Assessment of the conservation priority status of South African estuaries for use in management and water allocation

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Abstract

The future health and productivity of South Africa's approximately 250 estuaries is dependent on two main factors: management and freshwater inputs. Both management and water allocation decisions involve trade-offs between conservation and various types of utilisation. In order to facilitate decision-making in both of these spheres, it is necessary to understand the relative conservation importance of different estuaries. This study devises a method for prioritising South African estuaries on the basis of conservation importance, and presents the results of a ranking based on the collation of existing data for all South African estuaries. Estuaries are scored in terms of their size, type and biogeographical zone, habitats and biota (plants, invertebrates, fish and birds). Thirty-three estuaries are currently under formal protection, but they are not representative of all estuarine biodiversity. We performed a complementarity analysis, incorporating data on abundance where available, to determine the minimum set of estuaries that includes all known species of plants, invertebrates, fishes and birds. In total, 32 estuaries were identified as 'required protected areas', including 10 which are already protected. An estuary's importance status (including 'required protected area' status) will influence the choice of management class and hence freshwater allocation under the country's new Water Act, and can be used to assist the development of a new management strategy for estuaries, which is currently underway.

Introduction

There are approximately 250 functional estuaries in South Africa (Whitfield, 2000), together making up about 70 000 ha of one of the country's most productive habitats. Estuaries are well-known for their biodiversity, productive fish and invertebrate fisheries and for the important functions that they perform, such as providing nursery areas for marine fish, conduits for species which move between ocean and rivers (e.g. some eels and invertebrates) and feeding and staging sites for significant populations of migratory birds (Skelton, 1993; Turpie 1995). They also support a number of endemic species, many of which depend on estuaries for their survival. However, estuaries constitute one of the most threatened habitats in the country. In the past few decades there has been a plethora of marina and resort developments, reclamation and increasing human disturbance and exploitation. In many cases, freshwater inflows, vital to the maintenance of salinity profiles, sediment scouring and nutrient supply, have been siphoned off or polluted. As a result of all of these pressures, many South African estuaries have become functionally degraded, and this has frequently been accompanied by a loss of species (e.g. Goliath Heron from the Swartkops, Estuarine Pipefish from the Kariega – Whitfield, 1998) or a reduction in populations (Love, 2000; Wooldridge, 1999).

The future health of South Africa's estuaries is dependent on two main factors: their direct management and the quantity and quality of freshwater inputs. Very little consideration has been given to either in the past, but both of these aspects are currently under review in South Africa. Their management has now been entrusted to Marine & Coastal Management, Department of Environment Affairs & Tourism by the Marine Living Resources Act (Act 18 of 1998), and their water allocation is now being considered under the new National Water Act (Act 36 of 1998). Through the resource-directed measures (RDM) process, the latter will ensure a freshwater supply or 'reserve' for estuaries to maintain their ecological functioning, but the level of the reserve may vary, depending on socio-economic goals, to maintain estuaries in anything from a near-pristine state to a satisfactorily-functioning, but altered state (Adams et al., 1999).

Relative conservation importance is an important consideration in the decision-making processes regarding the management of or freshwater allocation to estuaries. Because of the demands for consumptive and non-consumptive use of estuaries, and for water from their catchments, it is not practical to ensure the high-quality functioning of all South African estuaries. Thus it is essential to formulate a sound way of prioritising estuaries in terms of their conservation importance, and to use this in determining the ways in which estuaries are managed and to what extent their water requirements are secured. The quantity and quality of water allocated to the estuarine reserve will be determined by the management class assigned to an estuary. Management class, in turn, will be assigned on the basis of an estuary's health and

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importance as well as other socio-economic considerations, the methodology for which is under development.

The aims of this study were to:

- develop a method to determine the conservation importance of estuaries;
- prioritise South African estuaries on the basis of existing information; and
- propose an efficient network of estuarine protected areas.

On the basis of the above, recommendations are made regarding the use of these findings in:

- determining an estuary's management class, and hence water reserve; and
- developing a workable system of estuary management.

Methods

Prioritisation of estuaries

The study began with a review of existing methods to prioritise estuaries on the basis of different criteria. Following this, we selected criteria and devised weightings and an overall index during two workshops attended by a selection of the country's top estuarine specialists. Data on the relevant biophysical attributes of South African estuaries were obtained from published and unpublished data sets. Estuaries were prioritised on the basis of the developed index, the methodology for which is described in detail below.

Identification of a minimum required set of estuarine protected areas (EPAs)

Using existing data, present EPAs (estuaries which are fully or partly protected as national parks, nature reserves etc.) were analysed in terms of their representativeness of the country's estuarine biodiversity. Following this, complementarity analysis was carried out to determine the minimum set of estuaries that would represent all estuarine species (in estuaries supporting viable populations), as far as could be determined.

A complementarity analysis is an iterative selection technique, which identifies how the greatest diversity of species can be conserved at the minimum number of sites (Pressey et al., 1993). Such analyses can vary in terms of approach and type of algorithms used. In this study a rarity algorithm was used, which gives priority to sites containing the highest number of rare species. Each site is assigned a rarity value:

$$Rarity = \sum_{i=1}^{n} \frac{k}{a_i}$$

where:

k is the total number of estuaries, and

a_i is the number of estuaries containing the *i*th species.

The analysis begins by identifying the site with the highest rarity value. This site is then considered reserved, and all species occurring at this site are removed from the analysis. Subsequent steps repeat this procedure until all species are included in the reserved sites. Thus, each consecutively selected site conserves species that have not been conserved in any of the previous sites.

Using a simple presence-absence database, complementarity analysis selects the minimum set of sites in which each species is included at least once. This algorithm can be altered to represent each species in more than one estuary, if required. There is, however, a danger in this approach, in that a species may be designated as 'conserved' at a site where it is insufficiently abundant to ensure its long-term survival. In order to circumvent this problem in the simplest mathematical way, abundance can be taken into account, whilst still using a presence-absence algorithm. Where data on abundance were available, species were only counted as present at the sites where they are most abundant (e.g. the top five sites), or where at least 10% of the total coastal population occurs.

For the complementarity analyses, the plant, invertebrate, fish and bird datasets were refined to include only estuarine species (e.g. excluding intrusive marine and freshwater species that are only occasionally recorded in estuaries or at estuary mouths). For fish and birds, abundance data were used to refine the presence-absence datasets to the top five estuaries for each species.

Prioritising estuaries: A review of issues and methods

From a conservation standpoint the notion of importance of an area is usually based on two main concepts:

- rarity, pertaining to rare physical types, rare habitats or rare species, where rarity implies scarcity, and means limited abundance or geographical range; and
- quantity (= abundance), pertaining to size, habitat area and diversity, species diversity, population size, and productivity.

A third component which should be considered is ecosystem function (e.g. nursery areas for marine fish), although this is usually very difficult to quantify in practice.

It may be argued that the importance of an estuary is influenced by its health status. Thus the question arises as to whether health status should be taken into consideration. Indeed, an estuary may even be more important in its altered state than in its pristine state. An example of this is the Mhlatuze system, where a change in hydrology and morphology has allowed colonisation of large areas by mangroves, with the result that this estuary now contains a major proportion of the country's mangroves. However, a more holistic look at the estuary would establish that the hydrological and morphological changes have also led to an equally or more important loss in ecosystem function, in that important lacustrine components of the previous Richards Bay have been lost. However, since the practical implications of determining the extent of deviation of an estuary from its pristine state are immense, and because altered states usually cause a decline in conservation status which should be reflected in a comprehensive index, we confined this study to determining the priority status of estuaries in their current state.

