# Country-level ecosystems accounts for estuaries: South Africa's experience with a Transitional Realm

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**ABSTRACT**

Estuaries constitute highly productive transitional ecosystems in the land-sea interface that provide 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% South Africa's territory) that function as critical ecological infrastructure that should be prioritised for planning, management, and protection. Stemming from their relatively small size and high socio-economic value, it is critical to develop separate ecosystem accounts and not aggregate these into larger freshwater or marine realms – running the risk of grossly under-valuing or masking their benefits to biodiversity and society.

Within this context a country-level estuarine ecosystem accounts were developed, focusing on extent, condition, and ecosystem services, as well as pressure accounts. The accounts apply a natural condition (~1750) as opening stock, with 2018 representative of closing stocks based on available country-level data. The ecosystem services accounts focused on a selection of key services, including carbon sequestration, nursery function for important fisheries, and habitat and refugia for rare and endangered estuarine species. A National Estuarine Ecosystem Condition Index was developed that provides a high-level overview of the condition of estuarine resources. The method organizes estuaries into biogeographical regions and ecosystem functional types, using specific abiotic and biotic indicators to account for changes in condition. Ecosystem types are as per the South African Estuarine Classification System that is broadly aligned with the IUCN Global Ecosystem Typology for the Freshwater-Marine Realm (Level 1) and Transitional Waters Biome (Level 2).

The National Estuarine Ecosystem Condition Index was estimated at 64 (out of 100), indicating a severe decline in the overall estuary condition of South Africa's 200,730 ha estuarine estate. Condition accounts showed only 23% of estuarine estate remaining in a natural/near-natural state, with 63% already in a heavily modified state or worse. The ecosystem service accounts reflected a concomitant decline in societal benefits with a nett loss of 1,365,323 Mg in 'blue' carbon sequestration potential (a regulating service). The nursery function for important fisheries (a provisioning service) also has been highly compromised with the only remaining productive nursery area for commercially important fish species estimated at 22-56% of natural functionality. In addition, 70-94% of important nursery areas are being overfished. Pressure accounts provide a means of contextualizing and tracking the shift in estuarine extent and condition. For example, 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. It is estimated that about 840 million $m^3$ of wastewater is discharged daily to estuaries directly, with 11% severely impacted. Land-use contributed significantly to estuary degradation, with 29% of area already subjected to severe land-use pressure.

The method proofed to be robust and was able to produce informative results, even with relatively sparse data availability as often encountered in the developing countries. The work has been published as a discussion document to contribute to advancing the knowledge on SEEA through application in a developing country context with severe data constraints.

**Key Questions**

- The real-world extent of South Africa's estuaries so small that using raster data (prescribed methodology) would have resulted in the under-reporting of change. We would like feedback on accounts of similar small ecosystem types and how they are being integrated within large accounts - within the context of Ocean Accounting.
- The "Pressure Accounts" were developed to contextualize changes in estuary condition. We would like feedback on how to integrate these into other forms of accounts, e.g. 'Ecosystem Services Supply and Use 'accounts for estuaries.

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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 Act | National Environmental Management: Integrated Coastal Management Act (No. 24 of 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 |
| | No data available |
| - | Not applicable |
| 0 | Figure too small to publish |

# 1. INTRODUCTION

Natural Capital Accounting (NCA) is a growing field of work globally and in South Africa, using international standards such as the System of Environmental-Economic Accounting (SEEA). Most recently the NCA introduced ecosystem accounting, focusing on accounting for ecosystem assets and ecosystem services compiled (referred to as the ecosystem accounting area (EEA) in SEEA). Since 2014, Statistics South Africa (Stats SA) and the South African National Biodiversity Institute (SANBI), in collaboration a range of national and sub-national stakeholders, commenced with a process to introduce ecosystem accounting in the national accounting systems.

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 Council for Scientific and Industrial Research (CSIR), in collaboration with the national department of the environment and the Nelson Mandela University (NMU), undertook research to develop ecosystem accounts for South Africa’s estuaries and to produce the country’s first extent, condition and ecosystem services accounts for this often over-looked ecosystem realm. This paper presents the method and outputs from this research, contributing to the application of ecosystem accounting in a developing country context, where the relevant data sets often are limiting.

