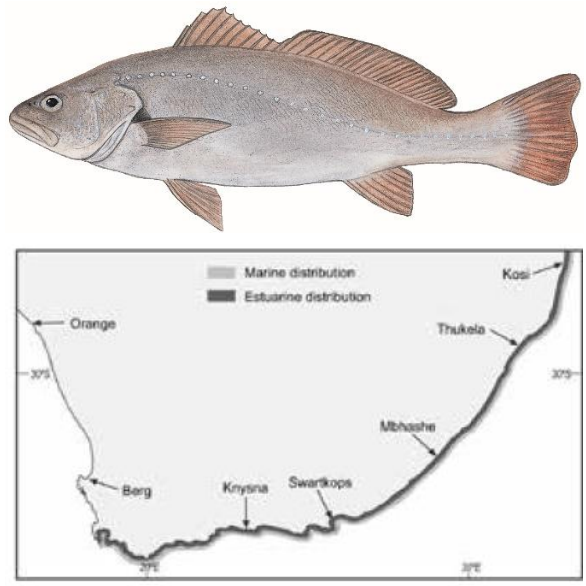


Figure 7.1: Important fish nurseries for estuarine and marine fish and fisheries (Van Niekerk et al. 2015)

Life-history characteristics of most of South Africa's coastal fish species - especially those exploited - are well known, and thus allow them to be categorised into the various levels of estuary-association developed by Whitfield (1994). Although there are close to 300 estuaries along South Africa's coast, specific habitat requirements of some fish at certain stages of their life make the choice of juvenile nursery habitat or spawning ground limited. Five key estuarine-dependent fish species of economic importance were selected to illustrate this:

- Dusky kob *Argyrosomus japonicus;*
- White steenbras *Lithognathus lithognathus;*
- Spotter grunter *Pomadasys commersonnii;*
- Mullet *Chelon richardsonii;*
- Leervis *Lichia amia; and*
- Elf *Pomatomus saltatrix.*

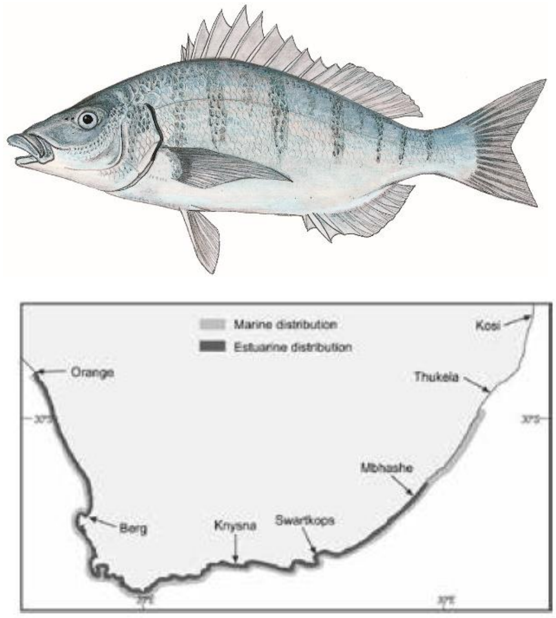
Dusky kob has an African range extending from Cape Point to southern Mozambique. Until recently, it was also held to occur in Indo-Pacific waters to Japan and Australia in the east and Pakistan in the west (Griffiths and Heemstra 1995). It was also acknowledged that cryptic (as yet unidentified) taxa were likely to exist within the very wide geographical range of this species. Not surprisingly, the local population has recently been identified as a genetically distinct endemic southern African species. Dusky kob is an obligatory estuarine-dependent species, with newly recruited juveniles entering southern African estuaries mostly during spring and summer. Juveniles do not migrate great distances from their natal estuaries or coastal marine environments and remain as separate localised populations until they reach sexual maturity (Childs & Fennessy 2012). Spawning may occur on multiple occasions throughout the year but more often in the warmer months.



(Heemstra and Heemstra 2004; Whitfield 2019)

This said, a component of mature adults seems to 'accompany' the annual sardine run to KZN waters where they spawn in the winter months (Griffiths 1996). Small juvenile Dusky kob less than 1-year old prefer the fine sediments of highly turbid estuaries being adapted to find refuge in a 'viscous' and often lower oxygen environment from which other predatory fish are physiologically excluded. This type of habitat comprises less than 5 % of the total estuarine area in South Africa. Of the 20 largest catchments in the country, only four, the Mbashe, Great Kei, Mzimvubu and Mtata have estuaries with a substantial area of the suitable sediment and turbidity characteristics for < 1-year old juveniles. For adolescents of this species, habitat requirements appear to be broader with at least 50% of large and medium size estuaries being suitable nursery environments. Dusky kob is vulnerable to flow reduction, over-exploitation, loss of connectivity, and poor water quality. Current stock status is collapsed and critical with biomass of spawning adults (breeding potential) at < 1% of pristine.

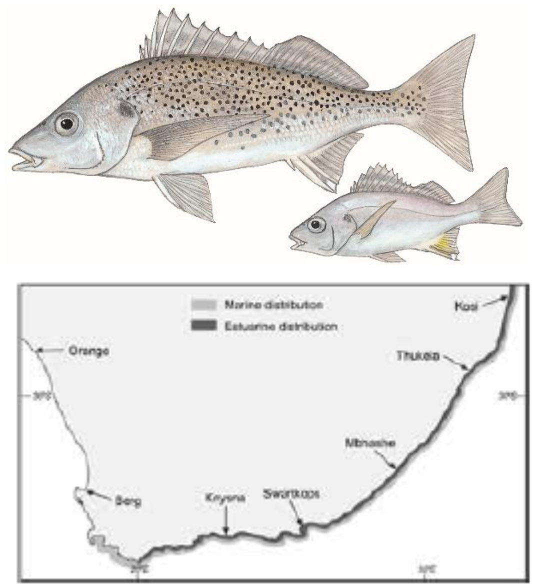
White steenbras (*Lithognathus lithognathus*) is a slow-growing, long-lived (> 30 years), late-maturing (6 years), and obligate estuarine-dependent species endemic to South Africa. White steenbras occur from the Orange River to the Warm Temperate/Subtropical transition zone on the east coast. There have also been some juveniles confirmed in a sample from the Cunene Estuary on the Namibia-Angola border (Lamberth unpublished data). This suggests that historically, there may have also been a west coast spawning population and migration with the Orange, and perhaps Berg and Olifants Estuaries, having a suitable fluvial fan on which these fish spawn. Intensive beach-seine and gillnet fishing over the first 50 years of the 20th century may have seen this population become functionally extinct or indiscernible. There is an annual spawning migration to the Temperate/Subtropical transition zone, spawning occurring late July to September on the fluvial fans off selected estuary mouths. If *L. Lithognathus* are restricted to spawning on these few fluvial fans, the entire South African spawning habitat may be <50 hectares.



(Heemstra and Heemstra 2004; Whitfield 2019)

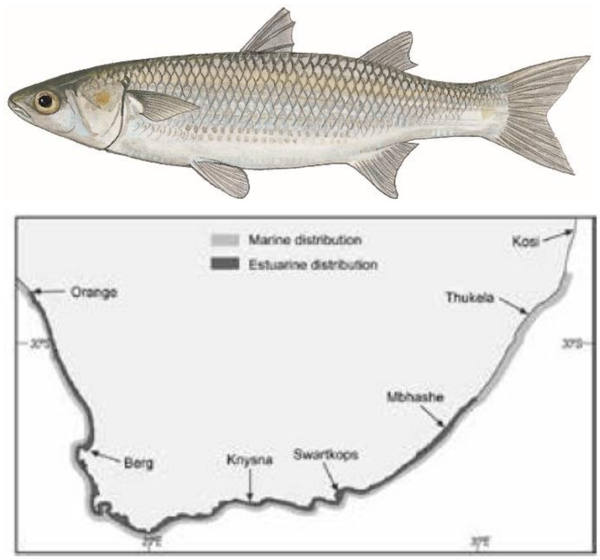
White steenbras populations are susceptible to fragmentation due to intrinsic characteristics such as strong site fidelity and a small home range. Furthermore, the estuarine phase of its lifecycle is extremely vulnerable to habitat degradation due to anthropogenic activities including infrastructural development, freshwater abstraction and overfishing of juveniles. These threats have profound impacts on recruitment, population size and structure and ultimately reduced catches by fishers that depend upon them. Whilst White steenbras is afforded some protection in several no-take MPAs throughout its range, stock-assessment confirmed collapse and drastic management measures have been implemented to rebuild the stock. Despite it now being designated a no-sale species, illegal line, beach-seine and gillnet fishing and noncompliance with minimum sizes and bag limits still pose threats to this species. Current stock status of White steenbras is collapsed with biomass of breeding adults (reproductive potential) at <6 % of pristine. Recent lobbying to remove the no-sale restriction on this species would likely drive stock-status to critical.