Although several indices have been developed, few countrywide assessments have been completed of the priority status of different estuaries in South Africa. Turpie (1995) used existing count data to explore methods and criteria for determining the importance of different estuaries for birds. Detailed summer counts of non-passerine waterbirds (species wholly or partially dependent on aquatic habitats) exist for most of South Africa's estuaries, with the exception of the Transkei region. Many of these data came from a published series of single summer counts of coastal wetlands that was carried out systematically around the coast during the two summer periods between 1979 and 1981 (Ryan and Cooper, 1985, Ryan et al., 1988, Underhill and Cooper, 1984, Ryan et al., 1986). On the basis of these counts, there are estimates of the total coastal population of each species. Estuaries were ranked according to

TABLE 1
Criteria used to evaluate importance of estuaries for fish in the FIR (Maree et al., 2000)

Measures of species importance			Measures of estuarine importance			
Number of exploitable species	Number of estuarine-dependent species	Number of endemic species	Type	Size	Condition	Isolation
			Estuarine bay > Permanently open > Estuarine lake > Temporarily closed > River mouth	large > > small	Excellent > Good > Fair > Poor	Isolated > > > Grouped

species richness, species diversity (Shannon Index), rarity and conservation status. These indices tested the effect of using limited (presence-absence) as well as abundance data. With the exception of the Shannon index, which was not considered to be a useful tool for evaluating conservation importance, the resulting rankings were significantly correlated (Turpie 1995). A key point made in the study was that the final evaluation of sites should ideally involve a subjective assessment of the results of single-criterion rankings, rather than using a multicriteria index, but this may not be practical when evaluating a large number of sites on the basis of several attributes or biota.

A fish importance rating (FIR) for South African estuaries was recently devised by Maree et al., (2000). This index was constructed from seven weighted measures of species and estuarine importance (Table 1), and was designed to work on a presence-absence data set, where species were only considered to be present if they constituted more than 1% of any total catch by number. The FIR assumes a potential distribution for species by assuming that each estuarine species occurs in all estuaries within its distribution range, and hence produces a ranking for all South African estuaries. Estuarine measures are included *within* the FIR (Table 1) because these variables are assumed to influence abundance, and can be used as a surrogate for quantitative data. Thus, the measures of estuarine condition are scored on categories of decreasing value (Table 1) according to how they might positively or negatively affect the importance of the fish community. The estuarine importance component of the FIR should therefore be seen as an essential part of the FIR, and should not be regarded as an independent estuarine importance rating that may be removed from the species importance component.

Obtaining quantitative data for fish is particularly difficult, as different sampling methods tend to be biased towards different groups or life-history stages. However, Harrison et al. (2000) have recently carried out limited, but uniform, sampling in most estuaries, providing the opportunity for a quantitative analysis in this study.

The botanical importance rating (BIR) index, developed by Coetzee et al. (1997), assigned values to estuaries on the basis of percentage area cover of different plant habitats, their condition (degree of impact), functional importance and plant community richness. This index was constructed as follows:

$$\text{BIR} = 1(A_{supra} \text{ x MF}) + 1.75\,(A_{inter} \text{ x MF}) + 2\,(A_{subm} \text{ x MF}) + 1.5\,(A_{reed} \text{ x MF})$$

where:

A_{supra}, A_{inter}, A_{subm} and A_{reed} are the area cover of supratidal saltmarsh (e.g. *Sarcocornia pillansii*), intertidal saltmarsh (e.g. *Triglochin* spp.), submerged macrophytes (e.g. *Zostera, Ruppia*) and reed and sedge communities;

MF is a multiplication factor representing community condition; and

the weightings are community importance values based on association, or functional importance, within the estuary; i.e. water dependence, primary productivity and the richness of the community they support.

The area cover was originally a score based on percentage cover of the estuary. Thus a 5 ha estuary and a 500 ha estuary, each having the same % cover distribution of macrophytes received the same score. This meant that the index measured health (e.g. Colloty et al., 1998), inasmuch as high scores represented a healthy and diverse plant community, irrespective of size. The index was first applied to 33 estuaries in the Cape, and the results were found to accord with the perceived botanical condition of those estuaries. The score has since been changed to use actual area, and no longer includes a measure of condition, making it more of a measure of importance. It now also includes other aspects usually associated with importance, namely species richness, community type richness and community type rarity (Colloty et al., 2000). A large proportion of South African estuaries has now been surveyed for plants, and a database exists which includes the components and scores of the index, in addition to species lists.

In the only attempt at constructing an importance rating of South African estuaries based on multiple attributes, the Consortium for Estuarine Research and Management (CERM, 1996) devised an index which incorporated a rarity, biological and physical value score (Table 2). The index included many critical elements, but its main drawback for application in the context of this study is that it combines measures of health and importance. The rarity criteria include three measures of importance and one of health. Most of the biological criteria are measures of importance, except the fish index, which includes a health score based on difference from the reference community. All the physical criteria are measures of health that assess the difference between present and reference state (the reference state refers to conditions that are assumed to have existed prior to anthropogenic impacts and is largely based on freshwater supply patterns). Nevertheless, the method was not implemented due to a lack of biotic data for estuaries, particularly those in the former Transkei and Ciskei (CERM, 1996). Since then both fish and botanical surveys have taken place in these areas and the opportunity now arises to develop further an overall importance rating system for South African estuaries.

TABLE 2
Criteria and score construction of CERM's (1996) proposed importance rating system

Rarity		Biological		Physical	
Criterion	**Score**	**Criterion**	**Score**	**Criterion**	**Score**
Estuarine type Geomorphology type Size Condition	0 - 25 0 - 25 0 - 25 0 - 25	Habitat Plants Inverts Fish Birds	0 - 20 0 - 20 0 - 20 0 - 20 0 - 20	Siltation Tidal exchange Water quality Hydrodynamics	0 - 26 0 - 33 0 - 19 0 - 22
TOTAL	0 – 100	TOTAL	0 - 100	TOTAL	0 - 100

TABLE 3
Possible variables for inclusion in an estuarine importance index. Variable categories are rarity (R), abundance (A) and ecological function (F)

Variable	Type	Selected in this study
1. Estuary size	A	✓
2. Rarity of the estuarine type in relation to geographic area	R	✓
3. Habitat diversity	A, F	✓
4. Biodiversity importance in terms of plants, invertebrates, fish and birds.	R, A, F	✓
5. Proximity of other estuaries	R, F	✗
6. Ecological services to neighbouring environments	F	✓
7. The sensitivity and resilience of the system to environmental change.	-	✗
8. Naturalness	-	✗
9. Conservation status, e.g. protected area, Ramsar or natural heritage site.	-	✗
10. Marine, estuarine and freshwater linkages	F	✗

Methodology for determining estuarine conservation importance

Identification of attributes for inclusion in the index

Ecological importance is an expression of the importance of a particular estuary to the maintenance of ecological diversity and functioning on local and wider scales. Some of the variables that can be considered as the basis for the estimation of ecological importance of an estuary are listed in Table 3. These variables can each be categorised as measures of rarity, abundance or ecological function.

These variables were discussed in a workshop setting, regarding their suitability for inclusion in an estuarine importance index. Size was initially rejected because it is a driving variable for diversity and abundance of biota**,** and is thus likely to be highly correlated with these. However, it is included because of the general paucity of information on the abundance of certain biota. It was agreed that sensitivity of an estuary does not confer importance, although it does become an important issue in setting freshwater requirements and in management. Similarly, naturalness was not considered as an appropriate indicator of importance, as it has more of an estuarine health connotation. Proximity of other estuaries is partially covered by the rarity variable. Conservation status does not confer importance *per se*; it is, however, an important consideration in determining the management class of estuaries, as we will argue later in this paper. Treatment of the selected variables is discussed below.

Attribute scoring systems and data availability

Size

Estuary size is defined as the total area (ha) within the geographical boundaries described in the RDM methodology (Adams et al., 1999). Area data for 89% of estuaries was compiled primarily from Colloty (2000), using supplementary information from Cowan and Van Riet (1998) and CERM (1996). There are several discrepancies between these sources, due to different definitions of estuarine boundaries, with the primary source tending towards higher estimates of area because of its inclusion of the floodplain area.

Link with freshwater and marine environments

Estuaries provide several ecological services to their surrounding environments, particularly the marine environment. These include:

- Export of detritus, nutrients and sediment to the coastal zone
- Nursery function for various marine-living fish and crustaceans
- Nursery function for freshwater organisms (e.g. river prawns such as *Macrobrachium* spp.)
- Movement corridor for migratory invertebrates (e.g. river crab *Varuna littoralis*) and fishes (e.g. anguillid eels)
- Roosting areas for marine or coastal birds.

