

Regional patterns of migration in the Banded Dotterel (*Charadrius bicinctus bicinctus*)

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ABSTRACT

Banded Dotterels (*Charadrius bicinctus bicinctus*) exhibit a variety of seasonal movement patterns ranging from sedentary behaviour, through migration within New Zealand, to trans-Tasman migration. From 1985 to 1990 the Ornithological Society of New Zealand (OSNZ) studied the regional patterns of movement of Banded Dotterels which had been colour-banded on the breeding grounds. Sight-recoveries indicated that most birds in inland regions of the southern half of the South Island migrated to Australia, but coastal breeding birds in the South Island were mostly sedentary. Inland birds north of Canterbury mostly moved within New Zealand, particularly to harbours in the North Island but with regionally specific patterns - Westland birds mainly to Farewell Spit, Marlborough birds to the northern North Island and Farewell Spit, southern North Island birds either locally or to the Auckland region, and most Hawkes Bay and Volcanic Plateau birds to Bay of Plenty and Auckland. Breeding habitat modified this pattern; coastal birds were mainly sedentary, whereas birds on nearby inland riverbeds were migratory. Migration patterns are discussed in terms of advantages and disadvantages of different wintering options.

KEYWORDS: Banded Dotterel, *Charadrius bicinctus bicinctus*, seasonal movements, migration, New Zealand, Australia

INTRODUCTION

Plovers are well known for their annual migrations, both trans-equatorially, e.g., some *Charadrius spp.* and all *Pluvialis spp.*, and regionally, e.g., the Wrybill (*Anarhynchus frontalis*) in New Zealand (Hayman *et al.* 1986). These migrations are characteristically latitudinal migrations, all or most individuals departing the breeding grounds to winter in more favourable climates and feeding areas to the north or south. The nominate race of the Banded Dotterel (*Charadrius bicinctus bicinctus*) is unique among waders in that a large part of the population undertakes an east-west migration.

Each year many thousands of birds cross the Tasman Sea from breeding sites in New Zealand to wintering areas in south-eastern Australia, a minimum distance of 1600 km (Blakers *et al.* 1984, Barter & Minton 1987, Lane 1987, Pierce 1988, Marchant & Higgins 1993); other winter concentrations occur in northern New Zealand. Although simultaneous winter counts in Australia and New Zealand revealed c. 5600 and c. 6850 birds respectively in the mid 1980s (Lane 1987, Marchant & Higgins 1993), these totals greatly underestimated the total population of Banded Dotterels which probably exceeds 50,000, with more than half migrating to Australia (Pierce 1988 and unpub., Heather & Robertson 1996).

Although some literature speculated about likely pathways of trans-Tasman migration, e.g., via northern New Zealand (Stead 1932, Oliver 1955) and Farewell Spit (Robertson & Dennison 1979), no migration data became available until 1979. Over the following five years, sightings of birds banded in New Zealand and Australia revealed that many trans-Tasman migrants were birds from the MacKenzie Basin (e.g., Dann & Pierce 1979, Pierce 1983). Other MacKenzie Basin birds were seen in post-breeding flocks in the MacKenzie Basin and on the South Canterbury coast (Pierce 1983). There was, however, a need for more extensive banding in New Zealand to reveal regional patterns of movement.

In the 1980s, the Banded Dotterel Study Group (BDSG) of OSNZ, and the Victoria Wader Study Group (VWSG) in Australia began a co-operative migration study of Banded Dotterels. The BDSG banded 2250 birds on the breeding grounds throughout New Zealand, while the VWSG increased its sample of banded birds wintering in Victoria (Barter & Minton 1987). Intensive searches for colour-banded birds were made on the wintering grounds throughout Australasia. This paper reports the recovery results of the sample banded in New Zealand.