Spotted grunter *Pomadasys commersonnii* is a mainly shallow water (<30 m depth) western Indian Ocean species common along the eastern coast of Southern Africa, with occasional specimens recorded as far west as False Bay during summer (Day et al. 1981, Lamberth et al. 1995). Spawning usually occurs at sea between August and December although it has been recorded in marine dominated systems and harbours such as Durban Bay (Cowley & Fennessy 2012). Egg and larval development occur at sea, with juveniles first entering estuarine nursery areas at 20-30 mm TL. Grunter has been recorded in salinities from 0-90 and can survive salinities <1 for prolonged periods (Blaber and Cyrus 1981). Juveniles newly recruited into estuaries prey mainly on small pelagic copepods and mysids before adopting a predominantly benthic (bottom) foraging mode. Adults of this important angling species are primarily crepuscular and nocturnal, foraging mostly on benthic invertebrates such as Mud prawns *Upogebia africana* that are extracted from their burrows using a gill chamber pump action which rapidly blows water out of the mouth, causing infauna to become suspended and then captured. Grunter is vulnerable to flow reduction, over-exploitation, and poor water quality. The most recent stock-assessment of the Eastern Cape population indicates stock collapse with spawner biomass (breeding potential) at < 25 % of pristine (Winker et al. 2015).

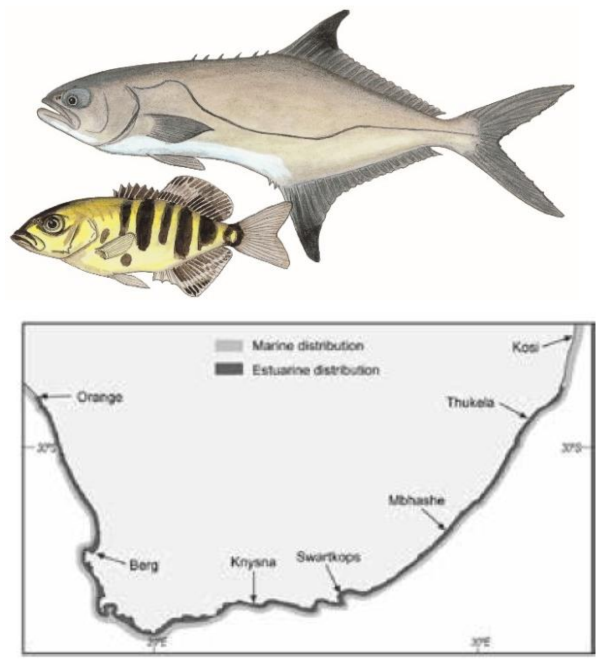


(Heemstra and Heemstra 2004; Whitfield 2019)

Southern Mullet *Chelon richardsonii* is an endemic species that is often abundant in Cool and Warm Temperate South African estuaries but, until recently, rarely recorded in subtropical and Topical systems. More recently, there's evidence for a northward expansion into subtropical waters on the southern African east and west coasts. Although juveniles and adults are common in Eastern and Western Cape estuaries, this species is equally abundant in the nearshore marine environment (Bennett 1989, Romer and McLachlan 1986). Southern Mullet spawn from spring to autumn with peak recruitment into estuaries varying geographically but often bimodal with a second peak following floods, emigration and spawning of adults that had been confined to Temporarily Closed estuaries for extended periods. Larval development takes place in the marine environment (Bennett 1989; Whitfield and Kok 1992). Depending on food availability, juveniles and adults opportunistically switch between benthic detrivory, grazing macrophytic plant material to filter-feeding blue-green algae blooms and surf-zone diatom accumulations. Southern Mullet are vulnerable to changes in mouth state, flow reduction, poor water quality and over-exploitation by high commercial fishing effort and illegal gillnet fisheries. A recent stock-assessment indicated collapse with spawner biomass per recruit at 24% of the pristine state (Horton et al. 2019).



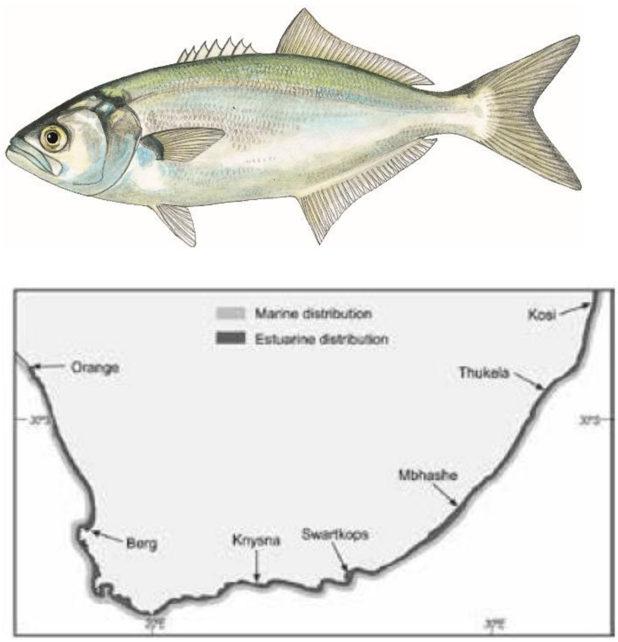
(Heemstra and Heemstra 2004; Whitfield 2019)



(Heemstra and Heemstra 2004; Whitfield 2019)

Leervis or garrick *Lichia amia* has a range extending from the Mediterranean Sea, southward along the entire African west coast and around Cape Point to northern KwaZulu-Natal (Smith-Vaniz 1986). Juveniles are mainly associated with estuaries, whereas the adults occur predominantly in the marine environment (van der Elst 1988). Adults spawn in the marine environment during late winter and spring in KwaZulu-Natal waters (Wallace 1975b). The southward transport of larvae is probable, with small juveniles being rare in KwaZulu-Natal estuaries but increasingly common towards the southwest (Wallace and van der Elst 1975). Cohorts 25-40 mm SL enter Warm Temperate estuaries during summer (Beckley 1984a, Bennett 1989, Whitfield and Kok 1992). Juveniles 40-100 mm TL from the Orange, Olifants and Berg Estuaries, indicate that breeding also occurs off the Cool Temperate west coast. Juvenile Leervis feed on mysids, shrimps and small fishes, whilst adults prey mostly on fish. Leervis is vulnerable to flow reduction and poor water quality, particularly increased turbidity. Leervis is especially vulnerable to overexploitation, all catch trends indicate decline and stock-assessment estimated spawner biomass per recruit (breeding potential) at is estimated at < 25 % so in a state of collapse (Mann & Potts 2012).

Elf *Pomatomus saltatrix* occur in all oceans between latitudes 50°N and 50°S (Smith and Smith 1986a). Within southern Africa it occurs on the cool temperate west coast but is particularly common along the warm temperate and subtropical south and east coasts, declining in abundance towards Mozambique (van der Elst 1976). Highest estuarine abundance is in the warm water refugia offered by estuaries on the cool temperate west coast, which unfortunately, also increases their vulnerability to illegal gillnetting with catches exceeding 100 t per annum. The life cycle of this species involves extensive migrations each winter from the Eastern and Western Cape to KwaZulu- Natal. Following maturation in spring, spawning takes place between September and January, with a peak in November (van der Elst 1976). The Thukela Bank has been identified as one spawning area, with other southern African breeding grounds on the Agulhas Bank and West Coast also likely. The pelagic larvae drift passively in shelf waters and are transported southwards, partially assisted by the Agulhas Current (Beckley and Connell 1996). The juveniles spend their first year in warmer coastal waters and surf-zones, with some individuals utilizing estuaries in the region, especially on the West Coast. Elf is vulnerable to changes in mouth state, flow reduction and poor water quality. Elf is especially vulnerable to over-exploitation by recreational, small-scale (subsistence), commercial fishing and illegal gillnetting. Spawner biomass per recruit is estimated at < 25 % of pristine and therefore collapsed (Winker et al. 2015).



(Heemstra and Heemstra 2004; Whitfield 2019)

The ability of South Africa's estuaries to support provisioning services such as nursery function for estuarine and marine fish of economic importance have been severely reduced (Table 7.2).