TABLE 4 Whitfield's (1992) physical classification of estuaries			
Type	**Tidal prism**	**Mixing process**	**Average salinity ***
Estuarine bay	Large (>10 x 10^6 m^3)	Tidal	20 – 35
Permanently open	Moderate (1-10 x 10^6 m^3)	Tidal/riverine	10 - >35
River mouth	Small (<1 x 10^6 m^3)	Riverine	<10
Estuarine lake	Negligible (<0.1 x 10^6 m^3)	Wind	1 - > 35
Temporarily closed	Absent	Wind	1 - > 35

* Total amount of dissolved solids in water in parts per thousand by weight (seawater = ~35)

TABLE 5 Number of estuaries of each physical type in each biogeographical zone, and their ZTR scores						
	Cool temperate		**Warm temperate**		**Subtropical**	
	Number	**Score**	**Number**	**Score**	**Number**	**Score**
Estuarine bay	0	-	1	*100*	3	*33*
Permanently open	2	*50*	29	*3*	16	*6*
River mouth	2	*50*	6	*17*	4	*25*
Estuarine lake	0	-	4	*25*	4	*25*
Temporarily closed	5	*20*	85	*1*	94	*1*

We proposed the calculation of a functional index score which ranges from zero (of no importance) to 100 (extremely important) for each. However, there is no collated information at this stage on functional importance of estuaries, and it was not possible to include this attribute in this study.

Rarity of estuary type with reference to geographic position

South African estuaries have been classified into five types (Table 4, Whitfield, 1992). There are only four estuarine bays and eight estuarine lakes in the country, therefore these systems are important in terms of rarity. If biogeographical zonation is also taken into consideration, then the classification of an estuary in conjunction with the biogeographical zone determines how "rare" or "unique" the estuary is for the zone under consideration. For example there are only two permanently open estuaries (Olifants and Berg) in the cool temperate west coast zone and therefore these systems are of national importance (Table 5). The Palmiet Estuary in the south-western Cape is the only system along that stretch of coastline that remains open for any length of time, and is thus very important in this region for fish and invertebrate recruitment. Thus, a zonal type rarity score was devised, as follows:

$$ZTR = 100 \times 1/N_{tz},$$

where:

N_{tz} is the number of estuaries of type *t* within the same biogeographical zone *z*.

This yields scores in the range of 1 to 100 (Table 5).

Habitat diversity

An estuary can be considered more important if it has a high diversity of habitat types, or on the basis of habitat representativeness, in terms of the size and rarity of those habitat types that it contains. Estuarine habitats include physical (unvegetated) habitats such as channel area, sandflats, mudflats, and rock, and plant communities, such as salt marsh, mangroves, submerged macrophytes, reeds and sedges. Habitat information is available for 92% of the country's estuaries (Colloty, 2000).

A habitat rarity score was designed to take into consideration the number of habitats in an estuary, and the extent to which rare habitats occur within the estuary, as follows:

$$HR = 1000x\sum_{i=1}^{n}\frac{a_i}{A_i}$$

where:

a_i is area of the *i*th habitat in the estuary and
A_i is the total area of that habitat in the country (Table 6).

The multiplication factor is necessary because without it the score yields very small values, such that the sum of all scores for all estuaries is equal to the number of habitats considered. The plant community type areas have been measured for a large proportion of South African estuaries (Table 6).

It should be borne in mind that several of these habitat categories undergo dynamic changes in area over the medium to long term (e.g. Cooper, 1991; Colloty et al., 2000). Natural changes in habitat areas are a major consideration in assessing estuarine importance with respect to habitats. Any snapshot measurement only records habitats at one particular part of an estuary's cycle. Thus snapshot measures of potentially highly unstable elements, such as *Zostera capensis* cover, do not reflect the range or average level of availability

TABLE 6
Estuarine habitats and total areas for incorporation in the habitat rarity score, based on cover data for 92% of the country's estuaries (Colloty, 2000)

Category	Habitat	Area (ha) (e.g. Mngazana)	National area (ha)
Physical	Channel area (MSL) (= phytoplankton habitat)	45.6	47 539
	Intertidal sandflats and mudflats (benthic microalgae)	5.6	4 234
	Intertidal rock (macroalgae)	0	227
Plant	Supratidal saltmarsh	7.4	5 093
	Intertidal saltmarsh	1.25	2 720
	Mangroves	145	1 575
	Submerged macrophytes	0.8	1 141
	Swamp forest	7.8	273
	Reeds and sedges	11.4	7 187
	TOTAL ESTUARY AREA	224.85	69 805

of that habitat. Ideally, this should be dealt with by using the estimated mean level of abundance over the full range of existing conditions.

Biodiversity importance

The four main biotic groups - plants, invertebrates, fish and birds, were selected for inclusion in a biodiversity importance score. The scoring for each group should ideally incorporate the following elements:

- species richness;
- species rarity or endemism; and
- abundance (numbers, area or biomass).

Here it is argued that a species rarity score would suffice as a measure of biodiversity importance for each group, as it incorporates all of these aspects.

South African estuaries fall within three broad biogeographical zones. The cool temperate zone extends from north of Walvis Bay in Namibia to Cape Point; the warm temperate zone from Cape Point to about Mbashe and the subtropical zone extends north from Mbashe (Whitfield, 1998). Faunal composition therefore changes around the coast, with the highest number of species associated with warm temperate and subtropical systems, and highest productivity associated with the west coast (Whitfield and Marais, 1999; De Villiers et al., 1999; Turpie et al., 2000). A species richness-dominated index would thus result in a general increase in importance from west to east. Taking abundance into account will temper this trend to some extent. Nevertheless, biogeographic zonation is an important aspect to take into account when selecting protected areas, as discussed in the following sections.

Thus, where possible, the biodiversity importance index should use abundance data, but it is recognised that in some cases (e.g. invertebrates), estimates of overall abundance, or presence-absence data will have to suffice. Species rarity is usually described in terms of red data status, rarity in terms of occurrence at all sites, or endemism (important by virtue of the fact that they have restricted ranges and occur mainly or entirely in South Africa). The species rarity index, which is a simple addition of a score for each species in the system, tending to give weight to the species that fall in any of these categories, is constructed as follows:

$$SRI = 100x\sum_{i=1}^{n} r_i$$

where:

r_i is the rarity score of the ith species.

The multiplier is smaller than for the habitat index because the larger number of species makes the index values larger. The way in which the rarity score for each species can be calculated differs depending on the level of data available, as follows. With abundance data:

$r_i = q_i/Q_i$,

where:

q_i = number (or area) in estuary; and
Q_i = total number (or area) in all South African estuaries.

With species presence-absence data only:

$r_i = 1/N_i$.

where:

N_i = the number of estuaries in which the species occurs in South Africa.

If possible, presence-absence data should be refined to only include species as present where they are known or thought to be in viable population numbers. Scores calculated using abundance are far more sensitive than scores based on presence-absence, and will tend to produce lower species weights. An estuary will score more highly if there are more species, and more highly if there are many rare species.

There are no abundance data for plant species *per se*, but plant species lists have been compiled for 92% of South African estuaries (Colloty, 2000). A dataset of 264 estuarine invertebrate species was compiled based on distribution data (Awad et al., 2000; Emanuel et al., 1992; Day, 1967a;b; Branch et al., 1994) and estuary type (Whitfield, 2000). All estuaries within the range of a species were assumed to contain these species, except those marine species which tend to occur at the mouths of permanently open estuaries were not considered present in temporarily closed estuaries. This dataset thus overestimates the presence of species, as it assumes the maximum possible diversity within each estuary,

TABLE 7
Calculation of the biodiversity importance score

Parameter	e.g. Nahoon	Weight
Plant importance score	90	25
Invertebrate importance score	60	25
Fish importance score	80	25
Bird importance score	70	25
Mean score	75	50
Max score	90	50
Biodiversity importance score	82.5	

without accounting for the fact that the actual species present will depend on estuary size, type and habitat availability. In future, the dataset will be refined as more estuaries are surveyed.

