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The ecology of the False Bay estuarine environments, Cape, South Africa. 2. Changes during the last fifty years

M. O'CALLAGHAN*

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ABSTRACT

Aerial photographs taken between 1936 and 1987 of the eleven rivers flowing into False Bay were studied. Various techniques were used to obtain quantitative values and value judgements for the changes that had taken place. It was found that large increases in industrial, residential, recreational areas and alien plant cover have taken place at the expense of open sand and natural vegetation types. The rivers along the eastern shore of the Bay are relatively undisturbed. Those along the western shore are more disturbed but still contain some noteworthy environments. The most detrimental changes have occurred around the rivers of the Cape Flats, along the northern shore.

UITTREKSEL

Lugfotos vanaf 1936 tot 1987 van die elf riviere wat in Valsbaai uitmond, is bestudeer. Verskeie tegnieke is gebruik om kwantitatiewe waardes en waardebeslissings vir die veranderinge wat plaasgevind het, te verkry. Daar is bevind dat groot toenames in nywerheids-, woon-, ontspanningsgebiede en uitheemse plantegroei plaasgevind het ten koste van oop sand en natuurlike plantegroeitipes. Die riviere aan die ooskus van die Baai is betreklik onversteur. Dié van die westekant is meer versteur, maar daar het tog enkele natuurlike omgewings langs die riviermondings behoue gebly. Die skadelikste veranderinge het langs die riviere van die Kaapse Vlakte aan die noordelike kuslyn plaasgevind.

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INTRODUCTION

Patterns of development vary in different environments. A typical pattern in a terrestrial environment might range from uniform natural landscapes to a mosaic of natural and man-made landscapes. As the demand for land increases, the landscape is inexorably converted from a natural to a man-made landscape (Schroevers 1982).

Gasson (1980), at a symposium discussing the management needs of False Bay, divided the area into five zones: the deep water area of the Bay itself; the near-shore zone; the intertidal zone; the back-shore zone; and the hinterland. Rivers are an important continuous connection from the hinterland, through the back-shore and intertidal areas, to the near-shore environment and, through dispersal, to the Bay itself. However, very little, if any, mention was made of the rivers flowing into False Bay at this symposium.

The quality of much of the water flowing into this bay has been reduced by developments in the hinterland, as shown by the deterioration of the estuarine environments (O'Callaghan 1990). However, the coastal environment is also under developmental threat, and has been for many decades. Calls have been made for an integrated management policy for the False Bay area (Malan 1982; Gasson 1980). Very little has, as yet, been achieved.

Along any coastline, the greatest diversity of habitats is usually to be found in and around estuaries. Not only are the coastal terrestrial environments present, but wetland habitats, saline habitats and combinations of these are also to be found. Unfortunately, estuarine areas are sensitive to man-induced disturbances and are often in great demand for various types of development. Being in

* National Botanical Institute, P.O. Box 471, Stellenbosch 7600.

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TABLE 1.—Aerial photographs of estuaries used for this study. Scale ± 1:10 000. Housed at Trigonometrical Survey, Mowbray, unless otherwise stated

	Buffels (W)	Elsies	Silver-mine	Sand	Zeekoe	Eerste	Lourens	Sir Lowry's Pass	Steen-bras	Rooiels	Buffels (E)
						Photo no.					
Job 61/44: B & W, 1944	374	189	193	103	—	—	—	—	—	—	—
Job 326/79: Col.; 1979; Dept. Land Surveying, Univ. Natal	375/3	372/3	369/3	367/3	363/3	362/3	359/3	358/3	356/3	354/3	352/3
Job 126/38: B & W, 1938	—	—	—	—	11723	11697	12611	12665	12696	12775	12807
Job 424/58: B & W, 1958	—	7009	7010	6997	6995	—	—	—	—	—	—
Job 335/53: B & W, 1953	—	—	—	—	—	6114	6113	—	—	—	—
Job 461/61: B & W, 1961	—	—	—	—	—	—	—	433	—	—	—
						Page; negative no.					
ECRU/EMA: Col.; 1987; CSIR, Stellenbosch	35; 1	37; 13	37; 10	38; 6	38; 10	39; 14	40; 4	40; 11	41; 13	42;11	42; 15–16

close proximity to a major city, the False Bay estuaries are no exception. The aim of this study is to ascertain and quantify, as an aid to management, the changes that have occurred around the estuaries of False Bay, as described by O'Callaghan (1990).

