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USE OF PLASTIC DRIFT CARDS AS INDICATORS OF POSSIBLE DISPERSAL OF PROPAGULES OF THE MANGROVE *AVICENNIA MARINA* BY OCEAN CURRENTS

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Plastic drift cards with the same buoyancy as propagules of *Avicennia marina* (Forssk.) Vierh. were used as an indicator of possible mangrove dispersal by ocean currents. The cards were dropped from an aircraft into the sea at the mouths of the Mhlathuze River off Richards Bay, the Mgeni River off Durban and the Nxaxo-Ngqusi rivers off Wavecrest on the east coast of South Africa. Details of the time and locality of strandings were recorded from cards returned. Of the 4 500 cards released, 133 (8.9%), 146 (9.7%) and 280 (18.7%) were returned respectively from the above locations. The high returns from Wavecrest were attributable to cards being washed ashore in the immediate vicinity of the dropping point. A high percentage of the cards dropped at Durban were transported northwards by the inshore counter-current. Approximately 68 and 32% of the cards recovered for Richards Bay and Durban respectively were transported by the Agulhas Current and were stranded farther south along the East and South-East coasts. Cards that reached the Agulhas mixing area were deposited ashore on the Cape Peninsula and the West Coast (3%), or were transported either across the Atlantic Ocean to South America or the Indian Ocean to Australasia (4%). Estimated transport rates of cards to South America and Australasia were similar to previously published values. The results indicate that the northern estuaries could provide propagative material over a considerable portion of the South African coast, which could result in a wider distribution of mangroves in the Eastern Cape.

Key words: dispersal, drift cards, mangroves, ocean currents, propagules

Steinke (1972) provided possible reasons for the absence of mangroves south of the Eastern Cape, South Africa. Ward and Steinke (1981) reported on the distribution of mangroves in South Africa and Steinke (1986b) described the mangroves in the East London area. These surveys led to studies on the characteristics of propagules and on some of the factors affecting the establishment and early growth of the mangrove *Avicennia marina* in an attempt to understand its distribution, especially its southern limit (Steinke 1975, 1986a, Steinke and Naidoo 1991). In particular, research on propagule buoyancy confirmed the significance of dispersal by ocean currents and indicated possible origins of propagative material for estuaries on the South-East Coast (Steinke 1986a). This paper reports on an investigation of possible dispersal of propagules from the north coast of South Africa, using plastic drift cards.

MATERIAL AND METHODS

As propagules of *A. marina* float on the surface of the water, it was essential to use drift cards of similar buoyancy. Solid, low-density, red polythene (90 × 65 × 2 mm) drift cards were selected (Duncan 1965). A brief message, requesting the return of the card with the required information on the date and place of recovery was printed on each card (in English and Afrikaans). In addition, each card was engraved with a number. No reward was given for returns.

A total of 4 500 cards was used in the study. They were divided into nine packets of 500 cards each. Three packets were dropped from an aircraft into the sea at the mouths of the Mhlathuze River (Richards Bay Sanctuary; 28.50°S), the Mgeni River (Durban; 29.48°S) and the Nxaxo-Ngqusi rivers (Wavecrest; 32.35°S – Fig. 1). These estuaries, which support good stands of mangroves (Ward and Steinke 1981), were chosen to represent the northern, middle and southern communities respectively of South Africa. A packet of cards was dropped from an aircraft at an altitude of 40–45 m at approximately 100, 500 and 1 000 m from each estuary mouth. At all estuaries, the drop took place on an outgoing equinoctial spring tide on 19 March 1988. This coincided with the natural period of release of *A. marina* propagules and, based on predicted tidal data, that date had the highest tide and fastest outflow for that period.

The distribution of all returned cards was recorded.