Two datasets are available for estuarine fish. The first was compiled by Maree et al. (2000), and comprises both hypothetical presence-absence data based on known distributions and a presence-absence database based on actual records of species in estuaries. The second, compiled by Harrison et al. (2000), contains empirical abundance and biomass data obtained in a single sampling effort of most of the country's estuaries. The latter are thus generally comparable from estuary to estuary. For analysis, abundance data were used to create a presence-absence dataset with species being considered present at the top five sites or where their numbers exceeded 10% of the total estuary sample.

Similarly, empirical species records and abundance data for birds are available for a large number (178) of South African estuaries, and having been ascertained in a single sampling effort, are comparable from estuary to estuary. Bird abundance data were used to refine the presence-absence dataset to species being considered present at the top five sites or where their numbers exceeded 10% of the total coastal population (Turpie, 1995).

Once aligned to a common scoring base (see below), the results of the four biotic indices can either be weighted and summed in a combined index or subjectively assessed to create an overall ranking. Subjective ranking could be justified, in that it would avoid the dampening effect that may result if an estuary were important according to one attribute, but had low corresponding values for other attributes. A resulting low overall rank, may not alert the expert to the fact that the estuary is important for one particular reason. However, in this study there are too many estuaries to make a subjective ranking viable. One could create a composite index, eliminate those sites with very low scores and then subjectively re-rank the higher-ranking sites. Alternatively, the method of aggregation could take into account the maximum attribute value as well as the weighted average values. Therefore, an estuary will score relatively highly if it were important for one taxonomic group as well as if it were important for all groups. The overall score is thus obtained by using the maximum score obtained in the four groups, as well as the weighted average score, as follows:

Biodiversity importance score = (mean score + max score)/2

where the mean score is a weighted mean of the four groups, and the maximum is the maximum of the four groups (Table 7).

Using this scheme in the example of Table 7, the estuary obtains an overall score of 82.5 rather than the 65 obtained with a simple weighted average. It is proposed that the score for each group carries an equal weighting. This means that the weight of an individual species is inversely related to the number of species in the same taxonomic group.

Development of a common scoring base

The calculation of these scores from existing data yields a variety of ranges of scores for each attribute. These scores need to be adjusted to a common scoring base before their incorporation into an overall index. A common method of dealing with this problem is to normalise the scores on a scale of 0 to 100, where the maximum and minimum scores are converted to 100 and 0, respectively, and intermediary scores are scaled accordingly. Applying this system resulted in strongly skewed distributions of scores, but with skewness differing from one attribute to the next. This means that a site scoring 50 for an attribute may rank very differently from a site scoring 50 for another attribute. Thus, in order to 'smooth' these distributions, we settled on a system of percentiles. For each index described above, the estuaries falling within each 10% percentile were given a score of 100, 90, 80, and so on (Table 8). Because of the skewness of scores, this means that there is often a considerable range of scores within a percentile category (especially in the case of estuary size).

Construction of the estuary importance index

Weights need to be assigned to each attribute in the construction of an overall index to reflect their relative impact on overall importance. These weights effectively stretch or shrink the scales of each attribute score. Weights were given to the attributes in a workshop setting. Specialists first ranked different estuaries which differed from each other only by attribute score, in order to bring to their attention the range of impact of a change in level of each different attribute. Following this, relative weights were agreed on for the different attributes, with and without considering functional importance as an attribute (Table 9).

The weightings originally devised were for use in the RDM process, but were adjusted for use with the preliminary data available for this analysis. Estuary size was given a relatively greater weighting to be used as a proxy for the lack of biological data and functional importance data for many estuaries, and for the lack of abundance or biomass data in most cases, even where species richness is known. Secondly, within the biodiversity importance index, the four biotic groups were not weighed equally, but invertebrates were down-weighted to 10%, with the other groups each weighted as 30%. The invertebrate data were very coarse, having a much smaller range of scores than would be the case with empirical data, and potentially overestimating the invertebrate score in many estuaries. In the analysis, where biodiversity data were missing for one or more taxa, the biodiversity importance score was taken as a mean of the existing scores, excluding missing scores. However, where size or habitat data were missing altogether, specialist opinion was used to assign a score.

TABLE 8
Adjusted importance scores from scores calculated for the different components of the estuary importance index, giving type of data that each score is based on

Adjusted importance score	Size	ZTR	Habitat rarity	Plant rarity score	Invertebrate rarity score	Fish rarity score	Bird rarity score
	[Area (ha)]	-	[Area (ha)]	[Presence-absence]	[Distributional presence/absence]	[Abundance]	[Abundance]
10	0 -1.5	1	0.0 – 0.3	0 – 0.5	0 – 93	0 – 2.5	0 – 0.05
20	1.6 - 4	3	0.31 – 0.9	0.6 – 3.5	93.1 – 95	2.6 – 5.5	0.06 – 0.25
30	4.1 - 8.5	6	0.91 – 1.5	3.6 – 7	95.1 – 97.9	5.6 – 9	0.26 – 0.75
40	8.6 - 12.5	-	1.51 – 2.5	7.1 – 11	98 – 100	9.1 – 12.5	0.76 – 1.50
50	12.6 - 17.5	17	2.51 – 5.0	11.1 – 17	100.1 – 102*	12.6 – 17.5	1.51 – 2.75
60	17.6 - 30	20	5.1 – 10	17.1 – 25		17.6 – 22.5	2.76 – 5.00
70	30.1 - 50	25	10.1 – 15	25.1 – 35	102.1 – 110	22.6 – 37	5.01 – 10
80	50.1- 100	33	15.1 – 25	35.1 – 50	110.1 – 120	37.1 – 61.5	10.1 – 20
90	100.1 - 200	50	25.1 – 50	50 – 100	120.1 – 125	61.6 – 90	20.1 – 60
100	> 200	100	> 50	>100	>125	> 90	> 60

* scores 55

TABLE 9
Construction of the estuary importance index, and the adjusted weighting system used when Functional Importance was excluded from the analysis

Criterion	Weights	Weights excluding last attribute
Size	15	40
Zonal type rarity	10	10
Habitat diversity	25	25
Biodiversity importance	25	25
Functional importance	25	
ESTUARY IMPORTANCE SCORE = Weighted Mean		

Results: Conservation importance and estuaries requiring protected area status

Estuary ranking in terms of conservation importance

The top 50 estuaries from the prioritisation exercise are shown in Table 10. The full results, with estuaries presented from west to east, are given in **Appendix 1.** Most of the estuaries near the top of the list are large systems, as to be expected. However, the ordering of the top few estuaries was carried out by biologists whose perception of estuarine importance is centred on biodiversity importance alone. These patterns are clearly influenced by zonal type rarity, which brings estuaries such as Knysna to a higher position than St. Lucia. Nevertheless, the top scores differ by small margins, and rankings within such close scores are somewhat arbitrary. Changing the weightings of the component criteria causes minor changes to these orderings, but no major changes.

It should be noted that among the top 50 estuaries, only eight are from the stretch of coastline from Tyolomnqa to the Mkomazi, which contains more than half (about 136) of the country's estuaries. This is probably largely due to the predominance of very small estuaries along this stretch, but may also have been to some extent an artefact of a relative lack of information on these estuaries, especially for birds. Many of these estuaries are in far better condition than the estuaries featured in Table 10.

Estuary rankings obtained in this study differ from the results of single-taxa analyses that have been carried out for plants, fish and birds (Table 11), due to combining all taxa as well as other attributes. The most important concern is that the top-ranking estuaries based on the different taxa are included in the top-ranking (i.e. scoring above 80) estuaries in the overall analysis (this study), with the exception of Nxaxo, Matigulu, Nhlabane and Durban Bay (Table 11).

There is, however, a notable difference between the results based on the fish importance rating and the estuaries classified as important for fish in this study: only 10 out of the top 25 estuaries are shared (Maree et al., 2000). Most of the parameters used in the FIR were intended as a proxy for fish abundance data, while actual abundance data were used in this study. The main difference between the two indices is that the FIR also reflects importance in terms of exploitable species.