METHODS & ANALYSIS

From 1985 to 1988 the BDSG colour-banded 2250 birds in 65 localities on mainland New Zealand and Chatham Island. Localities referred to in the text as L28, L29, etc. were generally individual riverbeds, beaches or mountain ranges. For analysis purposes, localities were grouped into ten geographically discrete banding regions (Fig. 1, Table 1). These ten regions were:-

- A. **Southland** - several inland braided riverbeds up to 250 m asl, coastal lagoons, estuaries and sandy beaches.
- B. **Central Otago** - many inland river terraces and subalpine herbfields, 250-2000 m asl.
- C. **MacKenzie Basin** - many inland braided riverbeds and river terraces, 400-1000 m asl.
- D. **Canterbury** - many coastal and inland braided riverbeds and pasture up to 600 m asl, coastal lagoons, estuaries and gravel beaches.
- E. **Marlborough** - several inland braided riverbeds up to 300 m asl and a few gravel beaches.
- F. **Buller-Westland** - many braided riverbeds up to 100 m asl and sandy beaches.
- G. **Southern North Island** - several inland braided riverbeds up to 150 m asl and a few sandy or gravel beaches.
- H. **Hawkes Bay** - several inland braided riverbeds up to 300 m asl.
- I. **Volcanic Plateau** - a few inland gravel lakeshores (especially Lakes Rotorua and Rerewhakaaitu) and subalpine herbfields up to 1100 m asl (especially Rangipo Desert).
- J. **Bay of Plenty** - sandy beaches and rivermouths to East Cape (L69-71).