# 2. STUDY AREA

South Africa has about 290 functional estuaries spanning for four biogeographical regions, namely Cool Temperate; Warm Temperate; Subtropical and Tropical regions (Adams et al. 2016; Sink et al. 2019; Van Niekerk et al. 2020a). These estuaries have been classified 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 (Van Niekerk et al. 2020a) (Figure 1). Estuarine Lagoons are the rarest type with only one 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.

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). It is therefore important to define the ‘space’ within which estuaries function over long time scales to safeguard the present and future health. To address this, the Estuary Functional Zone (EFZ) have been defined for all South Africa’s estuaries, 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 (van Niekerk et al. 2013, Van Niekerk and Turpie, 2012). The South African Estuarine Ecosystem Accounts are partially to fully spatial, but as a result of their relative small size (see Figure 1) not visually represented in maps in this document.

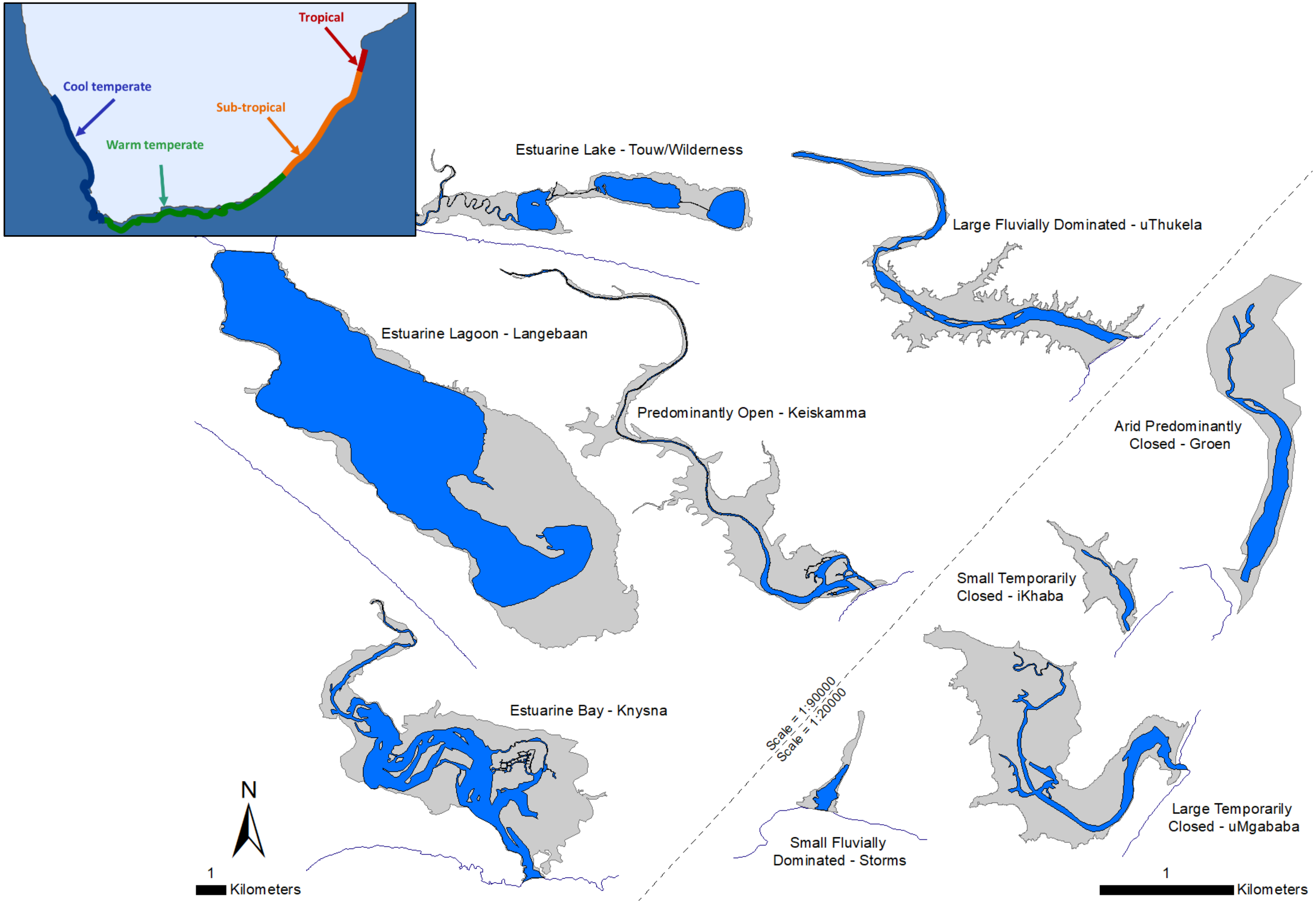


*Figure 1:* *Maps showing examples of South African estuary types, with larger types represented at 1:90 000 scale and smaller types at 1:20 000 scale*

# 3. APPROACH AND METHOD

Approach and methods are provided for **ecosystem extent and condition account**s, and also 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.