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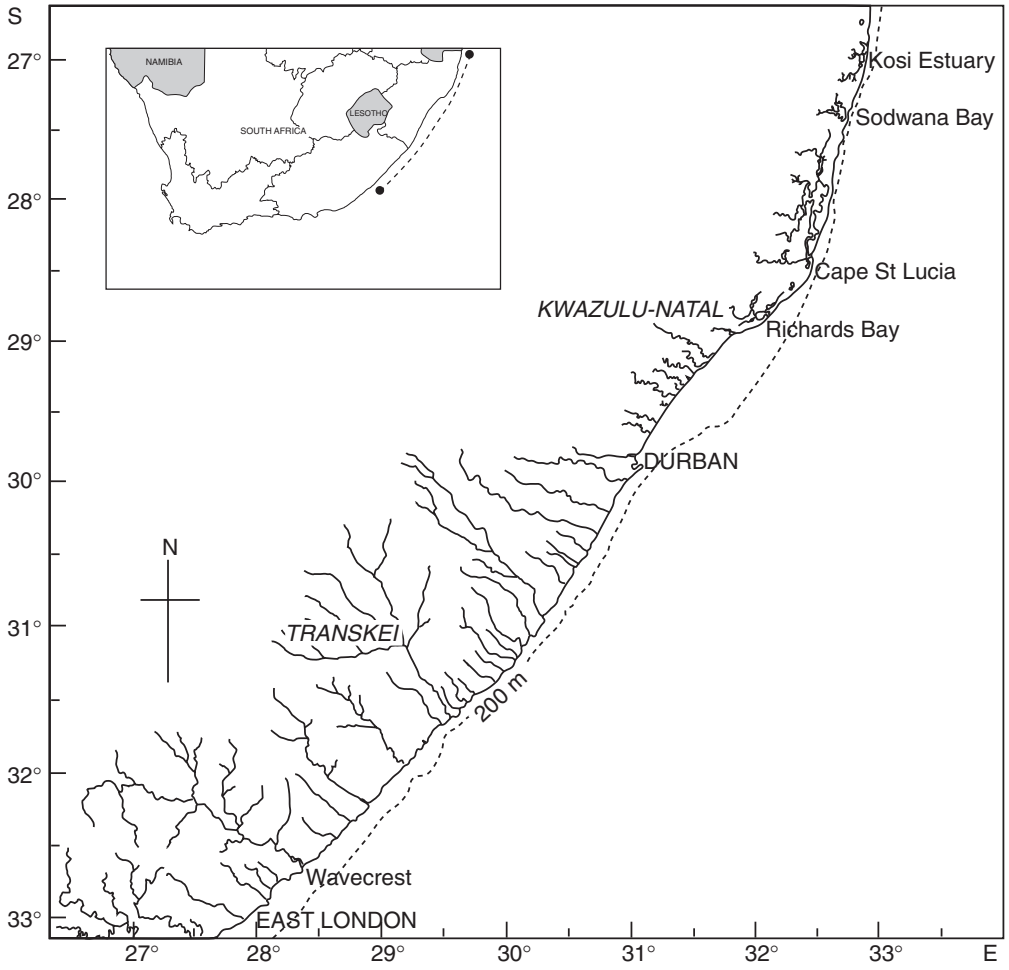

Fig. 1: Map of the eastern coastline of South Africa showing the points of drift card release at Richards Bay, Durban and Wavecrest

Because the cards bleach in the sun when dry, their colour was a rough measure of the time period since beaching (Shannon *et al.* 1973). Therefore, only unbleached cards were used to estimate drift (transport) rates (Lutjeharms *et al*. 1988).

RESULTS

In all, 559 (12.4%) cards were recovered with the required details of the card number and the exact place and date at which each was found. The numbers of cards recovered from Richards Bay, Durban and Wavecrest were 133 (8.9%), 146 (9.7%) and 280 (18.7%) respectively (Table I). This last, relatively high, recovery was largely the result of the stranding of 276 of the Wavecrest cards in close proximity (2–3 km) to the dropping point. From the two releases closest to the shore (100 and 500 m), 243 cards were found north of the estuary, whereas 33 of the cards released farthest from the coast (i.e. 1 000 m) were found south of the

Table I: Number and percentage recoveries of cards (1 500 per dropping point) at specific release sites

Release sites	Number (%) per dropping point					
	Richards Bay		Durban		Wavecrest	
	Mhlathuze River		Mgeni River		Nxaxo–Ngqusi Rivers	
	Number	%	Number	%	Number	%
100 m from mouth	42	2.8	103	6.9	122	8.1
500 m from mouth	42	2.8	29	1.9	123	8.2
1 000 m from mouth	49	3.3	14	0.9	35	2.3
Total	133	8.9	146	9.7	280	18.7

estuary. To the south, the shore is rocky and many cards may have been trapped and hidden by the rocks, resulting in a low recovery.