METHODS

Delineation of mapping units

Aerial photographs, from 1938 to 1979 (see Table 1), of each of the estuaries were studied to delineate various mapping units. It was ensured that, if present, the mapping units would be distinguishable on all the aerial photographs. After they had been selected, the homogeneity and practicability of each unit was checked by field observation.

The following mapping units were thus defined: 1, water; 2, rock; 3, sand and pioneer vegetation; 4, dune scrub (Boucher 1987; Moll *et al.* 1984; Taylor 1980); 5, wetlands; 6, riverine scrub; 7, fynbos (Boucher 1978, 1987; Moll *et al.* 1984; Taylor 1969, 1980); 8, alien vegetation (Stirton 1978); 9, agricultural lands; 10, residential areas; 11, recreational areas; 12, industrial areas; 13, roads and rail.

Either two or three photographs, depending on the amount of change that had taken place over the years, were selected to form a temporal series for each estuary. A Bausch and Lomb Zoom Transfer Scope (Model 53-05-04-23) was used to draw the outlines of the mapping units for each estuary from colour aerial photographs of 1979, thus producing a land use map for 1979. A copy was made of this map and the preceding photograph of the temporal series was superimposed thereon. The land use map was adapted by redrawing the mapping units so as to correspond with the preceding photograph. This process was repeated until land use maps had been drawn for all the estuaries and all the aerial photographs of a temporal series.

An area extending approximately 250 m on either side of the river mouth and 1 km inland from the shore was selected. The area of each mapping unit within this selected area was measured and corrected according to methods set out in O'Callaghan (1985).

The results of this procedure are shown in Table 2. From this table one can observe the changes in land use that have taken place at each estuary. These changes can be measured and compared. They can be related to developmental patterns in different parts of the environment. However, integrated measurements and environmental values are often required to compare different areas and to facilitate decision making.

Evaluation of changes

Numerous techniques exist whereby some measure of relative environmental importance can be determined (Linston 1975). These usually require much expertise, time and money; commodities which are not always readily available to those who make decisions about the environment. For this study, these methods were simplified, making use of some of the principles of more complex techniques.

The procedures used can be divided into four stages: 1, the determination of the relative environmental importance (I) of each mapping unit; 2, the determination of relative environmental states (E) for each estuary; 3, the determination of a co-efficient of change (A) which is a measure of how much the environmental state of each estuary has changed over the years; 4, the determination of a conservability co-efficient (C) which integrates the above.

1 Relative environmental importance (I)

The assigning of values to parts of the environment is a subjective process. Values can vary according to characteristics of the evaluators (Sandbach 1980). Numerous techniques have been developed to overcome this subjectivity (Fuggle 1983) and the use of specialist panels (Helmer 1963) is widely accepted. As these procedures are costly, a compromise is made by using a small panel and critically analysing the results.

TABLE 2.—Changes in area (ha) of each mapping unit from each aerial photograph of a temporal series