The study largely relied on available country-level information generated as part of a recently completed National Biodiversity Assessment 2018 ((Van Niekerk et al. 2019). Futher, the research was undertaken in consultation with SANBI and Stats SA through a range of interactive workshops and reviews, as well as interaction with other researhcers at the first Natural Capital Accounting Forum hosted by Stats SA in 2019.

## 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 2), 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.

Two parallel groupings were considered appropriate and useful for structuring of 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).

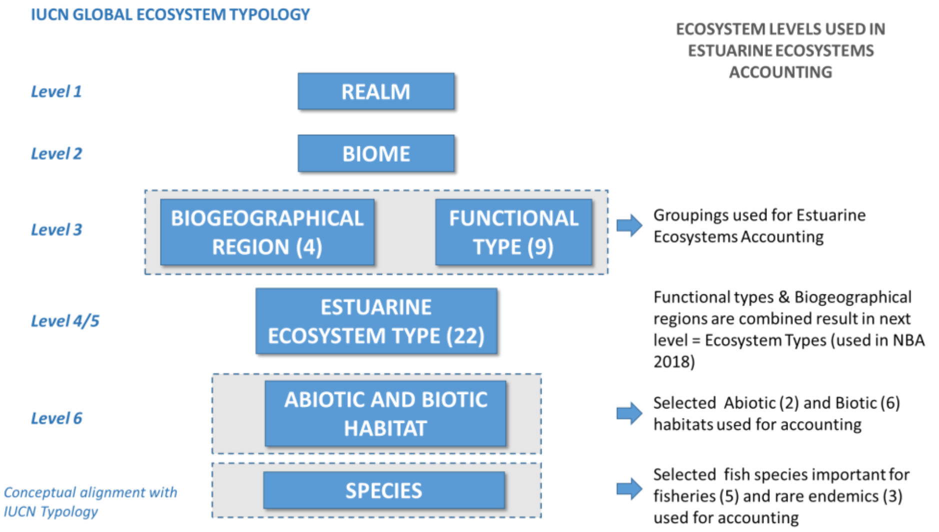


*Figure 2: Ecosystem levels evaluated in Estuarine Ecosystem Accounting and the conceptual aliment with the IUCN Global Ecosystem Typology*

For extent accounts by biogeographical region and functional type, the 'estuary' is used as the smallest unit. 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). For accounts by **estuary functional types** data were organised into the nine functional types within each of the regions. These accounts provide useful, transparent means of monitoring shifts in biodiversity against pre-set biodiversity targets, or to track trends over time.

For **habitat extent accounts** a range of proxies for estuarine abiotic and biotic habitats as is illustrated in Figure 3. (although abiotic habitats are not further discussed in this paper). **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). 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