TABLE 10
The top 50 South African estuaries ranked in terms of conservation importance (IMP). Conservation importance is calculated on the basis of weighted size (S), habitat (H), zonal type rarity (Z) and biodiversity (B) importance scores

Rank	Estuary	S	H	Z	B	IMP	Rank	Estuary	S	H	Z	B	IMP
1	Knysna	100	100	100	99.0	99.8	26	Richard’s Bay	100	50	80	85.0	81.8
2	Berg	100	100	90	94.0	97.5	27	Kariega	90	80	20	94.0	81.5
3	Olifants	100	100	90	94.0	97.5	28	Mbashe	90	90	30	80.0	81.5
4	Kosi	100	100	70	99.5	96.9	29	Mtata	90	90	30	79.0	81.3
5	St Lucia	100	100	70	98.5	96.6	30	Mkomazi	100	60	30	90.0	80.5
6	Swartvlei	100	100	70	97.0	96.3	31	Kowie	90	80	20	89.0	80.3
7	Orange	100	100	90	88.0	96.0	32	Goukou	90	90	20	76.5	79.6
8	Bot/Kleinmond	100	100	70	94.5	95.6	33	Duiwenhoks	90	90	20	75.0	79.3
9	Klein	100	100	70	93.0	95.3	34	Uilkraals	90	90	10	77.5	78.9
10	Mhlathuze	100	100	80	82.0	93.5	35	Matigulu/Nyoni	90	70	30	89.0	78.8
11	Swartkops	100	100	20	100.0	92.0	36	Mzimvubu	90	90	30	67.0	78.3
12	Great Fish	100	100	20	97.0	91.3	37	Xora	90	80	30	75.5	77.9
13	Mfolozi	90	100	70	92.5	91.1	38	Mgeni	80	90	10	88.5	77.6
14	Gamtoos	100	100	20	95.5	90.9	39	Sundays	90	70	20	87.5	77.4
15	Keiskamma	100	100	20	93.5	90.4	40	Nhlabane	100	50	70	70.0	77.0
16	Keurbooms	100	90	20	94.5	88.1	41	Nxaxo/Ngqusi	90	80	10	79.5	76.9
17	Kromme	100	90	20	87.5	86.4	42	Kabeljous	90	80	10	75.0	75.8
18	Breë	100	90	20	85.5	85.9	43	Seekoei	90	80	10	74.0	75.5
19	Mtati	100	100	10	79.0	85.8	44	Bushmans	90	60	20	89.5	75.4
20	Mlalazi	90	90	30	94.0	85.0	45	Mtentu	80	80	30	81.0	75.3
21	Mgwalana	100	100	10	75.0	84.8	46	Sand	90	70	10	81.5	74.9
22	Mngazana	90	100	30	82.0	84.5	47	Mzamba	80	80	30	79.5	74.9
23	Mpekweni	90	100	10	86.5	83.6	48	Bira	90	70	10	81.0	74.8
24	Wilderness	90	70	70	89.5	82.9	49	Groot Brak	90	80	10	70.5	74.6
25	Heuningnes	90	90	20	87.5	82.4	50	Gourits	90	60	20	83.0	73.8

TABLE 11
Comparison of results of importance status of estuaries with respect to overall importance (EIR), botanical importance (BIR), fish importance (FIR) and birds (based on subjective analysis of separate indices - Turpie 1995). Top ranking estuaries which are also within the top ten according to the EIR are shown in bold, and the EIR status (A = score of 80 or more, B = 60 or more, etc.) is shown

Rank	EIR	BIR	EIR Status (this study)	FIR	EIR Status (this study)	Birds CSI	EIR Status (this study)
1	Knysna	**St Lucia**	**A**	**St Lucia**	**A**	**St Lucia**	A
2	Berg	Mngazana	A	**Kosi**	**A**	**Berg**	A
3	Olifants	**Knysna**	**A**	Richard’s Bay	A	Richard’s Bay	A
4	Kosi	Swartkops	A	**Mhlathuze**	**A**	Langebaan	not incl.
5	St Lucia	**Berg**	**A**	Mlalazi	A	**Orange**	A
6	Swartvlei	**Olifants**	**A**	Matigulu/Nyoni	B	**Olifants**	A
7	Orange	Mbashe	A	Durban Bay	C	Rietvlei	B
8	Bot	Nxaxo	B	**Knysna**	A	Verlorenvlei	not incl.
9	Klein	Keiskamma	A	Nhlabane	B	Wilderness	A
10	Mhlatuze	Mlalazi	A	Mtakatye	not incl.	**Bot**	A

TABLE 12
Estuaries with protected area status, and the cumulative contribution they make to the representation of estuarine biodiversity. Estuaries marked with a # are only partially protected.

#	Estuary	Additional species conserved	Cumulative species conserved	%	#	Estuary	Additional species conserved	Cumulative species conserved	%
1	St Lucia	246	246	44.9	19	Mhlatuze	0	496	90.5
2	Wilderness #	103	349	63.7	20	Siyaya	0	496	90.5
3	Knysna #	38	387	70.6	21	Mhlanga	0	496	90.5
4	Diep #	23	410	74.8	22	Mgobozeleni	0	496	90.5
5	Nyoni	19	429	78.3	23	Mtentu	0	496	90.5
6	Kosi	18	447	81.6	24	Hluleka	0	496	90.5
7	Gamtoos #	12	459	83.8	25	Ngoma	0	496	90.5
8	Heuningnes	9	468	85.4	26	Quko	0	496	90.5
9	Swartvlei #	7	475	86.7	27	Gqutywa	0	496	90.5
10	Mpenjati	5	480	87.6	28	Groot (oos)	0	496	90.5
11	Orange #	4	484	88.3	29	Elands	0	496	90.5
12	Msikaba	3	487	88.9	30	Groot (wes)	0	496	90.5
13	Mlalazi	2	489	89.2	31	Goukamma #	0	496	90.5
14	Mgeni #	2	491	89.6	32	Seekoei #	0	496	90.5
15	Keurbooms #	2	493	90.0	33	Mbizana #	0	496	90.5
16	Mendu	1	494	90.1					
17	Sout (oos)	1	495	90.3					
18	Mfolozi	1	496	90.5					

TABLE 13
Desired protected areas: Minimum set of estuaries required in a protected area network to represent 100% of species in the analysis, based on complementarity analysis. Estuaries, or portions thereof, which are already protected are marked with an asterisk.

#	Estuary	Additional species conserved	Cumulative species conserved	%	#	Estuary	Additional species conserved	Cumulative species conserved	%
1	St Lucia *	246	246	44.9	17	Bot	2	518	94.5
2	Berg	95	341	62.2	18	Bushmans	1	519	94.7
3	Kosi*	17	358	65.3	19	Nhlabane	1	520	94.9
4	Swartkops	74	432	78.8	20	Rietvlei*	2	522	95.3
5	Nyoni*	16	448	81.8	21	Mtamvuna	3	525	95.8
6	Wildevoelvlei	11	459	83.8	22	Palmiet	4	529	96.5
7	Wilderness*	10	469	85.6	23	Mvoti	2	531	96.9
8	Manzimtoti	4	473	86.3	24	Great Kei	2	533	97.3
9	Gouritz	4	477	87.0	25	Mgeni*	2	535	97.6
10	Swartvlei	8	485	88.5	26	Mpenjati*	2	537	98.0
11	Heuningnes*	5	490	89.4	27	Mntafufu	2	539	98.4
12	Olifants	6	496	90.5	28	Mhlali	2	541	98.7
13	Knysna*	5	501	91.4	29	Mlalazi*	2	543	99.1
14	Keiskamma	5	506	92.3	30	Kromme	2	545	99.5
15	Kariega	6	512	93.4	31	Goda	2	547	99.8
16	Lovu	4	516	94.2	32	Mbashe	1	548	100.0

TABLE 14 Proposed rules for allocation of ERC, where EIS = estuary importance score, PES = present ecological state, given as a health class A to F, and BAS = best attainable state	
Current/future protection status and biodiversity conservation importance	**ERC**
Protected area	A or BAS
Requiring Protected Area Status	A or BAS
EIS = 80 – 100 (Highly important)	PES + 1, min B, or BAS
EIS = 60 – 80 (Important)	PES + 1, min C, or BAS
EIS = 0 – 60 (Of low to average importance)	PES, min D

Existing estuarine protected areas (EPAs)

A total of 33 estuaries in South Africa currently enjoy some degree of protected area status, although 11 of these are only partly protected (Whitfield ,1998; Table 12), and the status of some of these EPAs is effected primarily in protection afforded to surrounding areas and not to the estuary *per se*. The proclamation of protected areas in the past has, however, been on an *ad hoc* basis, rather than as part of a strategic national plan. Just over 90% of South Africa's estuarine species are represented (using rules of presence-absence described above) in these protected or semi-protected estuaries. In fact, this representation is achieved with just 18 of the estuaries.