River	Year	Water	Rocks	Sand & pioneers	Dune scrub	Wet-lands	River scrub	Fynbos	Alien veget.	Farm areas	Resid. areas	Recrea. areas	Indust. areas	Roads	Total
Buffels (West)	1944		0,84	16,37	5,74			5,62	19,14					0,16	38,87
	1979		0,66	4,66	0,68			2,34	28,98			0,44		0,26	38,02
Elsies	1944		0,35	15,10	12,06			1,69	4,36		3,51			1,36	38,43
	1958	0,33	0,33	8,06	12,18			2,08	10,24		3,81			1,16	38,19
	1979		0,36	4,86	2,61	7,94		1,02	9,37		6,78	0,46		3,36	36,76
Silvermine	1944	0,20		24,40	1,26	4,62		2,33	8,16		1,92	0,19		1,84	44,92
	1958	0,32		11,14	7,93	4,78		0,66	11,50		5,38	0,29		1,76	43,76
	1979	0,02		4,90	14,25	2,73		0,45	7,07		5,50	3,18		1,67	39,77
Sand	1944	3,04		6,22	9,93	10,43			1,29		11,28	2,23		2,25	46,97
	1958	5,52		4,04	4,23	7,54			5,79		15,04	3,79	0,15	2,46	48,56
	1979	7,02		5,32	2,02				0,05		18,13	13,99	0,85	0,31	47,69
Zeekoe	1938			21,64	23,36				3,27						48,27
	1958	2,68		13,26	27,36	0,24			6,24					0,62	50,06
	1979	1,28		12,36	7,79	0,50			7,41				22,10	0,63	52,07
Eerste	1938	0,83		19,95	17,55	2,58			12,80						53,71
	1953			11,94	9,15	2,91			24,46						48,46
	1979	6,38		5,16	3,29	2,70			7,18				26,09		50,80
Lourens	1938	3,73		4,90	5,81	0,08			8,26	3,11	2,30	2,78	0,19	0,91	32,07
	1953	2,13		10,57	5,18	0,08			5,10	2,96	3,06	1,89	5,71	0,55	37,23
	1979	1,41		5,63	1,50	0,14			3,35		8,57	3,88	8,68	0,55	33,69
Sir Lowry's Pass	1938			6,51	0,30					9,89	3,12				19,82
	1961	0,13		2,36	3,31				0,05	9,61	5,98				21,44
	1979	0,19		2,45					0,62		12,85	3,86			19,97
Steenbras	1938	0,40	4,45	0,40			2,23	38,77	0,17			0,43		0,51	47,36
	1979	0,26	2,28	0,48			2,78	35,48	1,17			1,38		0,57	44,34
Rooiels	1938	1,74	0,77	11,72	4,15	4,09		21,06							43,58
	1979	2,03	0,44	8,06	3,69	5,84		21,63	0,70		0,16	0,56		0,95	44,06
Buffels (East)	1938	9,77	0,40	6,12	8,66	1,47		16,81	0,24					0,22	43,68
	1979	4,59	0,55	6,46	6,78	1,70		11,61	2,66		0,90			2,43	47,68
Total	1938/44	19,71	6,81	133,33	88,86	23,27	2,23	86,28	48,74	13,00	22,13	5,63	0,19	7,25	
	1979	23,18	4,29	60,34	42,61	21,55	2,78	82,53	68,56		52,89	27,75	57,72	10,73	
% difference		+17,6	−37,0	−54,7	−52,0	−7,4	+24,66	−4,3	+40,7	−100	+138,0	+392,9	+30278,9	+48,0	

TABLE 3.—The relative environmental importance factor (I) of each mapping unit

Mapping unit	I
Water	8,2
Rocks	3,2
Sand & pioneers	1,4
Dune scrub	5,0
Wetlands	10,0
River scrub	2,8
Fynbos	4,8
Alien vegetation	−6,0
Farm areas	−8,75
Residential areas	−6,0
Recreational areas	−5,25
Industrial areas	−9,5
Roads	−6,0

Three biologists involved in coastal management and two botanists involved in coastal ecology were asked to evaluate the mapping units without the study area being named. Each assessor was asked to give each unit a relative value from −10 to 10 according to how an increase in the unit would affect the functioning of the estuary and immediate environs (a negative value would mean a detrimental effect on the environment). The values thus obtained were averaged for each unit to obtain a relative environmental importance factor (I) for each mapping unit (Table 3).

Table 3 shows that the panel used for this study determined that the most important beneficial change that can occur at an estuary is an increase in wetland vegetation. Wetland vegetation is generally accepted as being beneficial to the functioning of an estuary, performing functions such as flood attenuation, silt trapping, reduction of excess nutrients, provision of breeding sites, production of food, and others (see Walmsley & Botten 1987).

An increase in wetland areas is related to water flow. An increase in water surface area was regarded as the second most important beneficial change in an estuary. Provisos concerning the quality of the water and reasons for its increase were attached to this selection.

Increases in dune scrub and other terrestrial vegetation types were given similar ranks with respect to their beneficial I values. Increases in other natural environments (e.g. rocks and sand) were perceived as being less beneficial.

All developments which result in a loss of natural environments were taken to be detrimental to estuarine functioning. An increase in industrial areas was regarded as the the most detrimental. Not only does this type of development physically destroy the natural environment, but it also produces pollutants and utilizes water in various ways.

An increase in farming activities was also regarded as highly detrimental. The effects of agriculture on the estuarine environment are similar to those mentioned above.

Residential developments (including road and rail developments) and infestation by alien plants were regarded as having detrimental effects of a similar magnitude. An increase in recreational areas was regarded as the least destructive, although it still had a relatively high negative value. The magnitude of these negative values can be related to the rate and extent to which these developments bring about a detrimental effect on the functioning of estuaries.