Table 7.2: Ecosystem services account: Nursery function for Important fisheries species (as expressed in a range of measures reflecting nursery function and fishery status)

	IMPORTANT FISHERIES SPECIES					
	SOUTHERN MULLET	GRUNTER	DUSKY KOB	STEENBRAS	LEERVIS	ELF
Opening stock (~1750):						
ESTUARINE NURSERY AREAS						
Nursery systems (# estuaries)	88	69	79	59	53	52
Recruitment signal (% MAR remaining)	100	100	100	100	100	100
Good condition nurseries (% area)	100	100	100	100	100	100
High fishing pressure nurseries (% area)	0	0	0	0	0	0
STATUS OF FISHERIES						
Fisheries extent (across regions)[1]	C/W/S/T	W/S/T	C/W/S/T	C/W/S/T	C/W/S/T	C/W/S/T
Contribution to marine fishery (%)	-	-	-	-	-	-
Contribution to estuarine fishery (%)	-	-	-	-	-	-
National stock status	Natural	Natural	Natural	Natural	Natural	Natural
Pristine biomass (%)	100%	100%	100%	100%	100%	100%
Spawner biomass per recruit (%)	100%	100%	100%	100%	100%	100%
IUCN threat status	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern
Gain/Loss:						
ESTUARINE NURSERY AREAS						
Nursery systems (# estuaries)	*-*	*+8*	*-*	*-5*	*-*	*-*
Recruitment signal (% MAR remaining)	*-34*	*-20*	*-35*	*-46*	*-49*	*-49*
Good condition nurseries (% area)	*-68*	*-76*	*-78*	*-20*	*-47*	*-44*
Nursery area under high pressure (%)	*+91*	*+94*	*+92*	*+70*	*+70*	*+75*
STATUS OF FISHERIES						
Fisheries extent (across regions)	-	-	-	-	-	-
Contribution to marine fishery (%)	-	-	-	-	-	-
Contribution to estuarine fishery (%)	-	-	-	-	-	-
National threat status	↓	↓	↓	↓	↓	↓
IUCN threat status	→	↓	↓	↓	↓	↓
Closing stock (2018):						
ESTUARINE NURSERY AREAS						
Nursery systems (# estuaries)	88	77	79	54	53	52
Recruitment signal (% MAR remaining)	66	80	65	54	51	51
Good condition nurseries (% area)	32	24	22	80	79	84
High fishing pressure nurseries (% area)	91	94	92	70	70	75
STATUS OF FISHERIES						
Fisheries extent (biogeographical region)[1]	C/W/S/T	W/S/T	C/W/S/T	C/W/S/T	C/W/S/T	C/W/S/T
Contribution to estuarine fishery (%)	32%	20%	18%	3%	1%	3%
Contribution to marine fishery by estuarine associated species (%)	>75% [2]	1.0% [3]	1.7% [3]	1.4 % [3]	1.3% [3,4]	27.2 [3]
National stock status	Over-exploited	Collapsed	Critical	Collapsed	Collapsed	Collapsed
Spawner biomass per recruit (%)	24%	< 25%	<2%	6%	14%	<25%
IUCN threat status	Least Concern	Vulnerable	Critically Endangered	Endangered	Vulnerable	Vulnerable

[1] C = Cool Temperate; W = Warm Temperate; S = Subtropical; T = Tropical

[2]Commercial beach seine and gillnet fishery

[3]Small-scale & Recreational shore angling

[4] Recreational Spear fishing

Amongst others, the biogeographical extent analysis shows a contraction of range in White steenbras and an expansion in Spotted grunter, both driven by a combination of overfishing and climate change on these key stocks. Nursery function for selected estuarine-dependent species was supported by between 52 and 88 estuaries, with Elf being the most restricted and Mullet the least selective in critical nursery areas. Historically, key estuaries along the west coast would have also contributed extensively to nursery function for Steenbras, but as a result of excessive fishing pressure and population collapse only Langbaan Estuarine Lagoon still has a viable biomass of White steenbras (loss provision services in five estuaries). In contrast, as a result of climate change, Grunter occurs in eight more estuaries that provide nursery function for this important estuarine fisheries species.

Freshwater recruitment signals that assist fish with 'finding' estuaries, using MAR still reaching estuaries as a proxy, showed that key nurseries have lost between 49% (Leervis and Elf) and 20% (Grunter) of their recruitment signal; with Steenbras recruitment signal declining by about 46%, and Dusky kob and Mulllet recruitment signal declining by about 35% and 34% respectively. The remaining extent of highly productive key nursery estuaries capable of supporting fisheries (areas still in a natural to moderately modified state), varied between 22% to 32% for Dusky kob, Grunter and Mullet, and between 79% to 84% for Steenbras, Elf and Leervis. As a final measure, the percentage EFZ areas of important nursery estuaries under high to very high fishing pressure was also calculated. This shows that in most cases 70% to 91% of key nurseries is overfished thus reducing overall productivity.

Spawner biomass per recruit (SBPR % of pristine in the absence of fishing), a measure of breeding potential that represents the ability of a stock to recover, is critically low at < 2% and 6% for Dusky kob and White steenbras respectively. Leervis spawner biomass per recruit is estimated at 14%, Grunter at <25%, Elf < 25% and harder (Southern Mullet) 24%, all indicating a collapsed state. Harder is the directed catch of the commercial and small-scale beach-seine and gillnet fisheries in the sea and important to the livelihoods of most coastal communities on the West Coast. The status of these resources are a global concern with Dusky kob listed as critically endangered, White steenbras as endangered, and Grunter, Leervis and Elf as vulnerable on the IUCN Red List. The relative contribution to estuarine fisheries varies between 32% and 1%, with Mullet (32%), Grunter (20%) and Dusky kob (18%) contributing the most by weight. Estuary-dependent species comprise 83% of the catch of the recreational shore and commercial beach-seine and gillnet fisheries but only 7% of the catch of the recreational spear-fishery, commercial and recreational boat fisheries (Lamberth and Turpie 2003). This study only looked at a subset of five species to illustrate the concept, with most of the selected species in a severely depleted state (overexploited or collapse categories) which limits their relative contribution. Mullet are the only estuary-associated species of commercial importance and contribute over 75% of the catch of the commercial beach seine and gillnet fishery. The rest of the species are important to small-scale and recreational fishing, providing between 27% (Elf) and less than 2% (Spotter grunter, Dusky kob, White steenbras, Leervis) of the catch of shore-angling and nearshore spear-fishing. It should be noted, that whilst the latter contribute relative small percentages by weight to these fisheries, they are highly valued as eating and sporting fish much sought after by small-scale and recreational fishers

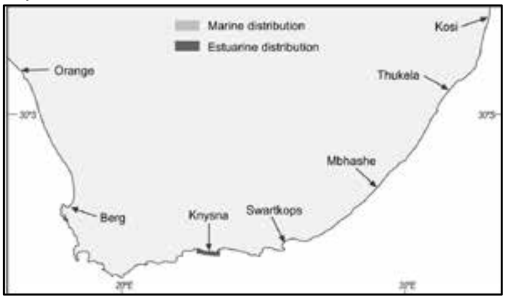
7.3 Habitat and Refugia for Rare Endemic Estuarine Species

Five rare endemic fish species were selected to illustrate supporting ecosystem services:

- Bot river klipvis *Clinus spatulatus;*
- Knysna seahorse *Hippocampus capensis*;
- Estuarine pipefish *Syngnathus watermeyeri*; and
- Sawfish (two species: Green sawfish *Pristis zijsron* & Largetooth sawfish *Pristis pristis*).

The Critically Endangered Knysna seahorse is endemic to three estuaries in South Africa: Knysna, Swartvlei, and Keurbooms (historical/anecdotal records in other estuaries most likely referred to Thorny Seahorse or Longsnout pipefish*)*. Knysna seahorse is associated with a range of submerged macrophytes, though they are most likely to be found grasping *Zostera capensis* eelgrass holdfasts (Bell et al. 2003). They also make use of artificial habitat (Claassens et al. 2018). The biggest threat to the Knysna seahorse is the continued increase in nutrient inputs from the surrounding catchments and Wastewater Treatment Works, which have resulted in ongoing algal blooms that displace eelgrass habitat (Allanson et al. 2016; Human et al. 2016). Artificial mouth breaching can also result in seahorses being stranded due to receding water levels. However, the population is likely to have historically been boom and bust in response to natural breaching events.

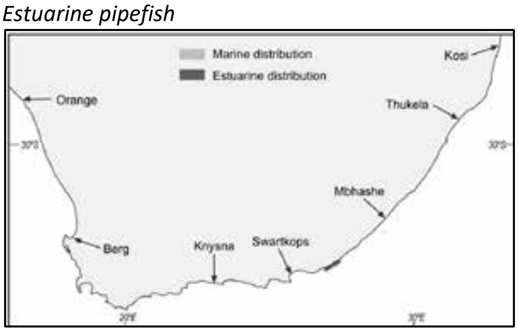
Knysna seahorse



(Whitfield 2019)

Knysna seahorses and other South African members of its family are being illegally harvested for the Chinese traditional medicine and the international aquarium trade. There are also disease and genetic concerns with respect to contamination of the wild populations by effluent, escapees or deliberate release from illicit aquarium and culture facilities.