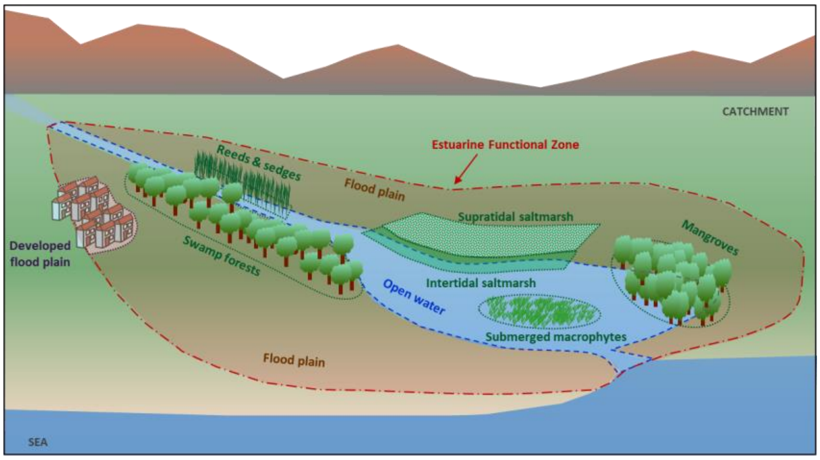


***Figure 3:* *Schematic of the relationship between abiotic and biotic estuarine habitats in South African estuaries***

## 3.2 Condition Accounting

The measurement of ecosystem condition (or 'health') 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 Estuary Health Index of South Africa reflects the overall change in condition relative to a natural condition, referring to the natural state of an estuary, around 1750, before subjected to major anthropogenic change. Four abiotic (hydrology, hydrodynamics, sediment dynamics and water quality) and five biotic (microalgae, macrophytes, invertebrates, fish and birds) Estuary Ecosystem Condition Indicators are included in the index evaluating change in an estuary's productivity and condition. Both abiotic and biotic condition indicators are included as the inter-relationships between these 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). The index change as a percentage similarity (0 – 100%) to the defined natural state and calculated by weighting individual abiotic (25% for each ) and biotic (20% for each) and then aggregating abiotic and biotic scores evenly (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 1). 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. 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.

| 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 | |

***Table 1: The Estuary Health Index translated to ecological condition and groupings proposed for ecosystem accounting (modified from Van Niekerk et al. 2013)***

Figure 4 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 biotic habitats in estuaries. The conditions accounts used the NBA 2018 estuary condition data 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).

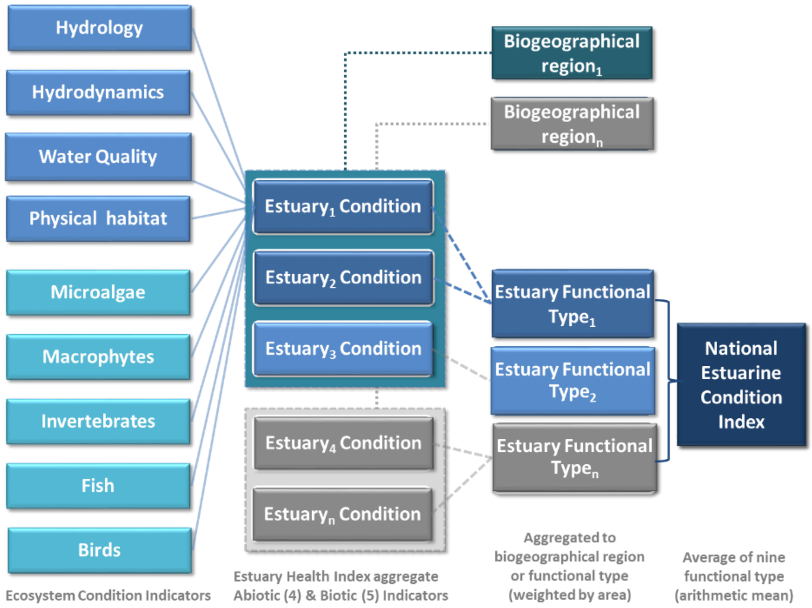


***Figure 4:*** ***Increasing levels of aggregation of estuarine ecosystem condition - from biotic and abiotic Estuary Ecosystem Condition Indicators, to condition per estuary, to condition per biogeographical region or estuary functional type, and ultimately to National Estuarine Ecosystem Condition Index***

*National Estuarine Ecosystem Condition Index*: The primary aim of the high-level 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 4). 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.

*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. 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.

*Estuarine habitat accounts:* 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, largely representative of the condition of the selected estuarine vegetation types. 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. 2016a,b). 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).