Only cards released closest inshore off Durban and Richards Bay were stranded within 2–3 km of the dropping point; recoveries were 46 (45%) and 16 (38%) respectively (Table II). Of the inshore releases off Durban, there was a steady decrease in returns northwards, the northernmost recovery being from Ballito in KwaZulu-Natal (29°32´S, 31°14´E). Cards released farther from the coast (500 and 1 000 m) off Richards Bay and Durban were more widely dispersed (Table II). Although slightly fewer cards were returned from releases off Richards Bay, more of these were found farther from their dropping point. Of the cards released off Durban, only 55 (38%) were distributed more widely than their dropping point and the coast immediately north of it. The 24 recoveries from all releases at Richards Bay were from between the Cape St Lucia area and the Kosi Estuary. From the two outer release points off Durban, five cards were found along the northern coast of KwaZulu-Natal as far as Sodwana Bay. In all, 93 (70%) cards released off Richards Bay were recovered south of their dropping point. It is noteworthy that 61 (46%) of these cards were found along the southern KwaZulu-Natal and Transkei coasts, which support good stands of mangroves. Five cards from each of the Richards Bay and Durban drops reached the Cape Peninsula and West Coast, one as far as Shell Bay (32°43´S, 17°59´E).

Table II: Recovery details of cards dropped at Richards Bay and Durban. Percentages are based on the cards recovered for each dropping point

Recovery area	Number (%) per dropping point			
	Richards Bay (Mhlathuze River)		Durban (Mgeni River)	
	Number	%	Number	%
Dropping point	16	12	46	32
KZN Coast north of drop	24	18	45	31
KZN Coast south of drop	31	23	10	7
Transkei to East London	30	23	4	3
South-East and South coasts	24	18	27	18
Cape Peninsula and West Coast	5	4	5	3
South America and Australasia	3	2	9	6
Total	133	100	146	100

KZN = KwaZulu-Natal

Rates of transport of the early recoveries are shown in Table III. These rates do not, however, provide a true indication of current speeds, because, over the relatively short periods, the time taken to reach the transporting current, especially the Agulhas Current, and to return to shore, would likely have taken up a relatively high proportion of the time from release to recovery. More important in regards to mangrove propagule distribution is the time taken to reach the sites of recovery (Table III). The most rapid rate of transport along the KwaZulu-Natal north coast was card 1487, which was most likely transported northwards by the inshore counter-current. The fact that cards reached the Transkei/East London area from Richards Bay within 14–15 days of release (cards 2420, 2667, 2146, 2422) is significant for mangrove dispersal. A card released off Durban (2826) was the first to be recovered in the Port Elizabeth area, and had taken approximately 42 days to travel some 700 km. The results suggest that the rate of transport south of the Transkei/East London area is slower than north of it.

The four most widely distributed cards released off Wavecrest were recovered from Rocky Bay (30°20´S, 30°44´E) and 5 km south of Sodwana Bay on the KwaZulu-Natal coast, and at Qolora (32°39´S,

Table III: Recovery details of the most rapidly transported cards dropped from Richards Bay and Durban

Card	Dropping point	Recovery details			
		Date recovered	Locality	Estimated rate of transport (cm s^{-1})	Days to recovery
2448	Richards Bay	27 March 1988	Near St Lucia Estuary	0.4	8
1487	Durban	19 March 1988	Umdloti Beach	3.6	–
79	Durban	19 March 1988	Umdloti Beach	2.6	–
82	Durban	19 March 1988	Glenashley	1.6	–
2420	Richards Bay	2 April 1988	Cebe, Bowkers Bay	1.8	14
2667	Richards Bay	2 April 1988	Kobole River, near Mbashe River	1.7	14
2146	Richards Bay	3 April 1988	Shelly Beach, East London	2.0	15
2422	Richards Bay	3 April 1988	Cintsa, near East London	1.9	15
2105	Richards Bay	9 April 1988	Fish River lighthouse	1.6	21
2309	Richards Bay	10 April 1988	Port Alfred (Riet River)	1.6	22
2955	Richards Bay	10 April 1988	Kwelera River, near East London	1.3	22
2826	Richards Bay	1 May 1988	Willows, near Port Elizabeth	1.0	43
305	Durban	11 May 1988	Willows, near Port Elizabeth	0.7	53
2365	Richards Bay	6 May 1988	Mostertshoek	0.9	48
1051	Durban	2 July 1988	Shell Bay (West Coast)	0.6	105
2651	Richards Bay	14 July 1988	Struisbaai	0.5	117

28°26′E) and Morgan Bay (32°42′S, 28°20′E), 12 and 24 km respectively south of the release point. Those recovered north and south of Wavecrest were from the mid and outer release points respectively.