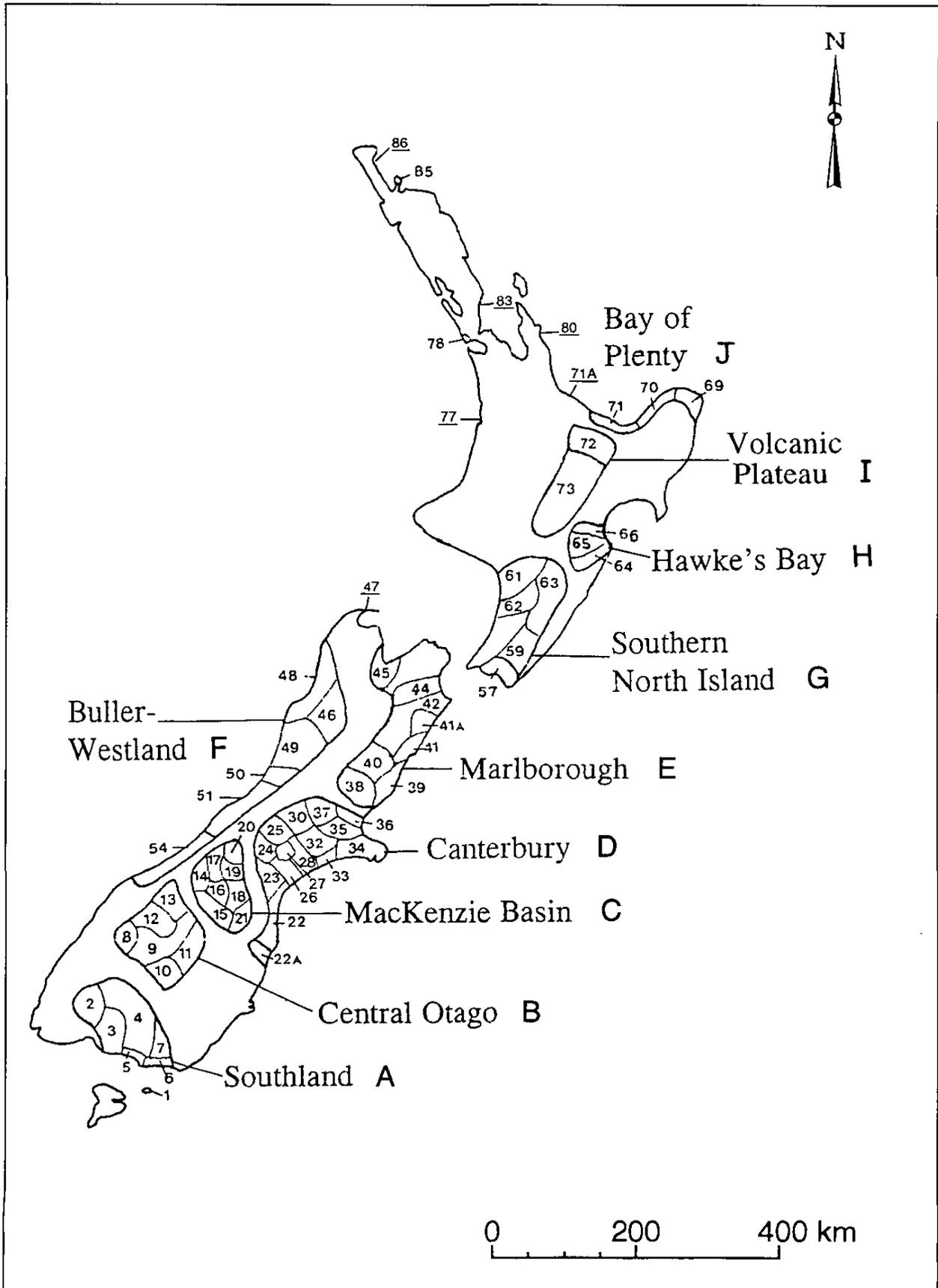


FIGURE 1 – Regions and localities in which Banded Dotterels were banded. Underlined numbers denote additional localities mentioned in the text where post-breeding or wintering birds were sighted.

TABLE 1 – Birds colour-banded in New Zealand 1985-1988

REGION	LOCALITY NO. (Refer to Fig. 1)	NO. BIRDS BANDED			
		Male	Female	Chick	Total
A. Southland	3-7	83	128	95	306
B. Central Otago	8-13	46	83	8	137
C. MacKenzie Basin	14-21A	101	200	235	536
D. Canterbury Plains	21B-37	117	250	149	516
E. Marlborough	38-46	46	102	40	188
F. Buller/Westland	48-54	16	32	38	86
G. Southern North Island	57-63	38	85	19	142
H. Hawkes Bay	64-67	44	148	54	246
I. Volcanic Plateau	71-73	18	30	10	58
J. NI Beaches	69-72, 78, 85	11	18	2	31
K. Chatham Island	86	2	2	0	4
TOTAL		522	1078	650	2250

Note: In 1985, an additional c. 160 individually colour-coded region C birds and c. 100 region D birds were still alive after studies begun in 1977 by M. Bomford, K. Hughey and R. Pierce. Sightings of these birds are included in recovery analyses.

Additional birds were banded at Whatipu (Auckland west coast, L78), Karikari Peninsula (L85) and Chatham Island. Nesting adults were caught individually by using walk-in nets propped up over the nest, whilst chicks were caught before they could fly. Size B or C numbered metal bands and size B wrap around coloured plastic bands were attached to the tarsus. Each locality was allocated separate colour-band codes for adult males, adult females, and chicks, with the chick code being changed annually. An additional c. 260 individually colour-coded birds were surviving in the late 1980s from earlier studies of breeding biology, mainly in the Tekapo (L18), Cass (L19), Rakaia (L32) and Ashley River (L36) study areas.

From December 1985 to July 1990, BDSG and VWSG searched for banded birds throughout New Zealand and Australia. Birds found in flocks from December onwards were considered to be post-breeding adults or fledged juveniles (Pierce 1983). For each region, the distribution of sightings was mapped into two separate four month periods, December to March ("post-breeding") and April to July ("winter").

These analyses exclude replicate sightings of the same band combination in the same year or in later years, unless there were simultaneous sightings of different birds carrying the same combination. This underestimates the number of individuals occurring at some localities, particularly those which are close to a major banding area.

For a few regions, the quantity of information is sufficient to permit monthly analysis of the timing of movements, including birds from different habitats within regions. These analyses of movement were grouped into 1-10 km (local), 11-100 (short distance), 101-1100 (New Zealand migrants), and >1600 km (trans-Tasman migrants). Precise distances are sometimes unknown because some banding "locations" had a span of up to 50 x 20 km.

RESULTS

Recoveries of birds banded in New Zealand

Southland

Post-breeding flocks of Southland birds first formed in late November and reached a peak in February. All post-breeding sightings of Southland birds were in coastal areas, mostly on the Southland coast where at least 49 of the 306 banded individuals were seen (Fig. 2). Initially, coastal flocks comprised mainly local (coastal) breeders, but in January-February inland-breeding birds moved short distances to join them. Post-breeding birds from the Aparima (L3) and Oreti (L4) Rivers (the main nesting riverbeds in Southland) were found at all regular flocking areas along the Southland coast from Riverton to Waituna Lagoon.