Estuarine pipefish



(Whitfield 2019)

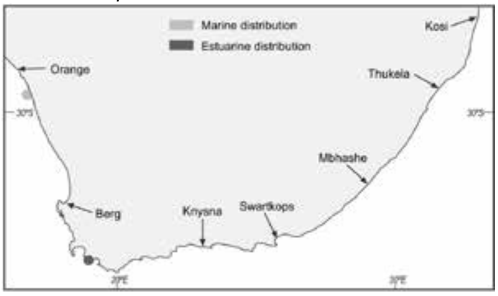
The Critically Endangered Estuarine pipefish, is endemic to South Africa currently occurring in only the Bushmans, Kariega, and Kasouga estuaries. Previously also occurring in the West and East Kleinemonde estuary but has not been found since the last survey in 1996. It is found primarily in association with submerged macrophytes (Whitfield 1995).

Estuarine pipefish depends on regular freshwater influxes, to maintain its food resource (Wooldridge 2007). High freshwater abstraction is having a negative influence on the availability of zooplankton and causing ongoing decline to this species.

The species has been listed as Critically Endangered due to a continued decline in habitat quality. It is also likely that there are less than 250 animals in total and 50 mature individuals or less in each estuarine subpopulation, with extreme fluctuations occurring linked to the availability of macrophyte habitat as well as to environmental perturbations such as floods, drought and estuary mouth breaching.

The Endangered Bot River klipvis is endemic to only the Bot and Klein estuaries in the Western Cape. Both of these estuaries are impacted by reductions in freshwater inflow, pollution, eutrophication, urbanization and agriculture. These pressures are causing an ongoing decline in habitat quality. This species experiences extreme fluctuations in populations densities, linked with the opening and closing of the estuaries' mouths (von der Heyden et al. 2015).

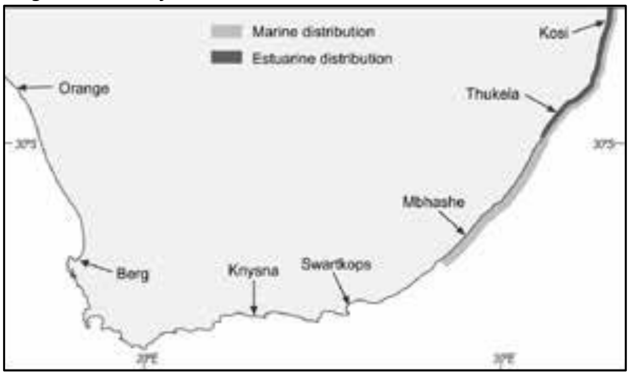
Bot River klipvis



(von der Heyden et al. 2015; Whitfield 2019)

Whilst these fluctuations appear to be a natural part of the species' biology, during periods after breaching when the population is low it is more vulnerable to threatening processes such as pollution eutrophication and waterborne pathogens. Connectivity and genetic exchange between the two estuaries' subpopulations occur during large coinciding floods when their flood plumes overlap. Agricultural activities in both catchments and climate change have seen a significant reduction in the frequency, occurrence and magnitude of flood events and an increase in the duration of mouth closure in recent years.

Large Tooth sawfish



(Heemstra and Heemstra 2004; Whitfield 2019)

Previously common along the KwaZulu-Natal (KZN) coast of South Africa (Compagno 1991), the Green sawfish *Pristis zijsron* and the Largetooth sawfish *Pristis pristis* are now extinct in South Africa (Everett et al. 2015). These Sawfishes have tropical Indian-West Pacific distributions with ranges extending south to KZN coastal waters. There are also historical records to Knysna and False Bay, the latter where they were mainly caught in beach-seine nets up until the early 1980s (Grindley 1976, DEFF unpublished, Kenny Hart, JJ Dirkse van Schalkwyk pers comm). Worldwide, these species have experienced marked population declines, and they are now listed by the International Union on the Conservation of Nature (IUCN) as Critically Endangered (Kyne et al. 2013, Simpfendorfer 2013). This is related to anthropogenic pressures in the form of high levels of exploitation (high commercial value, especially fins, and catchability in fisheries), degradation of Tropical and Subtropical nearshore, estuarine and freshwater habitats, flow alterations, and very low intrinsic rates of population increase because of late age at maturity and a relatively small number of young (Kyne et al. 2013, Simpfendorfer 2013, Dulvy et al. 2016).

The last reported occurrence of a sawfish in South Arica was in 1999, from KZN Shark Board bather protection nets off Richards Bay (Everett et al. 2015). Little is known of the estuarine affinities of these fishes in South Africa. Confirmed estuarine occurrences have all been Green sawfish *Pristis zijsron* and occurrences have only reported from St Lucia and Richards Bay (Mhlahuze Estuary). Comparison of sizes of fish caught in estuaries with fishes caught in nearshore marine waters provides evidence that estuaries were used as nursery areas and there are reports of large females entering these systems to pup (Compagno 1991, Everett et al. 2015). The use of estuaries, and even coastal freshwaters, as pupping and nursery areas by *Pristis* species is well known from other areas (Poulakis et al. 2011, Leeney at al. 2016). In

South Africa the restriction of reported estuarine occurrences of *P. zijsron* to St Lucia and Richards Bay is interesting. By far the majority of occurrences are actually reported from St Lucia (115) compared with Richards Bay (3) (Everett et al. 2015), but the latter system was sampled over a period of intense disturbance during the development of the Port of Richards Bay. Indeed, “Richards Bay” occurrences are actually all from the Mhlathuze Estuary, a conservation area formed by the southern section of the original Richards Bay estuarine lake which was divided by port development in the mid 1970s (Weerts and Cyrus 2002). The apparent absence of Green sawfish *Pristis zijsron* from the Kosi estuarine lakes suggests a pupping and nursery habitat preference for shallow muddy, turbid estuarine lakes, rather than deep sandy, clear systems. Elsewhere the species have also been shown to occupy very shallow waters, especially as juveniles (Lear et al. 2019) has been found to be strongly associated with mudflats and mangroves (Leeney 2017). Such habitats are typical of St Lucia, of the erstwhile Richards Bay estuarine lake, the present day Mhlathuze Estuary and the Durban Bay estuary.

While the oligotrophic waters of KZN have never supported large fisheries to the extent that temperate Cape water have, there is a long history of smaller-scale fishing operations, typically gillnets and, together with KZN Shark Board bather protection nets, these would certainly have contributed to the expiration of *Pristis zijsron* from South African waters (Everett et al. 2015). However, loss of estuarine pupping and nursery habitat has also almost certainly played a significant role. Port development in Richards Bay has been noted above. Large scale modification of the lower uMfolozi and St Lucia catchments, flow modification and mouth manipulation (largely to suit the requirements of commercial agriculture) has seen prolonged periods of hypersalinity in the St Lucia system (Whitfield et al. 2006). Sawfish have not been reported from either of these systems since 1977 (Everett et al. 2015) despite considerable research netting effort in both.

The supporting services account dealing with habitat and refugia for rare endemic estuarine species found no change in their range or geographical distribution of three of the iconic fish species (Table 7.3). However, Sawfish that used to occur in the Subtropical and Tropical biogeographical region are extinct from South Africa and no longer occurring in these regions or anywhere else along the coast. Overall, the populations of rare endemic estuarine species were supported by a few (2-7) key estuaries. By way of example, historically Estuarine Pipefish occurred in five systems while in 2018 it is only documented in three. Historically the core distribution of Sawfish also used to be supported by a likely maximum of only four estuarine systems.

Floods and synchronised estuary mouth opening play an important role in ensuring genetic exchange between such isolated biological communities. Using MAR still reaching estuaries as a proxy, the account indicated that opportunities for exchange have declined by 21% for Botriver klipvis; 15% for Knysna seahorse and about 18% for Estuarine pipefish, while ironically (given known extinctions) they still remain largely similar to reference for systems that used to be important for Sawfish. The Klipvis, Seahorse and Pipefish are small species that are not impacted by standard fishing activity. However, gillnet fisheries (mostly illegal) have decimated South Africa’s population of Sawfish.

The vulnerability of these severely restricted communities to changes in estuary condition is reflected in their IUCN Red Listing; the threat status of Botriver klipvis and Knysna seahorse is endangered and Estuarine pipefish critically endangered. Sawfish are extinct from South Africa.