One card (259) was recovered from Ponta Dobela (26°31′S, 35°56′E) in southern Moçambique. Two cards were returned from South America, but one did not have the exact date of recovery. In all, nine cards were recovered from Australasia, one from New Zealand. One recovery from South America and two from Australasia were released off Richards Bay; the rest had been released off Durban. Where possible, transport rates for these cards were estimated (Table IV).

DISCUSSION

The recovery of cards in South America and Australasia supports the finding of Shannon *et al.* (1973) that cards from the same release batch follow widely divergent paths, which can be attributed to the turbulent system of eddies in the Agulhas mixing area. Unless otherwise stated, the distribution of drift cards de-

Table IV: Drift card recoveries in South America and Australasia

Number (refer to Figure 2)	Card	Dropping point	Recovery details		
			Date	Locality	Estimated rate of transport (cm s^{-1})
1	661	Durban	7 December 1989	Bahia State, Brazil (13°05′S, 39°05′W)	15
2	1880	Richards Bay	October 1994	Parana State, Brazil (25°45′S, 48°30′W)	–
3	288	Durban	26 September 1989	Northcliffe, W. Australia (34°55′S, 116°10′E)	18
4	909	Durban	9 January 1990	Jurien Bay, W. Australia (30°05′S, 114°55′E)	16
5	423	Durban	18 November 1990	Fremantle, W. Australia (32°05′S, 115°45′E)	11
6	1633	Richards Bay	12 January 1991	Near Albany, W. Australia (35°05′S, 117°55′E)	11
7	400	Durban	7 July 1992	Augusta, W. Australia (34°30′S, 115°30′E)	6
8	1063	Durban	25 June 1994	Northcliffe, W. Australia (34°50′S, 115°45′E)	4
9	535	Durban	25 April 1991	Kingston, S. Australia (36°20′S, 139°40′E)	11
10	270	Durban	20 October 1991	Near Port Fairy, Victoria (38°20′S, 142°10′E)	11
11	2488	Richards Bay	17 January 1991	Near Wellington, New Zealand (41°05′S,174°55′E)	16

scribed here is presumed to have followed chiefly the current patterns elaborated by Shannon *et al.* (1973; Fig. 2). The cards recovered from South America were most likely transported initially by the Agulhas Current to the Agulhas-Atlantic mixing area, from where they were carried northwards in the Benguela Current, then westwards by the South Equatorial Current – in the case of one card, southwards in the Brazil Current. The cards recovered from Australasia were carried southwards by the Agulhas Current, which merges into the Return Agulhas Current at its southern boundary. These cards were then carried southwards and eastwards by the Return Agulhas Current into the latitudes of the West Wind Drift, which transported them to Australia and New Zealand. Those recovered from the west coast of Western Australia would have been carried northwards in the Western Australian Current before drifting ashore. It is noteworthy that the estimated transport rates of cards 661 (Bahia), 288 and 909 (Western Australia), 535 (South Australia) and 2488 (New Zealand; Table IV) are very similar to those calculated by Stander *et al*.(1969) and Shannon *et al.*(1973). The relatively high numbers of returns from Western Australia make for interesting speculation. Duke (1991) showed that in Australasia three varieties of *A. marina* are found, and that south-western Australia is characterized by var. *marina*, which also occurs in parts of tropical Asia and south-eastern Africa. Identification of these varieties was based upon genetic characters determined by isozyme electrophoresis, plus additional morphometric data (Duke 1991). On the basis of the drift card results, it is possible that propagules from southern Africa could have been carried across the Indian Ocean by the West Wind Drift to Western Australia. However, more recent evidence suggests that the Western Australian populations are more different from those in South Africa than was originally proposed (Duke *et al.* 1998, Maguire *et al.* in press). Experimental observations by the senior author have shown that mangrove propagative material could survive ocean transport for a prolonged period at low temperature and still remain viable, and thereafter maintain normal growth. Clearly, the possibility of long-range dispersal of propagules by ocean currents deserves further consideration.

The only returns from outside South Africa were those from South America, Australasia and southern Moçambique. There were no recoveries from countries north of Moçambique, as might have been expected from the work of Shannon *et al.* (1973). The fact that there was no inscription in Portuguese or French on the cards, the low level of literacy and the socio-economic conditions in many of the African countries may have contributed to this observation.