During the sole check of Ruapuke Island (L1, 15 km offshore from Bluff), in February 1988, two birds from each of Aparima and Oreti Rivers were found, but no coastal-breeding birds were found. During the post-breeding period, at least three Aparima River birds moved as far afield as Lake Ellesmere (L34), 450 km to the north-east (Fig. 2). The earliest sighting in Australia was on 18 March 1989 at Tamar River, Tasmania.

Winter sightings were mainly in Southland (18 individuals, most of which spent the entire winter there) and Australia (18 individuals). The northernmost sighting in New Zealand was an Oreti River male at Whanganui Inlet near Farewell Spit (L47) in May 1989.

Central Otago

Post-breeding birds were seen in Central Otago, the MacKenzie Basin, the Southland coast and Australia (Fig. 2). Three of the four band combinations seen in Southland were seen repeatedly and so may have been the same individuals. Three "post-breeding" sightings were in Australia, the earliest on 23 March 1986 at Avalon, Victoria.

Eighteen of the 19 winter sightings of Central Otago birds were made in Australia. Most Australian sightings were in Victoria, but two other birds represented the northernmost and westernmost sightings of New Zealand colour-banded dotterels in Australia - at Boonooroo, Queensland, and at Port Gawler, South Australia respectively. One winter sighting was at Lake Ellesmere on 4 April, but the bird was not seen there after that date (Fig. 2).

As with Southland birds, no banding recoveries came from the North Island. Small numbers (<100) of Banded Dotterels have spent the (usually severe) winter in Central Otago since the 1960s (Child 1979), but no colour-banded birds were found amongst them in this study.