Table 7.3: Ecosystem services account habitat and refugia for rare endemic estuarine species (as expressed as Biogeographical region extent, number of supporting systems that support species, ability to exchange genetic material, percentage area in good condition, fishing pressure, and the status of the species (IUCN threat status)

	RARE ENDEMIC ESTUARINE SPECIES			
	BOTRIVER KLIPVIS	**KNYSNA SEAHORSE**	**ESTUARINE PIPEFISH**	**SAW FISH**
Opening stock (~1750):				
ESTUARINE HABITAT				
Extent (Biogeographical region)[1]	C	W	W	ST/T
Number of systems (# estuaries)	2	3	5	4
Genetic exchange mechanism (% MAR remaining)	100	100	100	100
Good condition systems remaining (% area)	100	100	100	100
High fishing pressure nurseries (% area)	Not relevant	Not relevant	Not relevant	100
STATUS OF SPECIES				
IUCN threat status	Least Concern	Least Concern	Least Concern	Least Concern
Gain/Loss:				
ESTUARINE HABITAT				
Extent (Biogeographical region)[1]	-	-	-	Loss from ST/T
Number of systems (# estuaries)	-	-	-2	-4
Genetic exchange mechanism (% MAR remaining)	-21	-15	-18	
Good condition systems remaining (% area)	-	-	-	
High fishing pressure nurseries (% area)				
STATUS OF SPECIES				
IUCN threat status	↓	↓	↓	↓
Closing stock (2018):				
ESTUARINE HABITAT				
Extent (Biogeographical region)[1]	C	W	W	0
Number of systems (# estuaries)	2	3	3	0
Genetic exchange mechanism (% MAR remaining)	79	85	82	98
Good condition systems remaining (% area)	100	100	100	0
High fishing pressure nurseries (% area)	Not relevant	Not relevant	Not relevant	100
STATUS OF SPECIES				
IUCN threat status	Endangered	Endangered	Critically Endangered	Extinct in South Africa

[1] C = Cool Temperate; W = Warm Temperate, ST=Subtropical, T=Tropical

8. REFLECTION ON ESTUARINE ACCOUNT METHODS

8.1 National Perspective

Estuarine ecosystem accounting provides a means of quantifying and tracking change in estuaries as a form of natural capital, and their associated ecosystem services over time. This is intended to inform a range of policy, planning and decision-making processes relating to the management of ecosystems and the use of ecosystems services, and to enable links to be made between the measurement of ecosystems and the measurement of the economy (Van der Velde 2016). Estuarine ecosystem accounts were developed to support strategic decision making about natural resources management and trade-offs between different ecosystem services.

While most natural capital accounts amalgamate estuaries either into wetlands account or coastal account, **South Africa has elevated these important transitional waters ecosystem types into separate estuarine physical accounts** to reflect their disproportionally high socio-economic benefits to society per unit area compared to other natural systems (e.g. nursery areas for important fisheries, carbon sequestration). This also allows for reporting of change at meaningful scales, which is not possible if estuaries are combined with wetlands or other coastal habitats in systems accounting.

These experimental estuaries ecosystems accounts developed practical methods to capture and reflect changes in extent and conditions in the physical accounting framework in a data-limited environment. It did this by **aligning the accounts with exiting approaches**; using the EFZ as the spatial measure for the accounts, aligning with DWS Ecological Flow Requirements approaches (using Estuary Health Index), integrating the condition and pressure outputs of the NBA 2018 into accounts, using the broad IUCN ecosystems typology to align with international approaches, and presenting data in such a way that it is compatible with the requirements of management planning processes.

Thus estuaries ecosystems accounts can be used as a powerful set of measures and indicators for reporting on sustainable development. **Data were aggregated and presented in such a manner that can very easily be disaggregated to provincial or local levels**. The estuarine ecosystem accounting approach can thus be applied at different scales for different purposes. For example, at national and international levels, accounts can be used for raising awareness, monitoring progress or setting priorities. At the provincial or local level, accounts can be used to inform resource allocation, restoration efforts or to evaluate policies and programmes. Therefore, future versions of the national accounts should explore more focused physical accounts on selected subsets of estuaries, for example, accounts that reflect changes in estuaries that support protected areas, Ramsar sites or restoration activities.

Condition accounts were aggregated at a range of levels to support policy development and management actions. The **National Estuarine Ecosystem Condition Index provides a single value at the country-level** to track the overall change in its simplest form, but this indicator can, in turn, be evaluated with other national-level indicators, such as the 'River Ecosystem Condition Index to provide national government with a "Dashboard type" overview of progress made towards sustainable natural resource use and protection. **The condition accounts for biogeographical regions and estuary functional types are intended to inform regional or district level estuary management and resource use**. **Accounts for Estuary Ecosystem Condition Indicators reflect the status of estuary resources at the component level**. Ecosystem condition indicators were not disaggregated to a high level of detail (only to biogeographical level) as aquatic resources are inter-connected, and the intent here is to focus attention on indicators that are, as a whole, in rapid decline, showing marked recovery, or relative stable overtime.

Estuarine condition is sensitive to climate fluctuations, i.e. wet-dry cycles, and therefore is not updated annually but over a 5 to 10-year period. The **development of a set of pressure accounts allowed for an indirect, cost-effective manner to track potential decline in estuary condition**. It also emphasizes estuaries where pressures have increased and, therefore, need monitoring and more frequent assessment. Pressure accounts allow for the collation of pressure data on a sectorial basis, which in turn can be fed into future updates of condition accounts and sectorial management/action plans that deals with estuaries. **Updates of pressure data should be devolved to the various relevant sectors of government responsible for estuarine resource management for regular reporting at inter-ministerial /cross-sectorial working groups** (every 1 to 5 years at Environment MinTech Working Group 8: Oceans and Coast Meeting, e.g. fishing catches (t), the actual volume of wastewater discharged (ml/d), volume of water abstracted (m^3), the extent of alien plant infestation (ha), or sand mined for estuary (t)). Without regular updates of this information, there is no effective way to update condition estimates for estuaries. Emerging pressures, such as plastic, light and noise pollution will need to be added to future pressure accounts as information become available. The information captured in the pressure accounts should also be used to inform the development of 'Ecosystem Services Supply and Use' accounts for estuaries.

More research and data are needed on extent and condition estuarine abiotic and biotic habitat. Information was lacking on condition of critical habitat types, e.g. mud flats, mangroves or salt marsh. Future reassessments of estuary condition need to further disaggregate this critical information to allow for more detail reflection of habitat condition and future estimates of ecosystem productivity. Also, more local research is needed to refine carbon storage values for South Africa as limited data at a few sites indicate that South African storage value may be less than those reported elsewhere. The development of a national **carbon sequestration** account also supports initiatives on developing opportunities for Blue Carbon trading and Blue Carbon trading and Ecosystem-based adaptation (EbA) interventions moving forward.

In the international literature, ecosystem services accounts for fish reflect only stock abundance as a measure of extent. However, it should be noted that **fish stocks have geographical ranges which can expand, shrink or split,** through direct anthropogenic actions (e.g. overfishing of White steenbras caused loss of West Coast population) or indirect pressures (climate change induced ocean current and sea water temperature changes are causing southwards shift in Spotted grunter stock). It is **important that the spatial element of a stock extent be captured in ecosystems accounting to reflect underlying ecosystems shifts in resource abundance**. More research needs to be done on how to incorporate this element in estuaries accounting.

The underlying datasets developed of the NBA 2018 (e.g. ecosystem type, ecosystem extent, ecosystem condition data) serve as fundamental datasets in the development of estuarine ecosystem accounting. These data feed into both extent and condition accounts. While pressure data, reported by a range of sectors dealing with natural resource management, can inform, and in turn be informed by, condition data sets. It is therefore important that a 'tight coupling' be formed between the national programmes that support the NBA process and the development and/or update of national ecosystem accounting going forward. Timing of national ecosystem accounts should also be staggered so that feedback-loops and the flow of information from the two processes can feed into the other. In addition, the rigorous peer review processes of the NBA also allow for the inclusion of a range of datasets (even if not all are of the same level of confidence) to address data deficiencies in a limited funding environment. Regional or local level updates of the ecosystem accounts, in turn, can be fed into the NBA process.