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

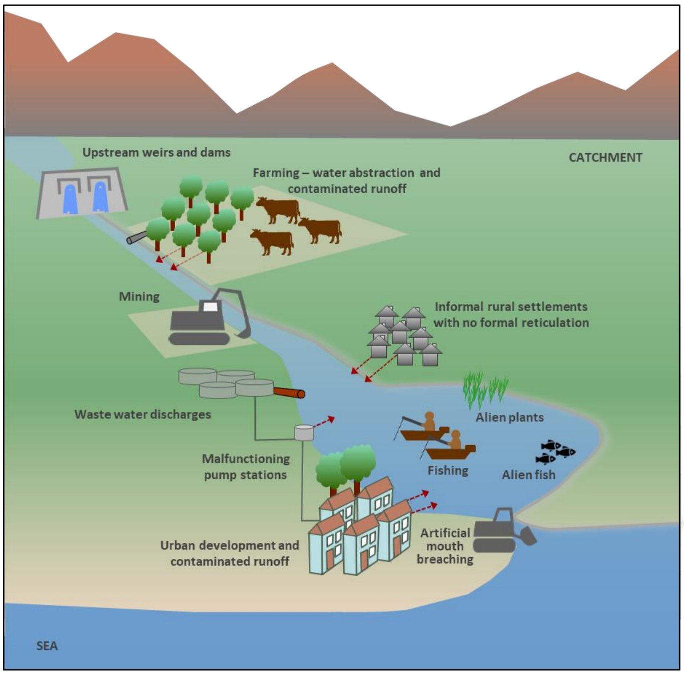


*Figure 5: Illustration of some of the key pressures on estuaries that need to be quantified in estuarine ecosystem accounting approaches*

Direct anthropogenic (human) pressures can be grouped into six categories 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. These are not discussed further in this paper.

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. 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. See van Niekerk et al. 2019 for more detail.

## 3.4 Ecosystem Services Accounting

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); and
- Nursery function for important fisheries (provisioning services).

*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 (Barbier et al. 2011). Blue carbon habitats 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.

*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 DFFE (Fisheries Research and Development) (Van Niekerk et al. 2019a; Sink et al. 2019). 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). 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.

# 4. ECOSYSTEM ACCOUNTS

## 4.1 Extent Accounts

### 4.1.1 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 Table 4.1 (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. This change is also reflected in the total EFZ area in the estuary functional types of the Subtropical region (Table 2).

***Table 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 |

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. 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.

### 4.1.2 Estuarine Habitat

The extent account for biotic habitat across the four biogeographical regions, as represented by key estuarine vegetation types amounts to 39,772 ha (Table 3). 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 3:*** ***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 4.2). 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).

## 4.2 Condition Accounts

### 4.2.1 National Estuarine Ecosystem Condition Index

The **National Estuarine Ecosystem Condition Index** provides a high-level overview of the condition of estuaries in South Africa, comprising **a single value aggregate** of the average condition of the nine estuary functional types. 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. The **National Estuarine Ecosystem Condition Index for South Africa is 63.7** (out of 100) (Figure 6), indicating that there has been a significant decline in overall estuary condition in South Africa from natural.

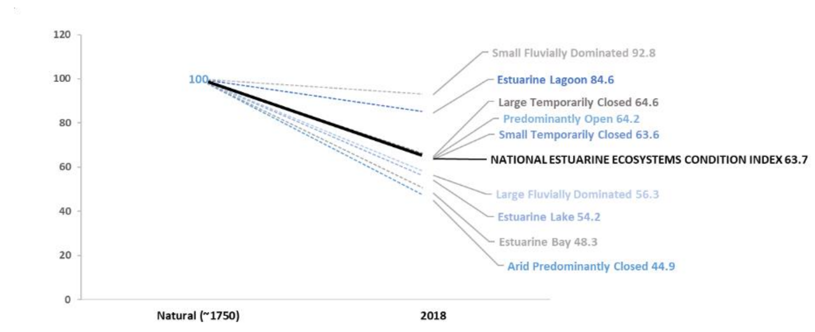


***Figure 6:** National Estuarine Ecosystem Condition Index aggregated from the nine estuary functional types overall condition*

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. In support of the **National Estuarine Ecosystem Condition Index**, Figures 7 depicts the condition of 290 estuaries in relation to geographical location and estuary size (larger bubbles represent larger estuaries).