The 'ideal set' of EPAs

Ideally, South Africa should have a reserve network of estuaries in which all estuarine species are represented and conserved. In this analysis, protected area priorities were determined with representativeness as the primary goal. The conservation of the top-scoring sites, as listed in Table 10, does not generally result in an efficient solution, as a number of species may only be present in lower-scoring sites. The top 10 and top 20 sites listed in Table 10 support only 84% and 89% of estuarine species, respectively. Although one can achieve representation of the majority of species by selecting the top sites in each biogeographical zone (Turpie, 1995), only the more sophisticated complementarity algorithms will select a perfectly efficient solution, in which all species are represented in the minimum set of sites (Turpie et al., 2000).

The results of a complementarity analysis showed that, without specifying any estuaries for inclusion at the outset, a set of 32 estuaries (11% of South African estuaries) is required to represent 100% of estuarine species (Table 13). It should also be noted that only 12 estuaries are required to represent 90% of this diversity. Of the estuaries making up this set, 10 already enjoy protected area status.

If the complementarity analysis is run starting with the existing protected areas, then an additional 21 estuaries are required to represent all estuarine biodiversity. Although the total number of species are effectively represented in 39 of these, the total number of estuaries with protected area status would amount to 54. In either case the total representation of estuarine species will require the proclamation of an additional 21 to 22 estuaries. Thus, the more pragmatic option is to strengthen the protected area status of the 10 protected areas included in the above list, and proclaim the 22 remaining estuaries in this list as estuarine protected areas. We classify the set of estuaries in Table 13 as "requiring protected area status".

Discussion

The results presented in this paper have been two years in the making, and, following several iterations and discussion sessions, are now widely accepted by the estuarine research community. We envisage these results as having two main applications: to aid in decision-making regarding the freshwater requirements of estuaries, and to aid in the development of a sound management strategy for the country's estuaries. We discuss each of these issues separately below.

Application to the RDM process for determining freshwater requirements of estuaries

The RDM process involves assigning a final management class (MC) to an estuary on the basis of its ecological reserve category (ERC) and other socio-economic criteria. The ERC is determined on the basis of the health and importance of an estuary. The MC is an expression of society's desired future state of health of the system, and determines the quantity and quality of water that needs to be allocated to the estuarine reserve, a higher reserve being associated with a healthier system. The MC may be higher or lower than the present state of health, depending on demands for allocating water to other uses, vs. demands for maintaining ecosystem goods and services (e.g. recreation, fisheries, etc.). The potential management class of an estuary ranges from A (near-pristine) to D (functional, but altered), whereas an estuary's present health may also be classed as E or F (totally degraded).

The ERC of an estuary will be allocated on the basis of its importance score, using the present ecological status (PES), or present health, as a starting point. We devised a system whereby the ERC can be determined on the basis of health and importance, so that a higher level of importance provides the motivation for improvement or maintenance of a higher level of health (Table 14). PES sets the minimum ERC. The degree to which ERC is higher than PES depends on level of importance, required level of protection, and the best attainable state (Table 14).

Note that estuaries classified as requiring protected area status are given special treatment in the setting of ERC (Table 14). We propose that it transcends this level of decision-making to have a strong influence in the final setting of the MC, even after taking socio-economic considerations into account. In other words, estuaries requiring protected area status should be guaranteed a relatively high estuarine water reserve in spite of other demands on this water supply. Whereas this may not lead to a welfare-maximising outcome from a local-level perspective, it is incumbent on the country to make provision for the conservation of biodiversity,

TABLE 15
Intensity of management effort for different classes of estuary

Type of measure	Type of estuary					
	EPA	A	B	C	D	E
No-go zones	****	***	**	**	*	
No-exploitation zones	****	***	**	**	*	
Bag and size limits	****	****	****	****	****	****
Effort control	****	***	***	***	***	***
Bordering no-development zones	***	**	*	*	*	

as a signatory to the biodiversity convention. Moreover, there are other ways of ensuring water supply to affected parties (e.g. conservation measures to improve catchment run-off, economic incentive measures to reduce demands), or by ensuring that these communities benefit from having an estuarine protected area.

Application to management

Management of South African estuaries has been uncoordinated and irregular in the past. At present a hiatus in legal protection has effectively rendered estuaries 'free-for-all' areas, following a change-over from provincial legislation to the national level Marine Living Resources Act (Act 18 of 1998), which is still undergoing refinement. Nevertheless, with this recent transfer of estuary management responsibility to the Department of Environment Affairs and Tourism, an opportunity has arisen to start afresh, hopefully with a more strategic approach to this problem. Efforts have begun to develop a national plan and mechanisms for managing South Africa's estuaries and to provide guidelines and priorities for research initiatives (Boyd et al., 2000). However, it is fundamentally difficult to design a cross-cutting management strategy for estuaries, due to their variability in size, type, functioning and setting, with some estuaries in sparsely populated areas, others in popular holiday areas, and others playing an important role in subsistence economies. Nevertheless, the need has been identified to put a national estuarine protocol in place, which is non-negotiable and legislated, to compel local authorities to follow certain management procedures (Boyd et al., 2000). This study can contribute to the formulation of such a protocol, as follows.

Firstly, we propose a set of 32 estuaries that should be managed as EPAs if good representation of biodiversity is to be attained in protected areas. This is not to say that the biodiversity conservation is not required in the remaining estuaries (see below), but we strongly recommend that these selected estuaries, which represent only 11% of the country's estuaries, are afforded even higher levels of protection than other estuaries. These estuaries are highly representative of the national set, including all five types of estuaries and falling within all three biogeographical zones. Although they include a range of sizes, they do tend to be larger than average estuaries, as larger estuaries generally contain higher diversity and larger populations. However, it is their size that potentially presents the biggest political obstacle to their proclamation as protected areas. Large estuaries, such as the Swartkops Estuary, are often associated with intensive development and large catchments with important water supply potential. Thus it is important to consider what level of protection would be required for EPAs. Ideally, EPAs should be maintained as 'reference' systems maintained in a minimally-altered state. The purpose of EPAs would be to secure stocks of the elements of biodiversity contained within them as well as provide the full economic benefits of ecosystem services provided by their functioning (e.g. nursery functions for maintaining coastal fisheries). Achieving such aims requires severe restrictions on consumptive and non-consumptive activities and on-site developments, as well as restricting catchment activities that affect water supply, siltation and pollution. For some of the estuaries listed in Table 12, this can potentially be achieved. For others, such as the Swartkops Estuary, it would be more difficult. Yet removing the Swartkops Estuary from the list would mean increasing the list by several estuaries, suggesting that it might be more pragmatic to attempt to improve conditions in the Swartkops.

Secondly, we propose that an estuary's importance status, irrespective of protected area status, has a bearing on its level and type of management. It is not only EPAs that require management attention. While the economic consequences of alternative management scenarios have not been explored for South African estuaries, it is almost certain that in many cases greater value will be obtained from estuaries maintained in a well-functioning state than in those degraded by activities associated with short-term gains, such as over-exploitation and excessive developments. Moreover, it does not take detailed economic studies to show that over-exploitation and degradation carry a cost to future generations as well as affecting present benefits obtained from recreational activities and even marine fisheries.