8.2 Considerations for International Application

The following innovations from the estuarine physical accounts method developed here may be relevant to the international arena:

- While internationally most natural capital accounts assimilate estuary ecosystems either into wetlands or coastal accounts, South Africa elevated these important transitional waters ecosystem type into a separate set of accounts to reflect disproportionally high socio-economic benefits to society derived from them (e.g. nursery areas for important fisheries, carbon sequestration) and the rapid decline they are subjected to on a local and global scale.
- The estuary accounts were broadly aligned with the IUCN Global Ecosystem Typology (Keith et al 2010), i.e. estuaries as a transitional water ecosystem type with nested biogeographical region and functional groups, to allow

for integration across national and international reporting frameworks and allow for aggregation of ecosystem units on a global scale moving forward. However, some alignment is noted with 'Large fluvially dominated' functional estuary types having commonalities with the 'Coastal river deltas' functional group reported on in the Marine/Freshwater/Terrestrial Realm (MFT1), Brackish tidal systems Biome (MFT 1.1). This anomaly prevents an elegant transposition of South African functional groups into the Global Ecosystem Classification system and needs further engagement with the broader IUCN Classification.

- Given the ever-changing nature of estuaries and need for contextualized condition assessment - 'Is change a response to natural or anthropogenic stress?' - the development of a set of pressure accounts allowed for a more direct manner to track the potential decline in condition and a way of highlighting estuaries in need of more frequent condition reassessment. Pressure data are easy to assimilate and to analyze for trends. Regular condition assessment in most countries is only done on larger systems, and therefore does not provide a readily available national data set. The information captured in the pressure accounts should also be used to inform the development of 'Ecosystem Services Supply and Use 'accounts for estuaries.
- Aligning physical accounts with other sectorial products and measure allows for an approach that can report across sectors (water, fisheries, environment) using the best available information. In a data-poor environment, it is important to not reinvent measures, but rather 'domesticate' accounts with existing information.
- In the SEEA framework ecosystem services accounts for fisheries reflect only stock abundance as a measure of extent. However, it should be noted that fish stocks have geographical ranges which can expand, shrink or split, through direct anthropogenic actions (e.g. overfishing) or indirect pressures (climate change). It is important that this spatial element be captured in ecosystems accounting to reflect underlying ecosystems shifts in resource abundance. Just using biomass/abundance as a measure does not reflect shifts in the ability to catch and process stock.

9. KEY FINDINGS AND RECOMMENDATIONS

9.1 Condition of South African Estuaries

Comparing change in the extent of South African estuaries from natural (~1750) to 2018 – expressed in terms of the 'number of estuaries' revealed an increase from 289 to 290 systems. This change occurred in the Subtropical biogeographical region where in the 1970s, an estuarine lake (uMhlathuze) was subdivided into an estuarine bay (Richards Bay Estuary) and a predominantly open system (uMhlathuze Sanctuary) to allow for a large commercial port development. Although the total EFZ area of estuaries remained the same, this modification did result in a redistribution of EFZ area among estuary functional types.

South Africa currently has incomplete data to populate opening stock (natural) for extent accounts for abiotic and biotic estuarine habitat. However, the closing stock (2018) estimates abiotic habitats comprising open water area and floodplain habitat at 58,994 ha (29% of EFZ extent) and 141,742 ha (71% of EFZ extent) respectively. Comparison of the biotic habitat extent accounts from 1920/1930s (best available baseline) with the closing stock in 2018 the greatest loss occurred in supratidal salt marsh habitats (4 979 ha), primarily as a result of urban and agricultural land-use. This is followed by a loss in intertidal salt marsh (568 ha), mainly as a result of the construction of bridges, causeways and jetties. Mangrove habitat (~300 ha) has also been lost from many systems, most notably from Durban Bay as a consequence of port and city development. However significant new mangrove habitat has established in the uMhlathuze and Richards Bay estuaries as a result if increased tidal fluctuation caused by port development in the 1970s. So significant is this increase in new mangrove area that overall national mangrove habitat has increased by 97 ha.

The National Estuarine Condition Index, providing a high-level overview of estuary condition, is estimated at 63.7, indicating a significant decline in the condition in South Africa's estuaries. The degradation of Arid Predominantly Closed systems (with only 45% of processes and functioning still intact) contribute the most to the decline in condition, while Small Fluvially Dominated systems (93% largely natural) show the least decline.

Comparing the condition of estuaries from natural with that encountered in the 2018 in terms of 'number of estuaries', only 21% of South Africa's estuaries are still in a natural state (A category), with 40% in a near-natural state (B category), 20% in a moderately modified state (C category), 12% in a heavily modified state (D category), and 7% in a severely/critically modified state.

Across bioregions, results reveal that systems remaining natural and near-natural condition are mainly located in the Warm Temperate (73% of systems in the region) and Subtropical (50% of systems in the region) regions, while the estuaries in the Cool Temperate region were characterised by heavily to severely/critically modified systems (55% of systems in the region).

However, a concerning result emerges when the condition is expressed as 'percentage EFZ area' across biogeographical regions. Only 5.3% and 17.3% of EFZ area remain in a natural to near-natural state, mostly located in the Warm Temperate and Tropical regions. More than 57% of the estuarine functional area is already in a heavily modified state (partly an artefact of the largest estuary in South Africa – St Lucia/uMfolozi system – falling within this category), and an additional 4.5% is critically modified. The comparison between 'number of estuaries' and 'EFZ area', indicates that smaller estuaries tend to be in better condition, not being subject to the same level of human pressures compared with the larger, more productive systems. Typically, larger estuaries are more heavily affected by catchment and direct development pressures, resulting in their overall poorer condition. However, larger systems remain more resilient to human pressures compared with the smaller systems.

Expressing condition in term of specific **Ecosystem Condition Indicators** (using EFZ area as measure), shows that the **hydrology** in 63% of estuaries is still in a relatively good condition (natural/near-natural condition). In contrast, from a **hydrodynamics** perspective only 36% is still in good condition, primarily due to artificial mouth manipulation. Condition of **salinity** and **water quality** also decreased markedly from natural (~1750) to 2018, with only 28% and 20%, respectively, still remaining in good condition, primarily associated with flow modifications and pollution. Similarly, **physical habitat** (benthic substrate) has been markedly modified with only 26% still in a good condition, mostly as a result of alterations in flood regimes and inappropriate land-use in the EFZ. The condition of biotic indicators also tends to gradually decrease along the trophic scale from natural to present, from **microalgae** (20%), to **macrophytes** (19%), through to **invertebrates** (16%), and ultimately to the (4%) components, revealing the cumulative effects of human pressures along trophic levels. In contrast, **birds** show less of a decline, with 26% still in good condition, highlighting the robustness of bird communities to anthropogenic pressures.

Comparing change in condition from natural (~1750) to 2018 across **estuary functional types**, four types (Estuarine Bays, Estuarine Lagoons, Large Fluvially Dominated and Arid Predominantly Closed estuaries) no longer exist in a natural state. Only two estuary functional types (Estuarine Lagoons and Small Fluvially Dominated estuaries) remain fully in natural or near-natural states, while 66% and 52% of EFZ area, respectively associated with small temporarily closed and estuarine bay systems remain in natural or near-natural condition. Predominantly Open estuaries are largely moderately modified (49% of EFZ area), with another 12% being heavily modified. Especially of concern are Estuarine Lakes, with only 10% of the EFZ area remains in natural or near-natural condition. Eighty-four (84) % has already been heavily modified and another 2% severely/critically modified. Large Fluvially Dominated systems are 87% heavily modified, with Arid predominantly closed systems also showing a bleak picture, with 72% being severely/critically modified. Thus, proportionally Estuarine Bays, Estuarine Lakes, Large Fluvially Dominated and Arid Predominantly Closed systems are in the worst condition with 53%, 50%, 57% and 50% of systems being in heavily to critically modified states, respectively. Proportionally, Large and Small Temporarily Closed systems, and Small Fluvially Dominated systems remain in relatively good condition, with 55%, 69% and 100% still remaining in natural/near-natural condition, respectively.

9.2 Pressures on South African Estuaries

Six direct anthropogenic (human) pressures on estuaries were considered for the purposes of this work, namely water resource use, land-use, exploitation of living resources, pollution and artificial breaching (manipulation of estuary mouths). **Water resource use** has reduced freshwater flows to estuaries by about 12,000 million m^3 per annum by 2018, with only about 67% of natural flows remaining (i.e. 24,800 million cubic meters per annum). Nationally, this pressure is ranked 'very high' in 24 systems (9%), 'high' in another 31 systems (11%) and 'medium' in 40 systems (14%). **Land-use within EFZ** has contributed significantly to deterioration in estuaries. With only 28 estuaries considered to be in a near pristine state. Overall, 29% of South African estuaries are subject to severe (high and very high) pressure from habitat modification and development. Over 3,730 tonnes of fish are caught annually, with 21% of estuaries subjected to high or very high fishing pressure. It is estimated that about 840 million cubic meters of **wastewater are being discharged** daily into 42 systems country-wide, either directly into estuaries, or to river reaches just upstream of estuaries. Effluent is mostly derived from municipal wastewater treatment works (WWTW). Nationally, the deterioration of estuarine water quality, associated with wastewater discharges, is ranked as 'high to 'very high' in at least 11% of estuaries, mainly system in and around the large urban centres. **Artificial breaching** of estuary mouths (inlet manipulation) is practised in at least 45 systems nationally. Although this amounts to only 15% of the total number of estuaries along the coast, the affected systems represent more than 60% of the total national estuarine habitat.