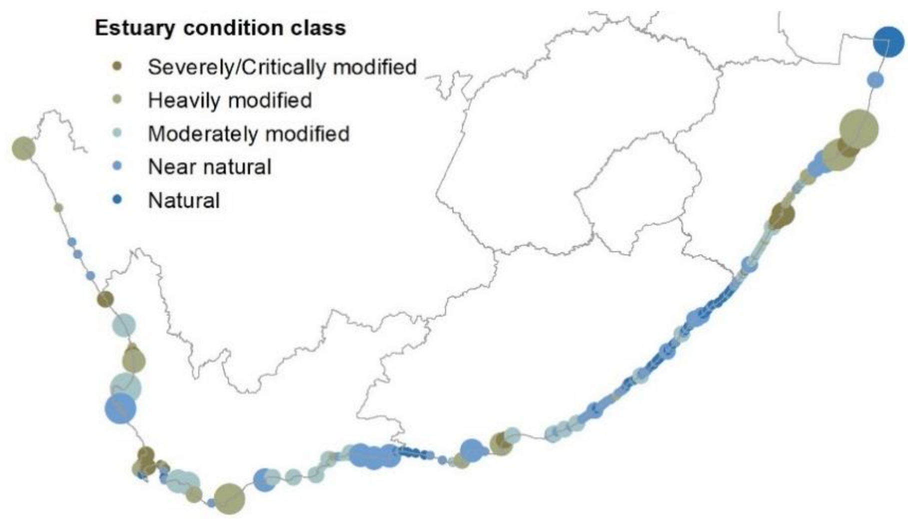


***Figure 7:** Estuary Condition grouped into five categories with bubbles displaying relative size and location of estuaries (Source: Van Niekerk et al. 2019a)*

Based on the condition account expressed as the number of estuaries (Table 4), 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).

***Table 4: 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*

Converting these numbers to percentages (Figure 5), 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).

***Table 5: 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 |

A different picture, however, emerges when condition distribution is expressed in terms percentage of EFZ area (Table 5 and Figure 9). 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. 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).

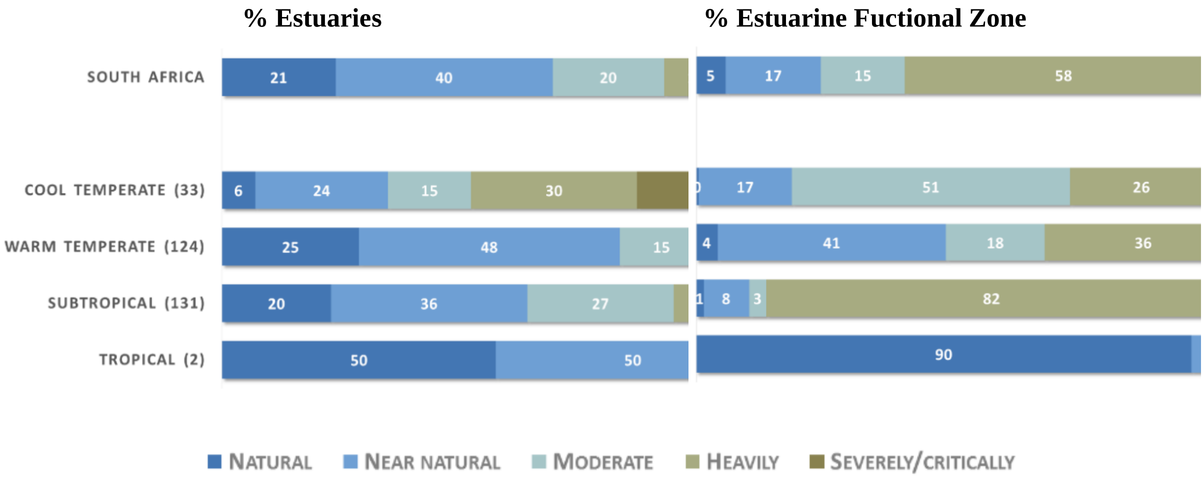


*Figure 8:* ***Relative distribution of ecological condition categories across biogeographical regions (2018) - expressed as a percentage of the [number of] estuaries per region (left) and a percentage of total EFZ area per region (right)***

### 4.2.2 Estuary Ecosystem Condition Indicators

To provide resolution on the condition of specific estuarine ecosystem indicators, Tables 6 and 7 present the condition accounts across the biogeographical region for abiotic and biotic indicators, respectively.