2 Relative environmental state (E)

As each mapping unit has a relative importance value, the relative environmental state of each study site can be determined for each year, according to the area of each mapping unit present. This was accomplished by first adding eleven to each relative importance factor to obtain positive values. Secondly, each of these positive values was multiplied by the area of the mapping unit for each estuary for each year. Thirdly, all the values thus obtained were summed for each estuary for each year. This sum was divided by the total corrected area studied at each estuary for each year to result in a measure of the environmental state (E) of each estuary for each year of observation (Table 4).

3 Coefficient of change (A)

When planning management policies, it is important to have an indication of the environmental state and the amount of change which has taken place at the study site (as shown above). However, it is particularly useful, especially for conservation policies (Roome 1984), to determine the present state of the environment in terms of its historical state and thus the amount of change that has taken place relative to each site. This was accomplished by establishing a coefficient of change (A) for each study site. For each mapping unit, the area present in 1938/44 was subtracted from the area present in 1979. This difference was divided by the sum of the total areas of the study site for these two years and multiplied by the relative environmental importance factor (I) for each unit. The values thus obtained were summed for each study site. This resulted in a coefficient of change presented in Table 4.

4 Conservability (C)

Even though very little detrimental change might have occurred at an estuary during this period of photography, it is possible that the estuary is not well suited to conservation because very little natural environment was present at the time the first aerial photographs were taken. Calculations thus far do not take the original state of the estuary into account.

This was rectified by establishing a factor arbitrarily termed 'conservability' (C). This was achieved by obtaining positive values for each coefficient of change by arbitrarily adding five to each value of A (the values for A varied from 0 to −3,35). This positive value was multiplied by the environmental state (E) of each study site for 1938/44. The values of C are presented in Table 4.

CHANGES OBSERVED IN DIFFERENT ENVIRONMENTS

As can be seen from Table 2, profound changes have occurred in land use around the estuaries entering False Bay.

Water and wetlands

Water surface area has shown a 17,6% increase during this period of photography. This could be seen as an indication of an increase of water entering the rivers from hard surface run off and sewage works. However, the factors affecting the surface area of water in an estuary are numerous and varied. This area can be affected by the season and time of photography with respect to tides and annual rainfall variability in the catchment. This variability can be illustrated by observing the photographs of 1987. These photographs show that at the Rooiels River, an increase in water surface area has resulted in a loss of open sand. The opposite has occurred at the Buffels (East) River where there has been an increase in open sand areas.

Direct comparisons of water surface area from different photographs is not recommended unless these variables can be correlated. On the other hand, wetland areas are affected by water flow characteristics. Changes in the extent and distribution of wetlands reflect long-term changes in hydrological characteristics. Even though there has been extensive physical destruction of wetlands (especially at the Sand River), wetlands in this study area have only decreased by 7,4%. With the exception of Silvermine, Sand (physical destruction) and Buffels (West), (at Steenbras wetlands absent), wetlands have increased at all the rivers. This indicates a long-term increase in the amount of water flowing into these rivers.

By 1979, a wetland of 7,94 ha had become established at the Elsies River estuary. Prior to 1910, this river flowed directly to the sea, or might have formed a small lagoon, usually in winter, which persisted for varying periods (E. McKie pers. comm.; D. de Villiers pers. comm.). The building of rail and road embankments across the river mouth (± 1910) restricted water flow, although water could still enter the sea via a culvert at the southern end of the beach and by seepage. By 1958, the road had been rebuilt and the base and embankments were presumably improved. It is likely that this development would have further reduced seepage, and, together with increased run off from hard surfaces, caused the wetland to become established.

Around the Silvermine River estuary, there has been a reduction of 1,89 ha in wetland areas between 1944 and 1979 (Table 2). During earlier years, the lower part of this river formed a marshy wetland (Dickson 1974; Burman 1962). However, the river in these parts has been channelled in recent years (Heinecken 1982a).