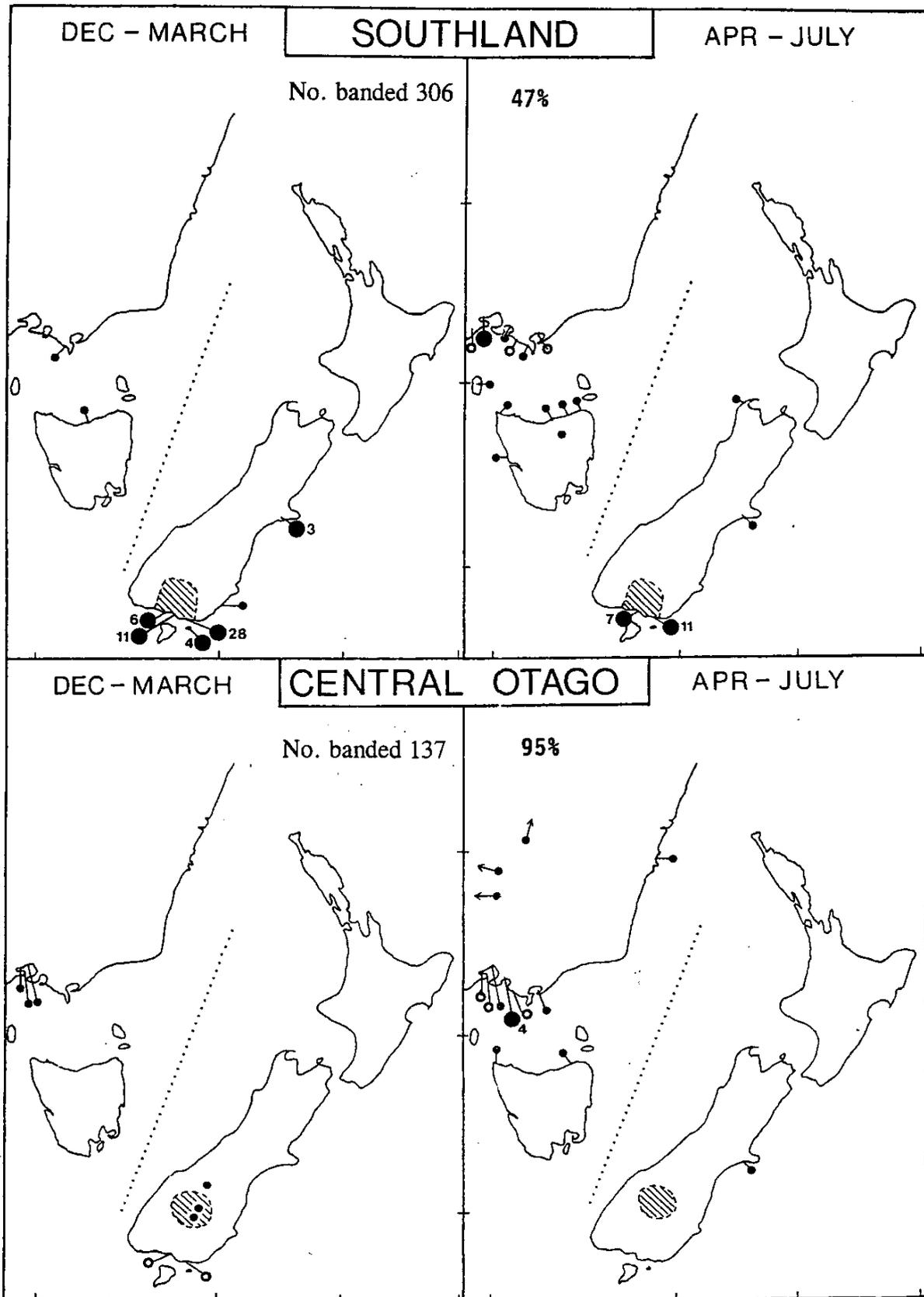


FIGURE 2 – Post-breeding (December-March) and wintering (April-July) sightings of colour-banded Banded Dotterels from Southland and Central Otago. Small closed circles denote one bird, open circles two birds and large black circles three or more birds (number given for more than three birds). The percentage figure in April-July denotes percentage of total sightings in Australia.

MacKenzie Basin

Post-breeding flocking began in late November, with most birds forming local flocks (of up to c. 300 birds) until March. Birds were in wing moult from November to March. This included some late nesting (incubating) birds in November-December. In the post-breeding period, 219 of the 536+ banded birds were seen, 169 (77%) in the MacKenzie Basin, mostly within a few kilometres of the breeding grounds. Mainly in January, a few birds dispersed long distances (up to 300 km) to coastal areas within New Zealand, especially Lake Ellesmere, Lake Wainono (L22) and the Southland coast (Fig. 3). Many individually-coded birds were found to stage at the same localities, (especially Lake Ellesmere), seven individuals each in two - four successive years, and two of these Lake Ellesmere stagers were subsequently sighted in Australia during winter.

Of 135 MacKenzie Basin birds seen in winter, 91 (66%) were in Australia. The 44 individuals sighted in New Zealand were mainly in the MacKenzie Basin (21 birds), but only 10 of these were known to have spent the entire winter there which, like Central Otago, can be very cold. At least five of these wintering individuals spent two or more successive winters in the Mackenzie Basin. Only seven birds (5% of winter sightings) were found in the North Island.

Peak dispersal from the MacKenzie Basin was in March, which corresponded with the arrival of MacKenzie Basin birds in Australia. The earliest arrival (an adult female) was seen on 2 March at Werribee, Victoria; it had been seen in a flock 2 km from its nest site at Cass River (L19) on 8 February. Approximately two weeks separated the sightings of several individuals between MacKenzie Basin and Australia.

Canterbury

In the post-breeding period, 143 of the 516+ banded birds were seen and of these 130 (91% of sightings) were in Canterbury, especially at Lake Ellesmere where 60 (43%) individuals were seen (Fig. 3). Many colour-banded birds were recorded at three other localities - Mayfield (L27, a key banding site; at least 39 individuals), Lake Wainono (11 individuals) and Ashley Estuary (L36; 8), but at all three localities most banded birds were of local origin.

Of 169 Canterbury birds seen in winter, 103 (60%) were in Canterbury (mainly at the four localities mentioned above), 44 (25%) in Australia, and the rest mostly scattered around the North Island (Fig. 3) and at Farewell Spit (L47).