While all estuaries require management and planning measures to maintain their productivity and functioning, we concede that different estuaries need to be maintained to maximise different types of benefits, and may best be managed in a state somewhat altered from the pristine condition. Estuaries which are important for recreation require different management approaches from those important for subsistence fisheries. Indeed, it is often the use of a resource itself which has the greatest impact on its supply.

In proposing the strict protection of 11% of South Africa's estuaries, we do not suggest that the remaining estuaries be allowed to degrade through lack of management. The priority ranking provided in this study should be used to guide a national-level management strategy for estuaries. We suggest that estuaries are classified on the basis of their EIS scores, into five different categories, A to E, based on scores of 80 to 100, 60 to 80, etc., and that the intensity of conservation management is allotted accordingly (Table 15). Past management practices have concentrated on exploitation, mainly through size and bag limits and gear regulations, but these have become increasingly ineffective, due to a lack of enforcement and in some cases, turning of a blind eye to illegal methods of fishing or bait collection for political reasons. Zonation has seldom been implemented, but is a promising tool for curbing exploitation and human disturbance of estuaries, and is far easier to police. Clearly much work has to be done to find effective institutions and strategies for achieving wise use of South African estuaries. These processes cannot be implemented simultaneously for all estuaries, but should be implemented as a matter of priority in high ranking (Class A and B) estuaries.

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APPENDIX 1

Ranking of South African estuaries (ordered from west to east) in terms of conservation importance score (IMP), calculated on the basis of size (S), zonal type rarity (Z), habitat importance (H) and biodiversity importance (B)

Rank	Estuary	S	H	Z	B	IMP	Rank	Estuary	S	H	Z	B	IMP
7	Orange	100	100	90	88.0	96.0	225	Elands	30	10	50	20.0	24.5
3	Olifants	100	100	90	94.0	97.5	215	Groot (Oos)	30	10	50	33.0	27.8
2	Berg	100	100	90	94.0	97.5	205	Tsitsikamma	30	20	10	49.0	30.3
61	Rietvlei/Diep	100	10	60	85.5	69.9	216	Klipdrif	30	10	10	46.0	27.0
177	Houtbaai	10	50	90	42.5	36.1	17	Kromme	100	90	20	87.5	86.4
59	Wildevoëlvlei	60	90	60	72.0	70.5	43	Seekoei	90	80	10	74.0	75.5
236	Bokramspruit	20	10	60	13.5	19.9	42	Kabeljous	90	80	10	75.0	75.8
237	Schuster	20	10	60	13.5	19.9	14	Gamtoos	100	100	20	95.5	90.9
190	Krom	20	10	60	72.0	34.5	125	Van Stadens	70	30	10	54.5	50.1
191	Silvermine	10	50	10	65.0	33.8	182	Maitland	10	70	10	51.5	35.4
46	Sand	90	70	10	81.5	74.9	11	Swartkops	100	100	20	100.0	92.0
153	Eerste	50	40	10	49.5	43.4	89	Coega (Ngcura)	70	40	10	80.0	59.0
152	Lourens	40	30	10	75.5	43.4	39	Sundays	90	70	20	87.5	77.4
187	Sir Lowry's Pass	30	20	10	66.5	34.6	99	Boknes	70	50	10	64.0	57.5
238	Steenbras	20	10	20	27.5	19.4	44	Bushmans	90	60	20	89.5	75.4
136	Rooiels	50	40	10	68.0	48.0	27	Kariega	90	80	20	94.0	81.5
120	Buffels (Oos)	60	30	10	74.5	51.1	86	Kasuka	70	70	10	58.0	61.0
73	Palmiet	70	60	20	76.5	64.1	31	Kowie	90	80	20	89.0	80.3
8	Bot/Kleinmond	100	100	70	94.5	95.6	167	Rufane	50	10	10	63.0	39.3
97	Onrus	70	60	10	55.5	57.9	91	Riet	50	80	10	71.0	58.8
9	Klein	100	100	70	93.0	95.3	53	Kleinemond Wes	80	90	10	67.5	72.4
34	Uilskraals	90	90	10	77.5	78.9	54	Kleinemond Oos	70	90	10	83.0	72.3
203	Ratel	40	10	10	46.0	31.0	12	Great Fish	100	100	20	97.0	91.3
25	Heuningnes	90	90	20	87.5	82.4	157	Old woman's	30	50	10	66.5	42.1
235	Klipdrifsfontein	30	10	10	17.5	19.9	23	Mpekweni	90	100	10	86.5	83.6
18	Breë	100	90	20	85.5	85.9	19	Mtati	100	100	10	79.0	85.8
33	Duiwenhoks	90	90	20	75.0	79.3	21	Mgwalana	100	100	10	75.0	84.8
32	Goukou	90	90	20	76.5	79.6	48	Bira	90	70	10	81.0	74.8
50	Gourits	90	60	20	83.0	73.8	82	Gqutywa	80	70	10	44.5	61.6
207	Blinde	20	10	10	74.5	30.1	239	Blue Krans	20	30	10	10.0	19.0
74	Hartenbos	70	60	10	80.5	64.1	94	Mtana	60	70	10	62.5	58.1
96	Klein Brak	80	10	10	89.5	57.9	15	Keiskamma	100	100	20	93.5	90.4
49	Groot Brak	90	80	10	70.5	74.6	131	Ngqinisa	50	60	10	54.5	49.6
201	Maalgate	50	10	10	32.5	31.6	113	Kiwane	60	70	10	49.5	54.9
240	Gwaing	20	10	10	26.0	18.0	51	Tyolomnqa	90	60	10	86.0	73.5
199	Kaaimans	40	10	20	45.0	31.8	241	Lilyvale	20	10	10	25.5	17.9
24	Wilderness	90	70	70	89.5	82.9	109	Ncera	70	50	10	56.0	55.5
6	Swartvlei	100	100	70	97.0	96.3	245	Mlele	10	10	10	32.0	15.5
68	Goukamma	100	40	10	65.5	67.4	180	Mcantsi	50	20	10	38.5	35.6
1	Knysna	100	100	100	99.0	99.8	93	Gxulu	80	50	10	51.0	58.3
223	Noetsie	40	10	10	20.0	24.5	143	Goda	60	30	10	54.5	46.1
57	Piesang	80	80	10	71.0	70.8	247	Hlozi	10	10	10	28.5	14.6
16	Keurbooms	100	90	20	94.5	88.1	233	Hickman's	30	10	10	27.0	22.3
212	Matjies/Bitou	20	10	10	65.5	27.9	90	Buffalo	80	40	20	59.5	58.9
83	Sout (Oos)	80	50	20	60.0	61.5	218	Blind	10	10	10	74.0	26.0
81	Groot (Wes)	70	50	10	82.5	62.1	244	Hlaze	20	10	10	19.0	16.3
102	Bloukrans	80	10	50	68.5	56.6	60	Nahoon	80	60	20	84.0	70.0
186	Lottering	60	10	50	13.5	34.9	70	Qinira	80	70	10	62.0	66.0
210	Elandsbos	40	10	50	20.0	28.5	69	Gqunube	80	50	20	81.0	66.8
144	Storms	80	10	50	26.5	46.1	78	Kwelera	80	60	20	58.0	63.5