TABLE 4.—The environmental state (E) of each study site for each photograph of a temporal series, the coefficient of change for each study site (A) and the conservability (C) of each study site (see text for explanations)

River	E			A	C
	1938/44	1953/58/61	1979		
Buffels (West)	11,50		6,89	−2,20	31,20
Elsies	11,92	10,86	10,61	−0,66	51,93
Silvermine	11,60	10,88	11,04	−0,29	54,63
Sand	12,62	10,73	8,62	−2,10	36,60
Zeekoe	14,02	13,73	7,42	−3,35	23,13
Eerste	12,33	9,86	7,30	−2,48	31,07
Lourens	9,59	8,76	6,57	−1,27	35,77
Sir Lowry's Pass	6,22	6,36	6,19	−0,04	30,85
Steenbras	15,31		14,86	−0,37	70,88
Rooiels	15,50		15,45	0,00	77,50
Buffels (East)	16,17		14,51	−0,64	70,50

Wetland vegetation has disappeared from the study site at the Sand River. The manipulations which changed the configuration of this vlei are summarized by Morant & Grindley (1982). By 1961, 32 ha of vegetated wetlands had been destroyed by dredging in this vlei and, by 1981, more than 100 ha of wetlands had been destroyed by further dredging, and residential and recreational developments.

There has been an increase of 0,50 ha in wetland vegetation at the Zeekoe River estuary (Table 2). This river was constructed in 1942 as an overflow channel for Zeekoevlei (Bickerton 1982). By 1944, an estuarine lagoon had formed on the beach. The coastal road (Baden-Powell Drive) had restricted this lagoon to the hind-dune area by 1958 and the development of the sewage works in the early 1960s (Summers *et al.* 1976) increased the water flow in this river, thus allowing the wetlands to increase.

The increase in wetlands measured for the Eerste River estuary between 1938 and 1958 could be related to the decrease in water surface area for this period (Table 2). However, there was a large increase in water surface area between 1958 and 1979, caused by increased run off due to developments in the catchment and the discharge of treated sewage effluent.

Prior to a bridge being built across the Rooiels River mouth in the early 1950s, this river followed a meandering course across the floodplain (Heinecken 1982b). This bridge relocated the main flow channel towards the northern side of the floodplain. A meander was re-established on the seaward side of the road and the damming effect of this bridge brought about a slight increase in wetland area (Table 2).

In 1938, the Buffels (East) River formed a large backshore lagoon. The considerable reduction of this lagoon was probably facilitated by the enlargement of the Buffels Dam in 1972 (Heinecken *et al.* 1982).

Dune vegetation

During this period, units 3 (sand and pioneers) and 4 (dune scrub) have decreased by approximately 50% each. The most widespread reason for this decrease is the growth of alien plants, which were found at all the rivers by 1979. At the Cape Flats estuaries (Zeekoe, Eerste, Lourens), industrial development is the most important factor contributing to the demise of dune vegetation. At Silvermine, Sand, Rooiels and Buffels (East), residential developments were most important with recreational developments at Sir Lowry's Pass. These developments are discussed in greater detail below.

Riverine scrub and fynbos

These vegetation types were found mainly around rivers on the eastern shores of the Bay. Little development has taken place around these rivers and fynbos and riverine scrub have hardly been affected.

Less fynbos was present near the estuaries of the western shore in 1938. Around these rivers (Buffels (West), Elsies, Silvermine), fynbos has decreased by 60,4%, mainly as a result of alien plant invasion and residential development. Fynbos was not found around the river mouths of the Cape Flats.

FACTORS CAUSING CHANGES

Alien vegetation

By 1979, alien plants, mainly Australian acacias, were found at every study site (Table 2). Acacias were introduced into the Cape between 1845 (Shaughnessy 1980) and 1870 (Roux & Middlemiss 1963).

Official bodies, local authorities as well as central government organizations, planted alien acacias at numerous places along this coast, among others: 1885, Eerste River Mouth (Shaughnessy 1980); 1893, Retreat Station, north of the Sand River (Shaughnessy 1980); 1936, Zeekoe River, vicinity of mouth (Bickerton 1982); 1942, Sand River coast (Shaughnessy 1980).

In addition to the above plantings, Opie (1967) maintains that aliens were planted by a farmer at the Buffels (West) River during the mid-19th century to stabilize deep sands in the area (Coke 1963). Acacias might also have been planted at the lower Elsies River by the De Villiers family who have farmed the area since the 1870s. Although this farmer planted an unknown *Hakea* species (probably *H. sericea*) at the Elsies River and acacias on the western coast of the Peninsula, no record of the planting of acacias at the Elsies River exists (D. de Villiers pers. comm.).