Within South Africa, there were also areas that yielded poor returns, e.g. the north coast of KwaZulu-Natal from Salt Rock to north of Richards Bay (29°30´S, 31°15´E–28°49´S, 32°05´E), the Transkei coast between the Mzamba and Mbashe rivers (31°05´S, 30°11´E–32°16´S, 28°55´E), the south coast from Cape St Francis to Cape Agulhas (34°13´S, 24°50´E –34°49´S, 20°00´E) and along the West Coast. Whereas some of the reasons suggested for the rest of Africa might apply also, the low returns from the Cape south coast are less easy to explain. The near-surface circulation patterns of the Agulhas Current off the South Coast, resulting in strong offshore flows (Boyd *et al.* 1992), may account in part for the paucity of card returns. Although the number of cards that drifted to the South Coast was less than those from farther north, the seed-drift data of Muir (1937) in the Riversdale area (between Mossel Bay and Cape Agulhas) suggested that greater returns might have been expected. It is possible that recoveries reflected human population densities along the coast. In many cases, high returns could be correlated with the presence of residential areas or tourist resorts; returns were low along more isolated stretches of coast.

Most cards found south of their points of release were transported by the Agulhas Current and likely brought ashore by eddies (Malan and Schumann 1979, Lutjeharms 1981). Those on the West Coast would have been transported northwards by the Benguela Current. Recoveries increased near promontories along the Cape south coast, e.g. Cape Recife, Cape St Francis and Cape Agulhas, possibly as a result of "entrapment" by associated onshore eddies in such areas. On the coast of KwaZulu-Natal, most of the cards recovered north of their point of release would have been carried by the strong, near-surface countercurrents inshore of the Agulhas Current (Pearce *et al.* 1978, Schumann 1982, 1987, Lutjeharms and Connell 1989). Anderson *et al*. (1988) noted that these currents have a slight onshore flow.

Drift cards dropped at Richards Bay and Durban were distributed widely. Cards were returned over a period of approximately 8.5 years. The late return of some cards was probably a result of them being overlooked. However, cards dropped at Wavecrest and found on the KwaZulu-Natal coast approximately two years later were probably carried southwards in the Agulhas Current and then transported by the Transverse Agulhas Current before being returned to South Africa (Shannon *et al.* 1973; Fig. 2). Wavecrest is at the confluence of the Nxaxo and Ngqusi rivers, which support important mangrove communities, but they do not have a strong outflow, even under eqinoctial tidal conditions. This is likely the reason why most of the cards were washed ashore soon after their release. In contrast, the strong outflow from the Mhlathuze River likely explains the