Biological invasions, considered an indirect pressure on estuaries, include **invasive plants** and **alien/extralimital (translocated) fish**. A third of estuaries have **invasive terrestrial plants** occurring within the EFZ, of which 10% experience a high degree of impact. Aquatic invasive plant species occur in 8% of estuaries. **Alien and extralimital (translocated) fish** occur in 25 % of South Africa's estuaries, of which 6% and 14% are experiencing severe (high to very high) impact from this pressure, respectively.

9.3 Insights into Estuarine Ecosystem Services

In this country-level determination of physical accounting for estuaries, three ecosystem service accounts considered important within the context of South Africa's estuaries also was touched on, namely carbon sequestration; support to important estuarine and marine fisheries; and supporting habitat and refugia for rare endemic estuarine species.

The carbon sequestration accounts showed that due to a decline in overall estuary condition there has been a concomitant decline in the benefits society derives from them. For example, there has been a **nett loss of 1,365,323 Mg in 'blue' carbon sequestration potential** of South Africa's estuaries as a result of ongoing decline in habitat extent and condition, specifically salt marsh habitat. This is based on internationally derived values of soil carbon content and also does not include values for 'teal' carbon as captured in swamp forest. These accounts will need updating once better local estimates of soil carbon content are available. The development of a national **carbon sequestration** account will support initiatives on developing opportunities for Blue Carbon trading and Ecosystem-based adaptation (EbA) interventions moving forward.

The ability of South Africa's estuaries to support provisioning services such as nursery function for estuarine and marine fish of economic importance have been severely reduced. Amongst others, the biogeographical extent analysis shows a contraction of the distributional range of White steenbras and an expansion in that of Spotted grunter. These ranges changes have been driven by a combination of overfishing and climate change on these key fish stocks. Nursery function for selected estuarine-dependent species was supported by between 52 and 88 estuaries, with Elf being the most restricted and Southern Mullet the least selective in critical nursery areas. Historically, key estuaries along the west coast would have also contributed extensively to nursery function for White steenbras, but as a result of excessive fishing pressure and population collapse only Langbaan Estuarine Lagoon still has a viable biomass of White steenbras (loss provision services in five estuaries). In contrast, as a result of climate change, Grunter occur in more estuaries (+8) that provide nursery function for this important estuarine fisheries species. Freshwater recruitment signals that assist fish locating and recruiting into estuaries, using MAR still reaching estuaries as a proxy, showed that key nurseries have lost between 49% (Leervis and Elf) and 20% (Spotted Grunter) of their recruitment signal; with Steenbras recruitment signal declining by about 46%, and Dusky kob and Mulllet recruitment signal declining by about 35% and 34% respectively. The remaining extent of highly productive key nursery estuaries capable of supporting fisheries (remain in a natural to moderately modified state) varied between 22% to 32% for Dusky kob, Grunter and Mullet, and between 79% to 84% for Steenbras, Elf and Leervis. As a final measure, the percentage EFZ areas of important nursery estuaries under high to very high fishing pressure was also calculated. In most cases 70% to 91% key nurseries are overfished thus reducing overall productivity. Spawner biomass per recruit (SBPR % of pristine in the absence of fishing), a measure of breeding potential that represents the ability of a stock to recover, is critically low at < 2% and 6% for Dusky kob and White steenbras respectively. Leervis spawner biomass per recruit is estimated at 14%, Grunter at < 25%, Elf < 25% and harder (Southern mullet) at 24%, all indicative of collapsed states. Mullet are the directed catch of the commercial and small-scale beach-seine and gillnet fisheries in the sea and important to the livelihoods of most coastal communities on the West Coast. The status of these resources is a global concern with Dusky kob listed as critically endangered, White steenbras as endangered, and Grunter, Leervis and Elf as vulnerable on the IUCN Red List.

The **supporting services account dealing with habitat and refugia for rare endemic estuarine species** found no change in the ranges or geographical distributions of three of the five iconic fish species considered. However, **Sawfish that used to occur in the Subtropical and Tropical biogeographical region, are now extinct from South Africa** and no longer occur in these regions or anywhere else along the coast. **Overall, the populations of rare endemic estuarine species were supported by a few (2-7) key estuaries.** By way of example, historically Estuarine Pipefish occurred in five systems but in 2018 they are only documented in three. Historically the core distribution of Sawfish used to be supported by only four estuarine systems. Floods and synchronised estuary mouth opening play an important role in ensuring genetic exchange between these isolated communities. Using MAR still reaching estuaries as a proxy, the account indicated that opportunities for genetic exchange have declined by 21% for Botriver klipvis; 15% for Knysna seahorse and about 18%

for Estuarine pipefish. Ironically marine estuarine connectivity largely remains similar to reference for systems that used to be important for Sawfish. Botriver klipvis; Knysna seahorse and Estuarine pipefish are all small bodied species and as such are not impacted on by standard fishing activity. However, gillnet fisheries (mostly illegal) have decimated South Africa's population of Sawfish. The vulnerability of these severely restricted communities to changes in estuary condition is reflected in their IUCN Red Listing; the threat status of Botriver klipvis and Knysna seahorse is endangered and Estuarine Pipefish critically endangered. Sawfish are extinct from South Africa.

9.4 Addressing Data Gaps

Estuarine Functional Zone extent: A fine-scale mapping exercise (1:3,000 - similar to coastal ecosystem map) should be undertaken to improve the resolution of the estuary ecosystem map as captured in the EFZs. This should be supported by ground-truthing of the lesser known, more remote rural systems and a refined delineation of the natural state for severely/critically modified systems. In addition, the historical delineation of some of the highly transformed estuaries (e.g. Diep/Rietvlei, Sout, Zeekoei) should be refined through more detailed 'historical ecology' studies. This will allow the development of an opening account for abiotic habitats.

Open water area extent: Open water area should be determined from a range of high-resolution imagery over an extended period (> 10 years) representative of both open and closed mouth condition. In 2009 the open water area of South Africa's estuaries was mapped (once-off) at a 1:10,000 scale based on a satellite composite image for that year. It is recommended that more iterations of this mapping exercise be undertaken in future to generate a more representative baseline over time.

Biotic Habitat: More detailed information is needed on the condition of biotic habitats per estuary to inform ecosystem services accounts moving forward, e.g. the condition and stump density of mangroves habitat in South Africa, salt marsh biomass of systems under grazing pressure.

Abiotic and Biotic Ecosystem Condition Indicator data: Up-to-date national scale field surveys of the abiotic (topography, bathymetry and sediment structure) and biotic components (plants, inverts fish and bird) are urgently needed (Van Niekerk et al 2019a). National surveys were last carried out in the early 1980 and 1990s. These surveys urgently need to be repeated in a once-off effort that is comparable with the earlier surveys. Towards this, it is recommended that DEFF expands its current fish (and invertebrate) monitoring surveys to include a representative sample of small and large estuary types across biogeographical regions (where no such datasets presently exist, e.g. in protected areas).

Pressure data: Updates of pressure data should be devolved to the various relevant sectors of government responsible for estuarine resource management for regular reporting at inter-ministerial /cross-sectorial working groups (e.g. every 1 to 5 years at Environment MinTech Working Group 8: Oceans and Coast), e.g. fishing catches (t), the actual volume of wastewater discharged (ml/d), volume of water abstracted (m^3), the extent of alien plant infestation (ha), or sand mined for estuary (t). Without regular updates of this information, there is no effective way to update condition estimates for estuaries. Emerging pressures, such as plastic, light and noise pollution will need to be added to future pressure accounts as information become available.