The presence of alien plants at other sites is likely to have occurred by natural encroachment (Glyphis *et al.* 1981). At the lower Silvermine River, major encroachment seems to have occurred from the south where these plants are still used for hedges, windbreaks and shade in Fish Hoek town, established in 1918 (Burman 1977). At the Lourens River estuary, alien plants appear to have entered the study site along the river course from neighbouring farms. At the lower Steenbras River, alien plants were first found on disturbed areas near the road, while at the Rooiels and Buffels (East) estuaries, the presence of these plants can be related to the advent of residential development.

Residential development

In the area studied, there has been a 238% increase in residential areas, most of this development has taken place on the hillsides along the western and eastern shores of the Bay.

The Buffels (West) River lies within the Cape of Good Hope Nature Reserve, proclaimed in 1938. Consequently, development has been restricted to the creation of picnic sites around the tidal pool to the south of the river.

Much residential development has taken place around the lower Elsies River (93% increase), Silvermine River (186% increase) and Sand River (61% increase). These developments took place mainly at the expense of fynbos and the open sand/pioneer vegetation, although the latter had often been dominated by alien vegetation prior to residential development. At the Sand River, most of the development has taken place on filled-in wetland vegetation.

No residential development has taken place around the estuaries of the central Cape Flats, but an increase in housing of 272% and 312% has occurred respectively at the Lourens and Sir Lowry's Pass estuaries, mainly at the cost of dune scrub and agricultural areas. Some minor developments have taken place at the lower Rooiels and Buffels (East) Rivers. These are mainly in the form of seaside cottages.

Recreational development

Recreational developments are closely allied to residential development. Some minor development has taken place around the Buffels (West) and Elsies Rivers. There has been a major increase in the percentage recreational area at the Silvermine River in the form of the golf club. The golf course covers approximately 3 ha of what was previously farmland, open sand and dune scrub. The 504% increase in recreational area at the Sand River has been in the form of tended parklands on what was previously wetlands. A caravan site of 3,8 ha has been developed at the lower Sir Lowry's Pass River at the expense of dune scrub and open sand. Although the steep topography around the Steenbras River is not suited to residential development, recreational development has proceeded in this area and, in 1979, consisted of 1,3 ha of the study site. Minor developments in the form of picnic sites have taken place at the lower Rooiels River.

Industrial development

Major industrial development seems to be restricted to the rivers of the Cape Flats, away from the major residential and recreational areas. At the Sand River, a small nursery has been established near the head of the vlei, hardly compatible with residential and recreational development. The major industrial developments have been in the form of sewage treatment works: 22,10 ha at the lower Zeekoe River and 26,09 ha at the lower Eerste River. The 8,65 ha of industrial development at the Lourens River is in the form of a buffer and security zone around a chemical and explosives factory. Although very few buildings have been erected in this area, it is prone to environmental destruction and invasion by alien plants.

DISCUSSION OF INDIVIDUAL ESTUARIES

Buffels (West)

The low conservability of this estuary can be explained by a single factor: the encroachment of alien plants. Early aerial photographs and historical records show that this river valley consisted of a sand plume, and sediment interchange took place with the near-shore environment (Heinecken *et al.* 1982). Sparse dune pioneers and dune scrub would have been found on this sand. Between 1944 and 1978, open sand and pioneers decreased by 71,5%; dune scrub decreased by 88,2%; and fynbos decreased by 58,3%. During this period, alien plant cover increased by 185,8%.

The removal of alien plants from this reserve is an ongoing policy of the local authorities, but with varying success rates. MacDonald *et al.* (1989) quote reports which state that this area was completely cleared of aliens in 1945 and again in 1959. However, the 1979 photographs show that the area was again heavily infested. The 1987 colour aerial photographs show that approximately 2 ha of alien plants had been removed from this site and dune pioneers and scrub had re-established. These developments will serve to increase the conservability of this river.

Elsies

At this estuary, major impacts have been due to the encroachment of alien plants (114,9% increase) and residential developments (including roads: 108,2% increase). Open sand and pioneers, and dune scrub have decreased by 67,8% and 78,4% respectively. These changes should have had the effect of somewhat decreasing the conservability. However, a wetland has formed in areas which were previously sand and dune vegetation. As wetlands were given a higher relative importance factor (I) (Table 3), this development has ameliorated the decrease in conservability.