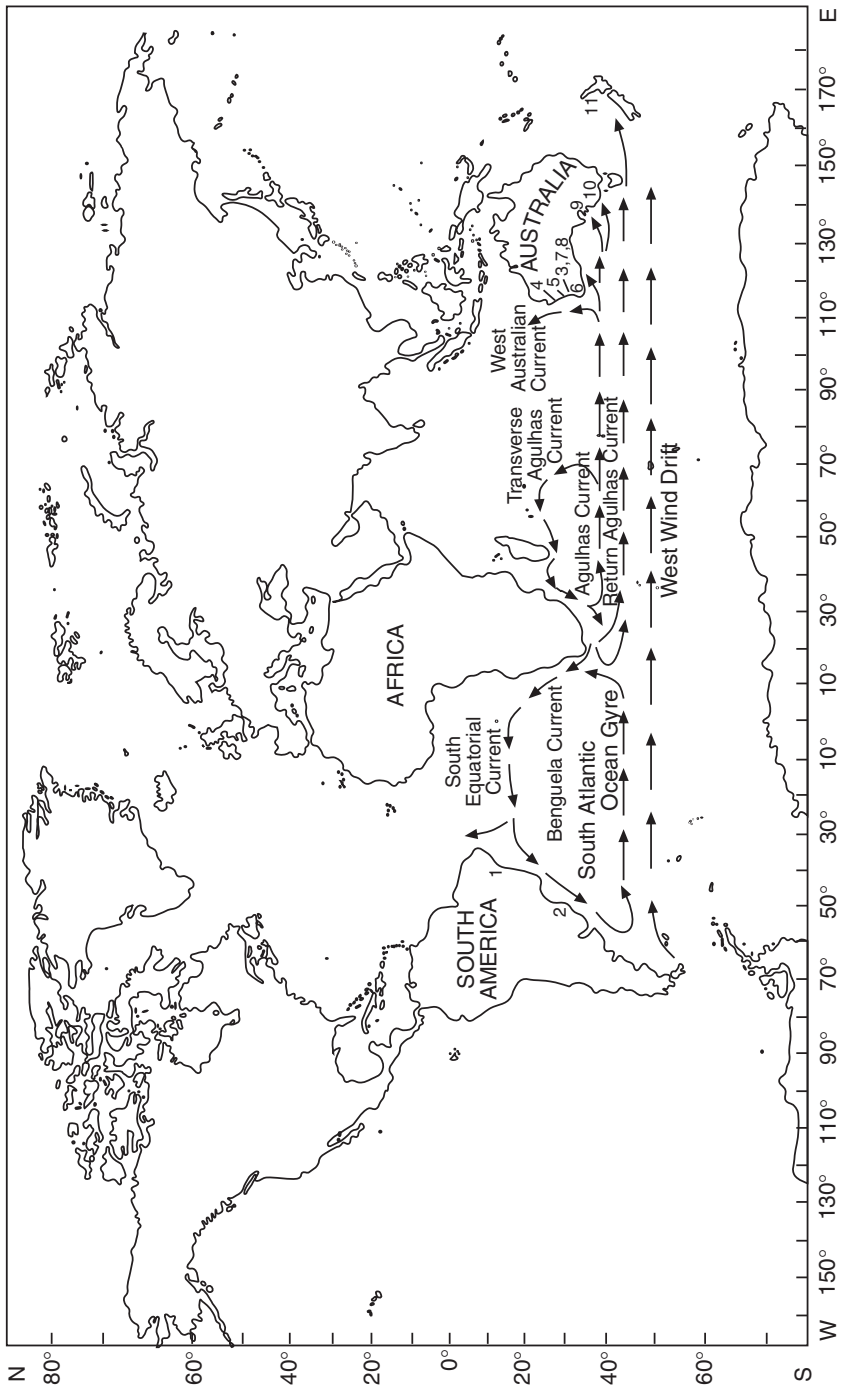

Fig. 2: Depiction of card recoveries in South America and Australasia and the main ocean currents potentially responsible for their distribution (after Shannon *et al.* 1973)

greater dispersal of cards from Richards Bay.

The returns of cards southwards to East London are significant for mangrove distribution in South Africa. Cards were returned from the vicinity of many estuaries in which mangroves have been recorded (Steinke 1986b, TDS pers. obs.). Perhaps the most convincing evidence of this was at Kwelera River (32°54′S, 28°04′E) near East London, where *A. marina* was established naturally around 1969 (Steinke 1986b). One of the cards dropped at Richards Bay was found in the estuary <100 m from the natural stand. There was a similar recovery in the number of cards dropped at Richards Bay and Durban, but along the coast from Port Edward to East London, more cards from Richards Bay were recovered. These results suggest that the northern estuaries, which have relatively large stands of mangroves, may serve as a source of propagative material for those areas and for the estuaries to the south, and that colonization may take place from estuaries far afield. There is evidence of genetic differences in South African populations of *A. marina* (Steinke 1986a). That propagative material from different sources may be dispersed to other estuaries, and become established, suggests that opportunities for gene flow are being created.

Clarke (1993) suggested that the range for dispersal of *A. marina* propagules in South-Eastern Australia is limited to up to 10 km. In that region of Australia, propagules sink after casting off their pericarp, causing most to strand and establish themselves near the parent tree (Clarke and Myerscough 1991). However, in South Africa, propagules from many estuaries remain afloat (Steinke 1986a), suggesting that the range over which dispersal may take place is extended considerably. A relatively recent colonization of *A. marina* took place in the Kwelera River, in which the nearest stand of mangroves was in the Kobonqaba River, some 60 km to the north-east (Steinke 1986b). Other relatively recent colonizations by *A. marina* in the Eastern Cape have been on the Kei and Gqunube (Gonubie) rivers, where the nearest source of propagative material was also the Kobonqaba River (15 and 70 km away respectively; Steinke 1986b, TDS pers.obs.). In the past, dispersal of this species (over even longer distances) has likely occurred along the KwaZulu-Natal coastline.

South of East London, there were good card recoveries in areas with estuaries suitable for the growth of mangroves. However, no mangroves have been recorded there, although there have been occasional, but as yet unsubstantiated, reports of their presence in some estuaries there. Few cards were recovered west of Cape St Francis in an area where there are also fewer estuaries suitable for mangroves.

Off Australia and New Zealand, *A. marina* is found at approximately 38°S, under more extreme environmental conditions than found along the south-eastern and southern coasts of South Africa (Bridgewater 1982, Crisp *et al*. 1990). Therefore, based on the present results and on the presence of beach-drift mangrove propagules (of unknown origin) along the Eastern Cape (TDS, pers. obs.), it is difficult to understand why *A. marina* is not found in more estuaries in that region of South Africa.

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