Rank	Estuary	S	H	Z	B	IMP	Rank	Estuary	S	H	Z	B	IMP
112	Bulura	70	50	10	54.0	55.0	151	Sinangwana	50	30	10	61.5	43.9
246	Cunge	10	10	10	30.5	15.1	22	Mngazana	90	100	30	82.0	84.5
105	Cintsa	70	50	10	57.5	55.9	139	Mngazi	60	20	10	68.0	47.0
76	Cefane	80	80	10	43.0	63.8	195	Bululo	20	30	10	66.5	33.1
95	Kwenxura	70	50	10	65.5	57.9	165	Mtambane	60	20	10	37.5	39.4
135	Nyara	60	40	10	52.5	48.1	36	Mzimvubu	90	90	30	67.0	78.3
219	Haga-haga	30	20	10	30.5	25.6	221	Ntlupeni	30	10	10	38.0	25.0
175	Mtendwe	50	40	10	24.0	37.0	142	Nkodusweni	70	40	10	30.0	46.5
110	Quko	70	40	10	65.5	55.4	75	Mntafufu	60	70	30	78.0	64.0
146	Morgan	60	30	10	49.5	44.9	101	Mzintlava	80	50	30	36.5	56.6
232	Cwili	20	10	10	43.5	22.4	217	Mzimpunzi	40	20	10	17.0	26.3
52	Great Kei	90	70	20	70.0	73.0	71	Mbotyi	80	70	10	60.5	65.6
209	Gxara	10	40	10	54.5	28.6	178	Mkozi	30	30	10	62.5	36.1
162	Ngogwane	50	30	10	46.5	40.1	242	Myekane	20	10	10	23.5	17.4
79	Qolora	60	90	10	64.0	63.5	183	Lupatana	30	40	10	49.5	35.4
197	Ncizele	40	10	10	54.5	33.1	173	Mkweni	40	60	10	23.5	37.9
100	Kobonqaba	70	50	20	57.5	56.9	98	Msikaba	60	50	30	73.0	57.8
41	Nxaxo/Ngqusi	90	80	10	79.5	76.9	118	Mgwegwe	40	80	10	63.5	52.9
198	Cebe	20	40	10	55.5	32.9	200	Mgwetyana	30	10	10	65.0	31.8
172	Gqunqe	40	40	10	43.5	37.9	45	Mtentu	80	80	30	81.0	75.3
148	Ngqwara	50	40	10	54.0	44.5	166	Sikombe	50	50	10	23.5	39.4
176	Sihlontlweni/Gcini	50	20	10	43.5	36.9	206	Kwanyana	40	10	10	43.0	30.3
64	Qora	80	70	20	67.5	68.4	126	Mnyameni	70	40	30	36.5	50.1
196	Jujura	40	10	10	54.5	33.1	214	Mpahlanyana	30	10	10	49.5	27.9
160	Ngadla	50	30	10	48.0	40.5	213	Mpahlane	30	10	10	49.5	27.9
127	Shixini	60	40	20	56.0	50.0	47	Mzamba	80	80	30	79.5	74.9
72	Nqabara	90	70	20	37.0	64.8	193	Mtentwana	50	20	10	30.0	33.5
184	Ngoma/Kobule	50	40	10	17.5	35.4	85	Mtamvuna	80	50	10	63.0	61.3
149	Mendu	60	40	10	37.0	44.3	250	Zolwane	10	20	10	16.5	14.1
28	Mbashe	90	90	30	80.0	81.5	168	Sandlundlu	30	40	10	64.5	39.1
140	Ku-Mpenzu	50	60	10	43.5	46.9	234	Ku-boboyi	20	20	10	31.0	21.8
138	Ku-Bhula/ Mbhanyana	40	70	10	51.5	47.4	169	Tongazi	10	70	10	64.5	38.6
108	Ntlonyane	70	50	10	56.5	55.6	230	Kandandhlovu	20	20	10	35.5	22.9
133	Nkanya	60	50	10	47.0	49.3	116	Mpenjati	50	50	10	79.0	53.3
37	Xora	90	80	30	75.5	77.9	103	Umhlangankulu	50	80	10	61.5	56.4
211	Bulungula	10	40	10	52.0	28.0	220	Kaba	20	40	10	24.5	25.1
226	Ku-amanzimuzama	30	20	10	24.5	24.1	114	Mbizana	50	70	10	63.0	54.3
155	Mncwasa	60	20	10	50.5	42.6	249	Mvutshini	10	20	10	16.5	14.1
189	Mpako	50	30	10	24.5	34.6	137	Bilanhlolo	30	60	10	77.5	47.4
150	Nenga	50	30	10	63.0	44.3	248	Uvuzana	10	20	10	18.0	14.5
154	Mapuzi	60	30	10	42.0	43.0	204	Kongweni	20	40	10	47.0	30.8
29	Mtata	90	90	30	79.0	81.3	222	Vungu	20	30	10	32.5	24.6
67	Mdumbi	80	60	30	71.0	67.8	181	Mhlangeni	30	40	10	50.0	35.5
192	Lwandilana	50	20	10	31.0	33.8	115	Zotsha	40	80	10	67.5	53.9
145	Lwandile	60	40	10	44.0	46.0	208	Boboyi	20	40	10	42.5	29.6
62	Mtakatye	90	70	30	50.5	69.1	224	Mbango	10	60	10	18.0	24.5
188	Hluleka/Majusini	50	30	10	24.5	34.6	129	Mzimkulu	10	100	30	71.0	49.8
107	Mnenu	80	60	10	31.0	55.8	122	Mtentweni	40	80	10	55.5	50.9
119	Mtonga	70	50	10	44.0	52.5	229	Mhlangamkulu	30	10	10	29.5	22.9
156	Mpande	50	30	10	56.5	42.6	171	Damba	20	90	10	26.0	38.0

Rank	Estuary	S	H	Z	B	IMP	Rank	Estuary	S	H	Z	B	IMP
185	Koshwana	20	80	10	24.5	35.1	106	Manzimtoti	40	70	10	85.5	55.9
161	Intshambili	20	80	10	45.5	40.4	141	Mbokodweni	40	40	10	79.0	46.8
123	Mzumbe	60	50	10	52.0	50.5	77	Sipingo	40	100	10	87.0	63.8
147	Mhlabatshane	20	90	10	52.0	44.5	88	Durban Bay	10	100	80	91.5	59.9
170	Mhlungwa	30	60	10	40.5	38.1	38	Mgeni	80	90	10	88.5	77.6
163	Mfazazana	20	80	10	44.0	40.0	55	Mhlanga	90	70	10	69.5	71.9
164	Kwa-Makosi	20	90	10	32.5	39.6	56	Mdloti	80	90	10	63.5	71.4
202	Mnamfu	20	80	10	10.0	31.5	84	Tongati	70	80	10	49.5	61.4
128	Mtwalume	60	50	10	49.0	49.8	65	Mhlali	60	90	10	82.5	68.1
227	Mvuzi	10	50	10	23.0	23.3	174	Seteni	20	80	10	35.0	37.8
87	Fafa	70	80	10	45.0	60.3	92	Mvoti	60	30	70	79.5	58.4
243	Mdesingane	10	30	10	16.5	16.6	66	Mdlotane	70	90	10	65.5	67.9
124	Sezela	50	50	10	67.5	50.4	121	Nonoti	60	60	10	44.5	51.1
231	Mkumbane	10	40	10	29.5	22.4	63	Zinkwasi	60	90	10	84.5	68.6
134	Mzinto	40	80	10	47.0	48.8	58	Tugela/Thukela	80	50	70	76.5	70.6
228	Mzimayi	10	40	10	33.0	23.3	35	Matigulu/Nyoni	90	70	30	89.0	78.8
179	Mpambanyoni	20	50	10	57.0	35.8	132	Siyaya	40	60	10	70.0	49.5
158	Mahlongwa	40	40	10	58.5	41.6	20	Mlalazi	90	90	30	94.0	85.0
130	Mahlongwana	40	80	10	50.5	49.6	10	Mhlathuze	100	100	80	82.0	93.5
30	Mkomazi	100	60	30	90.0	80.5	26	Richard’s Bay	100	50	80	85.0	81.8
194	Ngane	20	40	10	57.0	33.3	40	Nhlabane	100	50	70	70.0	77.0
104	Umgababa	60	60	10	63.5	55.9	13	Mfolozi	90	100	70	92.5	91.1
111	Msimbazi	50	50	10	87.0	55.3	5	St Lucia	100	100	70	98.5	96.6
80	Lovu	50	80	10	87.0	62.8	117	Mgobezeleni	20	80	70	72.0	53.0
159	Little Manzimtoti	20	80	10	47.0	40.8	4	Kosi	100	100	70	99.5	96.9