Photographs taken during 1987 show that little change has taken place at this site. However, residential development is taking place in the vicinity which could bring about an increased run off from hard surfaces, further affecting the wetland.

Silvermine

Around the lower part of this river, open sand and pioneer vegetation, and fynbos has decreased by 79,9% and 40,9% respectively. Residential and recreational developments have increased by 186,5% and 157,4% respectively. However, much of this development has taken place in areas which were previously dominated by alien plants. This has led to a net decrease in alien plant cover of 13,4% over the period covered by the aerial photography (in 1958, alien plant cover was 38,5% greater than in 1979). Furthermore, dune scrub has established in areas which were previously open sand. These environmental changes ensure that the conservability of this area remains relatively high.

Aerial photographs of 1987 show that a further 5 ha of dune vegetation has been destroyed by residential developments.

Sand

The major development that has taken place at the Sand River is a 527% increase in recreational areas. This has led to the almost total elimination of wetland vegetation and a 79,7% decrease in dune scrub. Some of the residential (60,7% increase) and recreational development has taken place in areas that were previously dominated by alien vegetation, resulting in a decrease in alien vegetation of 96,1%.

The conservability of this estuary is comparable to those of the other four estuaries of the Cape Flats (Zeekoe, Eerste, Lourens, Sir Lowry's Pass). The reasons for the low value of C for the Sand River are, however, unique, due primarily to recreational developments.

Zeekoe

This estuary has the lowest conservability and the highest coefficient of change. The major reasons for this are the establishment of sewage settling ponds (22,1 ha) and a 126,6% increase in alien vegetaion. Dune scrub and open sand and pioneers have decreased by 66,7% and 42,9% respectively.

The construction of the settling ponds destroyed large areas of dune scrub, but they are no longer used, except possibly in emergencies. They have become an important coastal habitat for water birds and recommendations have been made for these ponds to be proclaimed as a nature reserve (Curtin *et al.* 1975; Cooper *et al.* 1976; Brummer 1981; Bickerton 1982). If this proclamation were to take place, these ponds might be regarded as open water. This estuary would then be the only one along False Bay with a positive coefficient of change, resulting in a conservability of 80,8%. This would be an artificially induced beneficial change and might serve to mask detrimental changes in the area.

The 1987 photographs show that approximately 4 ha of land have been cleared, presumably for low-cost housing. This has brought about a loss of dune scrub and some alien vegetation.

Eerste

The reasons for the low conservability of this estuary are similar to those discussed for the Zeekoe River estuary: the establishment of a sewage works of 26,09 ha. This development resulted in a decrease in dune scrub and open sand and pioneers of 81,3% and 74,1% respectively. Alien shrubs have long been established in this area (Shaughnessy 1980) and the construction of this sewage works served to decrease alien vegetation by 43,9%.

Another factor serving to increase the conservability is a 668,7% increase in estuarine water surface area. Although tidal and climatic factors might have led to this observed increase of water surface area on the photographs, large areas of the catchments of the Eerste River and Kuils River (a tributary) have become developed over the last decades (Grindley 1982). Increased run off from hard surfaces as well as effluent discharge from at least five sewage works in this catchment have undoubtedly increased the amount of water flowing into the sea via this estuary.

At this river, photographs taken in 1987 show that approximately 2 ha of alien plants have been cleared in what was previously classified as industrial areas.

Lourens

There has been a 4 468,4% increase in industrial area and a 272,6% increase in residential area around this estuary. In addition, there has been a 74,2% demise of dune scrub. These developments would serve to decrease the conservability. However, they have resulted in a net

decrease of alien vegetation (59,4%) and agriculture which has disappeared from this area. There has also been a slight increase in open sand and wetland vegetation, factors which would increase the conservability.

Nevertheless, the conservability of this estuary was relatively low when aerial photography began in 1938. The conservability of this estuary remains low, even though the coefficient of change (A) is lower than for most of the estuaries of the Cape Flats.

The 1987 photographs show that some eradication of alien plants has taken place within industrial areas. But outside of these areas, approximately 1 ha of open sand has been consolidated by alien shrubs.

Sir Lowry's Pass

Even though the coefficient of change for this estuary is close to zero, this estuary does not have a high conservability. This is because much of the area had been developed by the time of onset of photography for this study. In 1938, most of this area was used for agricultural purposes. By 1979, these agricultural areas had been converted to residential areas. Between 1938 and 1961, dune scrub had become established on much of the open sand and pioneer vegetation. By 1979, this dune scrub had largely been destroyed for recreational purposes.