Considering the condition of the Estuary Ecosystem Indicator 'hydrology' (Table 6), 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 6: 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 |

In the biotic Estuary Ecosystem Condition Indicator account (Table 7), 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.

**Table 7:** *Account for biotic 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 |

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 9 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.

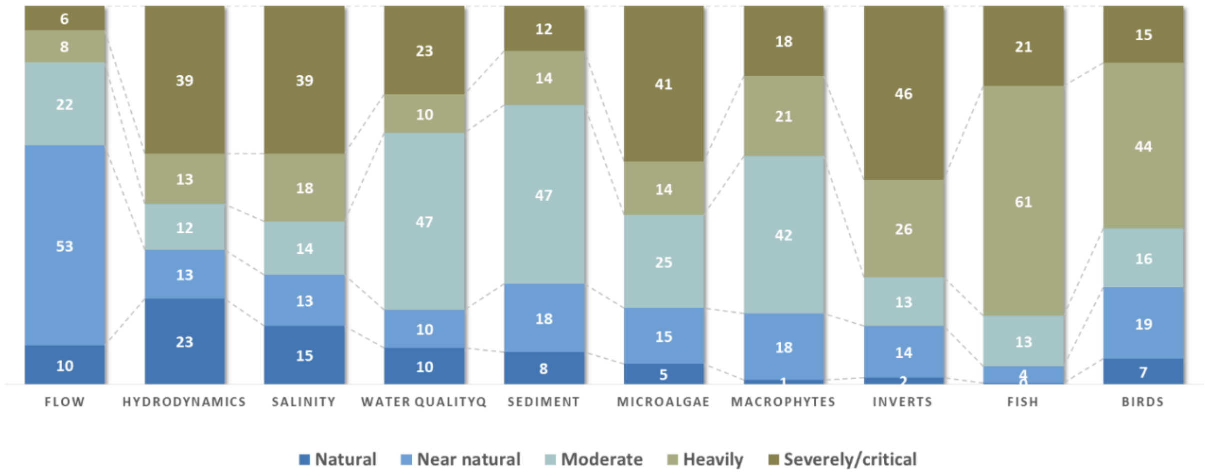


***Figure 9:*** ***Comparison of Ecological condition across abiotic and biotic ecosystem indicators in South African estuaries (2018) (expressed as a percentage of EFZ area)***

Reflecting on the overall condition of biotic ecosystem condition indicators (Figure 5.4), 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.

### 4.2.3 Condition Accounts for Estuarine Habitat

The Estuary Health Index score for 'Macrophytes' was used as a proxy for biotic habitat condition (Table 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 8:*** ***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* | | | | | | |

| | INTACT AREA (ha) | ECOLOGICAL CONDITION CATEGORY (% of habitat type) | | | | |
|---|---|---|---|---|---|---|
| | | Natural | Near-Natural | Moderately Modified | Heavily Modified | Severely/ Critically |
| *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** | | | | | |

## 4.3 Pressure Accounts

Table 9 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. Anthropogenic pressure accounts can also be assessed in terms of estuary type.

*Table 9: 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 |

**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).. 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. 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 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. **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. I**t 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. 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 and Subtropical region. A**rtificial 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 10). 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.

The above pressure account can also be graphically illustrated as a percentage of total estuaries in a biogeographical region or affected estuaries (Figure 10). Colour coding is used to represent the degree of pressure: **Dark red** = very high pressure, **red** = high, **orange** = medium; **yellow** =- low, **grey** = none.