9.5 Ecosystem Accounting in support of Estuary Management

This country-level physical accounting exercise on South Africa's estuaries highlighted the ongoing, national-level decline in the condition of these valuable natural systems. Strategic interventions across multiple sectors are required to not only conserve, but also to start restoring estuarine condition to protect benefits to people. To avoid further compromising of the benefits derived from estuaries the NBA 2018 advocated a Strategic Estuarine Management Framework focusing on implementation and compliance across key sectors – including freshwater allocation, fish resource use, water quality management, land-use planning, agriculture and mining. Complex ecosystems, such as estuaries, require an integrated approach to address the ongoing decline in condition. To be effective all management actions and programmes need to be integrated into one coordinated framework with regular feedback to ensure implementation. Estuarine Ecosystems Accounting provides a platform for tracking progress in this regard. Key actions that should be supported and monitored include recommendations to:

- Increase estuarine protection levels and share the benefits of estuarine protected areas equitably among coastal communities through the setting of short- to medium-term targets for Estuarine Protected Areas. Progress can be reflected in a set of focussed Protected Areas Accounts (extent and condition) for estuaries (including Ramsar and Critical Biodiversity Areas). Sub-accounts can be generated for habitat types within protected areas to reflect efforts to increase protection of salt marsh, seagrass and mangrove habitats.
- Several estuarine-dependent fish species are threatened by overfishing, declining water quality, and reduced flows with their concomitant influence on recruitment and marine connectivity. The NBA 2018 recommended that stock/population recovery be facilitated by reducing fishing pressure, increased compliance, ensuring adequate freshwater inflow, decreasing nutrient pollution, managing noise pollution and boating activity. The estuaries ecosystems services accounts and pressure accounts provide the ideal vehicle to report on progress on this cross-sectorial approach in an integrated manner.
- Healthy functional estuaries support the cultural, aesthetic, commercial, recreation and subsistence benefits upon which coastal communities depend. In support of this, the NBA 2018 called for a comprehensive 'Pollution Reduction Strategy' for estuaries, with a focus on reducing impacts from municipal wastewater treatment works (WWTW), agricultural return flow and urban stormwater. Thus, in addition to refinements in condition and pressure accounts, progress in this regard can also be captured in restoration accounts or focused industry/sector accounts.
- Similarly, extractive activities that have disproportionally large ecological impacts, such as mining, may need sector-specific sub-accounts (e.g. fraction of sediment extracted to available estuarine and coastal sediment budgets, land-use change) to reflect on change from an ecosystem perspective vs a sector perspective, i.e. not just accounting of monetary value or total resource extracted (e.g. tonnage of sand).
- The NBA 2018 highlighted a pressing need for a National Estuary Restoration Programme to halt and reverse the on-going decline in estuary condition and the wealth of ecosystem benefits derived from them. Such a programme would focus on degraded and novel systems, with an emphasis on the larger systems of high biodiversity importance and the socially important urban systems. The ecosystem extent and condition accounts developed here are seen as a way to report on restoration progress as an increase in habitat and/or estuary condition will be reflected in the proposed estuarine physical accounts. It may even require the development of a more focussed 'Restoration account' to highlight progress in this regard.
- Lastly, it may be of value to develop an account that reflects progress in governance activities that support wise use and protection of estuarine resources, such as: completed ecological water requirements /classification studies, implemented Estuary Management Plans, or progress in long-term monitoring or national survey programmes. This information, in turn, can be fed into national reporting frameworks such as Outcome 10 and global indicators such as SDGs.

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APPENDIX A: DATA SOURCES USED IN ASSESSMENT

Anthropogenic activity pressure accounting

PRESSURE	DATA DESCRIPTION
Flow modification	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b; DWS 2017a & b, including supporting reports; Adams et al. 2016)
	WRC EcoClassification of Temperate Estuaries (van Niekerk et al. 2015)
	Provisional Desktop EcoClassification Temperate - Subtropical Transition Zone Estuaries (Van Niekerk et al. 2014)
	Water Situation Assessment Model (Schultz and Watson 2002)
	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b, DWS 2017a & b, including supporting reports; Adams et al. 2016)
	Scientific publications (e.g. De Villiers and Thiart 2007; Lemley et al. 2014)
Wastewater disposal	National Biodiversity assessment 2018 (Van Niekerk et al. 2019, Adams et al. 2020)
Exploitation of living resources	WRC EcoClassification of Temperate Estuaries (van Niekerk et al. 2015)
	Provisional Desktop EcoClassification Temperate - Subtropical Transition Zone Estuaries (Van Niekerk et al. 2014)
	Subsistence bait collection (field observations) and NBA 2018
	Habitat destruction due to bait collection (field observations) and NBA 2018 (Van Niekerk et al. 2019)
	DEFF and KZN-Wildlife records of illegal catches (Van Niekerk et al. 2019 – NBA 2018)
Land-use	2014 National land-cover layer (South African National Biodiversity Institute)
	NMU National Estuarine Botanical Database (2018 updates) (Adams et al. 2016)
	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b; DWS 2018)
	WRC EcoClassification of Temperate Estuaries (van Niekerk et al. 2015)
	Provisional Desktop EcoClassification Temperate - Subtropical Transition Zone Estuaries (Van Niekerk et al. 2014)
	Field observations
	Google Earth
Manipulation of inlets	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b; DWS 2017a & b, including supporting reports; Adams et al. 2016)
	Field observations
	NBA 2018 (van Niekerk et al. 2019b)
	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b; DWS 2017a & b, including supporting reports; Adams et al. 2016)

Estuarine alien invasive pressure accounting

PRESSURE	DATA DESCRIPTION
Alien invasive/ extralimital species	Nelson Mandela University National Botanical Database
	Publications (Adams et al. 2016; Riddin et al. 2016)
	Environmental Water Requirement (EWR) and Classification studies (DWS 2015a & b; DWS 2017a & b, including supporting reports; Adams et al. 2016)
	DEFF rivers fish species database
	Field observations

Estuarine extent accounting

DATA	DATA DESCRIPTION
Estuarine Functional zone (EFZ) 2018	2018 Estuarine Functional Zone (Van Niekerk, L., Adams, J., Fernandes, M., Harris, L., Lamberth, S.J., MacKay, C.F., Petersen, C., Ramjukhad, C-L., Riddin, T., Van Deventer, H. and Weerts, S.P. 2019, 'Chapter 5: Extending the Estuary Functional Zone to include all processes', in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Environment)
Estuary ecosystem type map	2018 Estuary Classification assigned to each EFZ (Van Niekerk, L., Adams, J.B., James, N., Lamberth, S.J., MacKay, C.F., Turpie, J.K., Rajkaran, A., Weerts, S.P. and Whitfield, A.K. 2019, 'Chapter 4: A new Ecosystem Classification for South African estuaries', in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Environment)
Land cover change	Land cover change raster developed by SANBI with two time points 1990, 2014. Based on national land cover products by GeoTerra Image 2015. GeoTerraImage, 2015, Technical Report: 2013/2014 South African National Land cover Dataset version 5. Pretoria, 53 pp. GeoTerraImage 2015. Technical Report: 1990 South African National Land cover Dataset version 5.2. Pretoria, 63 pp.

Estuarine ecosystem-level condition accounting

DATA	DATA DESCRIPTION
Estuarine Functional zone (EFZ) 2018	2018 Estuarine Functional Zone (Van Niekerk, L., Adams, J., Fernandes, M., Harris, L., Lamberth, S.J., MacKay, C.F., Petersen, C., Ramjukhad, C-L., Riddin, T., Van Deventer, H. and Weerts, S.P. 2019. 'Chapter 5: Extending the Estuary Functional Zone to include all processes', in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Environment)
Estuary ecosystem type	2018 Estuary Classification assigned to each EFZ (Van Niekerk, L., Adams, J.B., James, N., Lamberth, S.J., MacKay, C.F., Turpie, J.K., Rajkaran, A., Weerts, S.P. and Whitfield, A.K. 2019. 'Chapter 4: A new Ecosystem Classification for South African estuaries', in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Environment)
Estuary Condition	2018 Estuary Condition assigned to each EFZ (Van Niekerk, L., Adams, J.B., Clark, B., Lamberth, S.J., MacKay, C.F. and Weerts, S.P. 2019. 'Chapter 7: Condition of South Africa's estuarine ecosystems' in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Environment)
Land cover change	Land cover change raster developed by SANBI with two time points 1990, 2014. Based on national land cover products by GeoTerra Image 2015. GeoTerraImage 2015, Technical Report: 2013/2014 South African National Land cover dataset version 5. Pretoria, 53 pp. GeoTerraImage, 2015, Technical Report: 1990 South African National Land cover dataset version 5.2. Pretoria, 63 pp.

Estuarine habitat condition accounting

COMPONENT	DATA DESCRIPTION
National Botanical database	Adams, J., Fernandes, M., and Riddin, T. 2019. 'Chapter 5: Estuarine Habitat extent and trend' in South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm. South African National Biodiversity Institute, Pretoria. Report Number: SANBI/NAT/NBA2018/2019/Vol3/A.