Steenbras, Rooiels and Buffels (East)

Most of the changes that took place around these estuaries were discussed above. These changes are relatively minor, as can be seen from the high conservability values. However, they all show slight increases in alien plant cover, residential and/or recreational areas, with decreases in the natural dune vegetation.

Photographs taken in 1987 show that these developments are ongoing. Some recreational and residential development has taken place at the Steenbras and Buffels (East) Rivers. There have also been slight increases in alien scrub at the Rooiels and Buffels (East) Rivers. Soon after these latest photographs were taken, major upgrading of the main thoroughfare across the Rooiels River was commenced. The stage could be reached when these developments may destroy the attractiveness of these areas, i.e. the natural environment. This, unfortunately, is largely the pattern observed along the western shores of the Bay.

COMPARISON OF ESTUARIES

The effects of development can be determined by using the descriptive methods discussed under Methods: evaluation of changes. However, quantitative measurements, or environmental values, are often needed to compare different areas and to facilitate decision-making.

Table 3 shows that the environmental state of all the estuaries decreased during the period spanned by aerial photography. When the first aerial photographs were taken, the most easterly rivers of the Cape Flats (Lourens and Sir Lowry's Pass) had the lowest E value (9,59 and 6,22 respectively) whereas the highest E value was found at the Buffels (East) River (16,17). In 1979, this range for E values was similar (6,19 at Sir Lowry's Pass; 15,45 at Rooiels). However, the environmental state of the other rivers of the Cape Flats (Sand, Zeekoe, Eerste) had deteriorated so as to be in accordance with Lourens and Sir Lowry's Pass. The state of the Buffels (West) River had also deteriorated drastically.

This deterioration of the environmental states of these rivers is further demonstrated by the coefficient of change (A). The value of A for all the rivers is negative for the period covered by the aerial photography. The most change has taken place at the Zeekoe River (A = −3,35). The changes that have taken place at the lower Rooiels River are minor and A is given as zero.

Although conservability (C) is a relative factor, it is possibly the most important as it integrates all the factors calculated above. The lowest value of C is seen at the Zeekoe River estuary (23,13) where much industrial development and invasion by alien plants has taken place. The Rooiels River estuary has the highest value for C (77,50). Only a small amount of recreational and residential development has taken place at this estuary and the environment retains a healthy state.

The estuaries of the Cape Flats (Sand to Sir Lowry's Pass) have the lowest C values. The C values for the estuaries on the western side of the Bay (Buffels (West) to Silvermine) are lower than those on the eastern side of the Bay (Steenbrass to Buffels (East)). This is understandable as, being closer to the city of Cape Town, the western side of the Bay would be in greater demand for housing and other developments.

CONCLUSIONS

Aerial photographs are readily available for large parts of the coast. For False Bay, these photographs span a period between 1938/44 and 1987. The environmental coefficients presented here are easily and rapidly calculated. They give quantitative indications of the state of the environment and can be used to facilitate decision-making and policy formulation. For example, using the data presented above, management of the most easterly rivers of False Bay should be orientated towards conservation while smaller sanctuaries could be established at the Elsies and Silvermine Rivers, particularly the wetland areas. The rivers of the Cape Flats should be managed as developed areas and attempts should be made to remove alien plants from the Buffels (West) River.

A similar exercise can be carried out for the entire coastline of False Bay. Communication between local governmental bodies could establish an integrated management policy for this coast with little expenditure in terms of time, effort and equipment.

The results of such an exercise must, however, be analysed critically. Without some understanding of the reasons for changes in these environmental factors, erroneous conclusions can be reached. For example, a large part of the observed increase in water surface area at the Eerste River is due to an increased run off from developments in the catchment. The observed increase in water surface area at the Rooiels River is more likely due to climatic phenomena. Furthermore, if it was decided that

residential developments were more detrimental to the environment than agricultural developments, the environmental state (E) of the Sir Lowry's Pass River would have decreased from 1938 to 1961. Any statement concerning the importance of any part of the environment is subjective and could thus be a source of error. Although data could be collected by non-specialists, it is recommended that environmental evaluation be carried out by specialists or evaluation panels (Fuggle 1983).

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