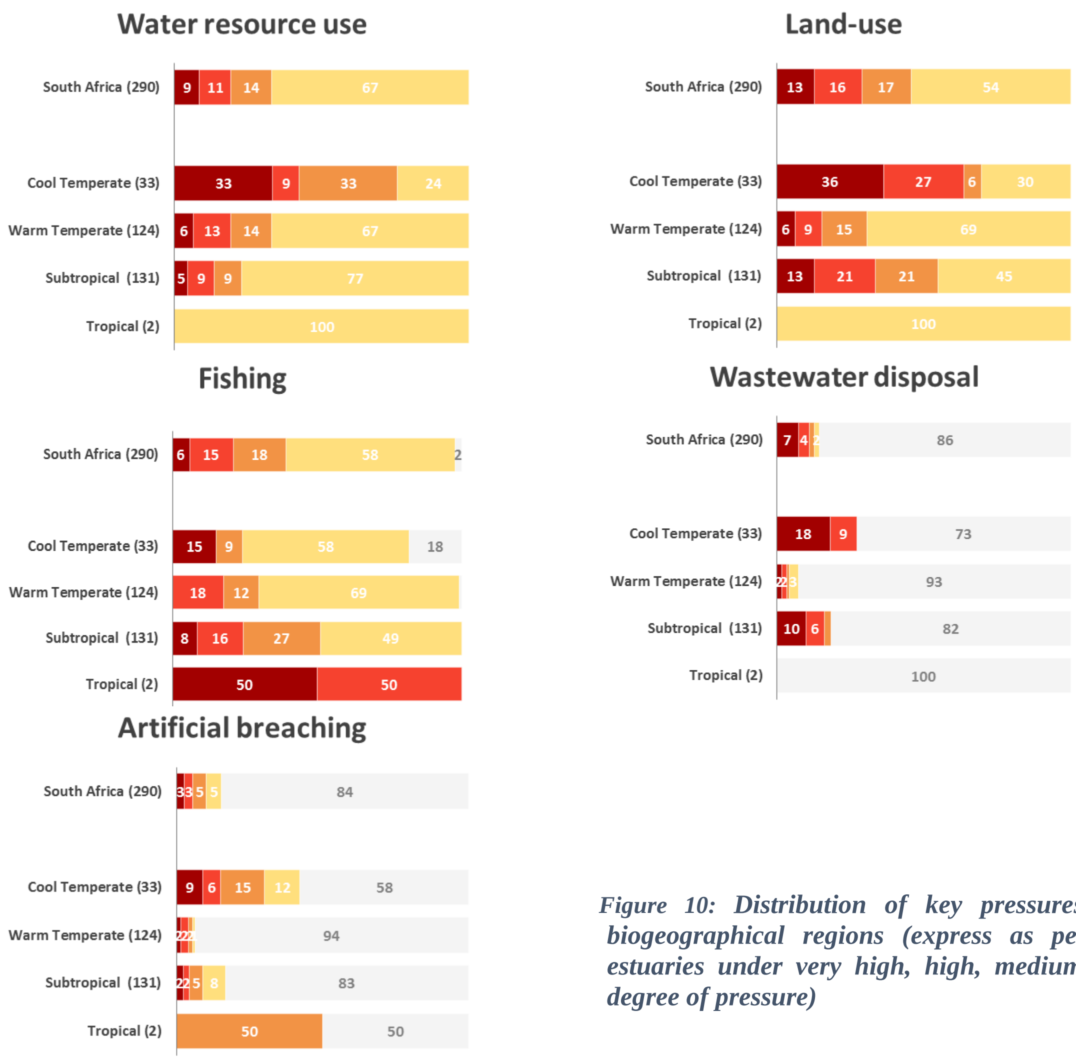


*Figure 10: Distribution of key pressures across biogeographical regions (express as percentage estuaries under very high, high, medium or low degree of pressure)*

## 4.4 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;

### 4.4.1 Carbon sequestration

Table 10 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 10: 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. 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).. 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.

### 4.4.2 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.

***Figure 11:*** ***Important fish nurseries for estuarine and marine fish and fisheries (Van Niekerk et al. 2015)***

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 11), 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. 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.* **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 11).**

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.

***Table 11:*** ***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*

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 relatively 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.

# 5. INSIGHTS FROM NATIONAL ECOSYSTEM ACCOUNTS

## 5.1 Extent and Condition

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 biotic estuarine habitat. However, a 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 because 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.

## 5.2 Pressures on 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.

## 5.3 Ecosystem Services Accounts

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. 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, showed that key nurseries have lost between 49% and 20% of their recruitment signal. 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 84%. 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. 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.

## 6. 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.

- **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**.

- **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.

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