Marlborough

Post-breeding birds were found in the Marlborough and Nelson areas (10 birds) and at scattered localities in the North Island (11 birds, Fig. 4). The earliest sightings of moved Marlborough birds were a Wairau River (L44) female seen at Whangateau Harbour (North Auckland, L83) on 23 December 1988 and an adult at Tauranga

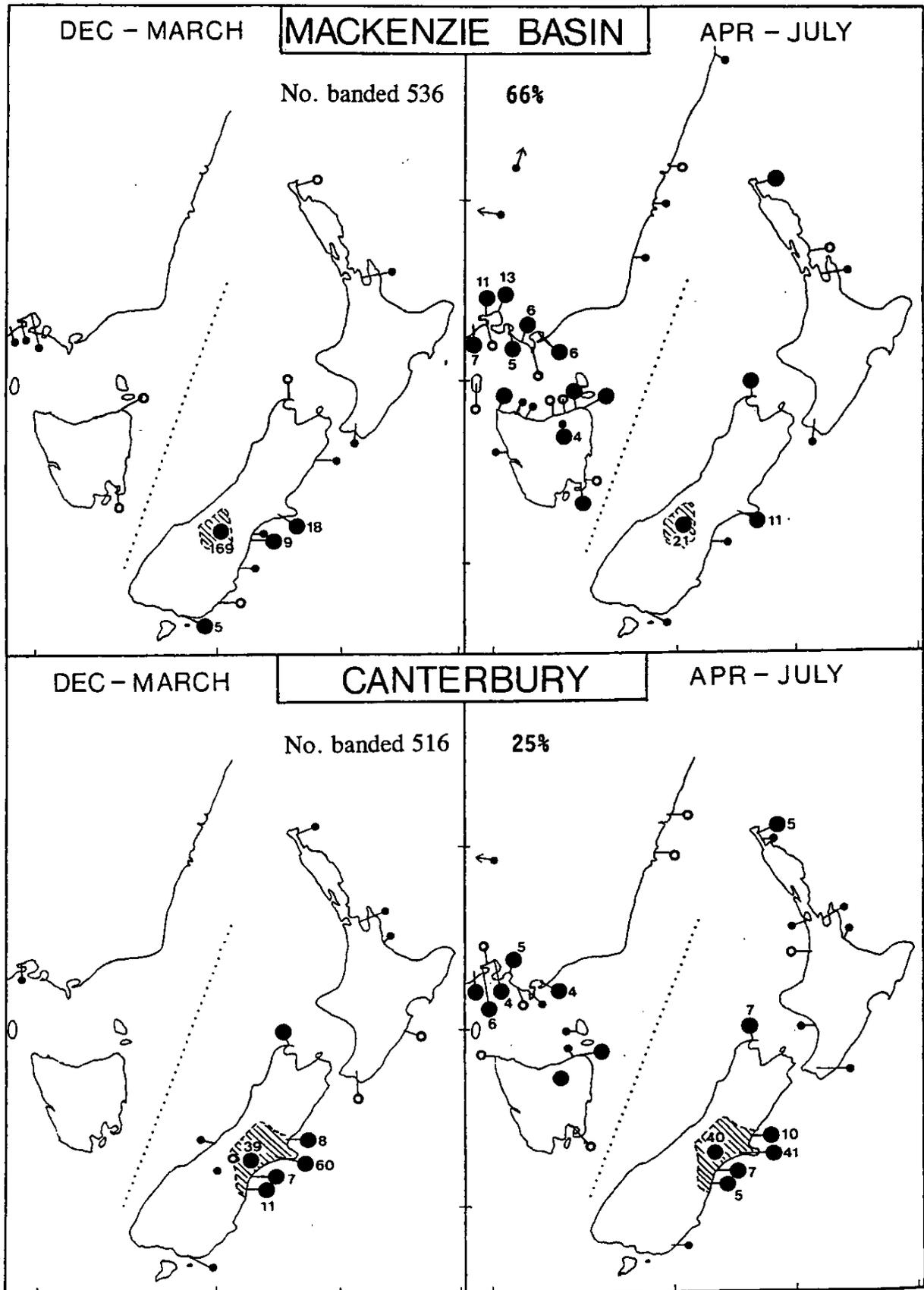


FIGURE 3 – Post-breeding (December - March) and wintering (April - July) sightings of colour-banded Banded Dotterels from MacKenzie Basin and Canterbury.

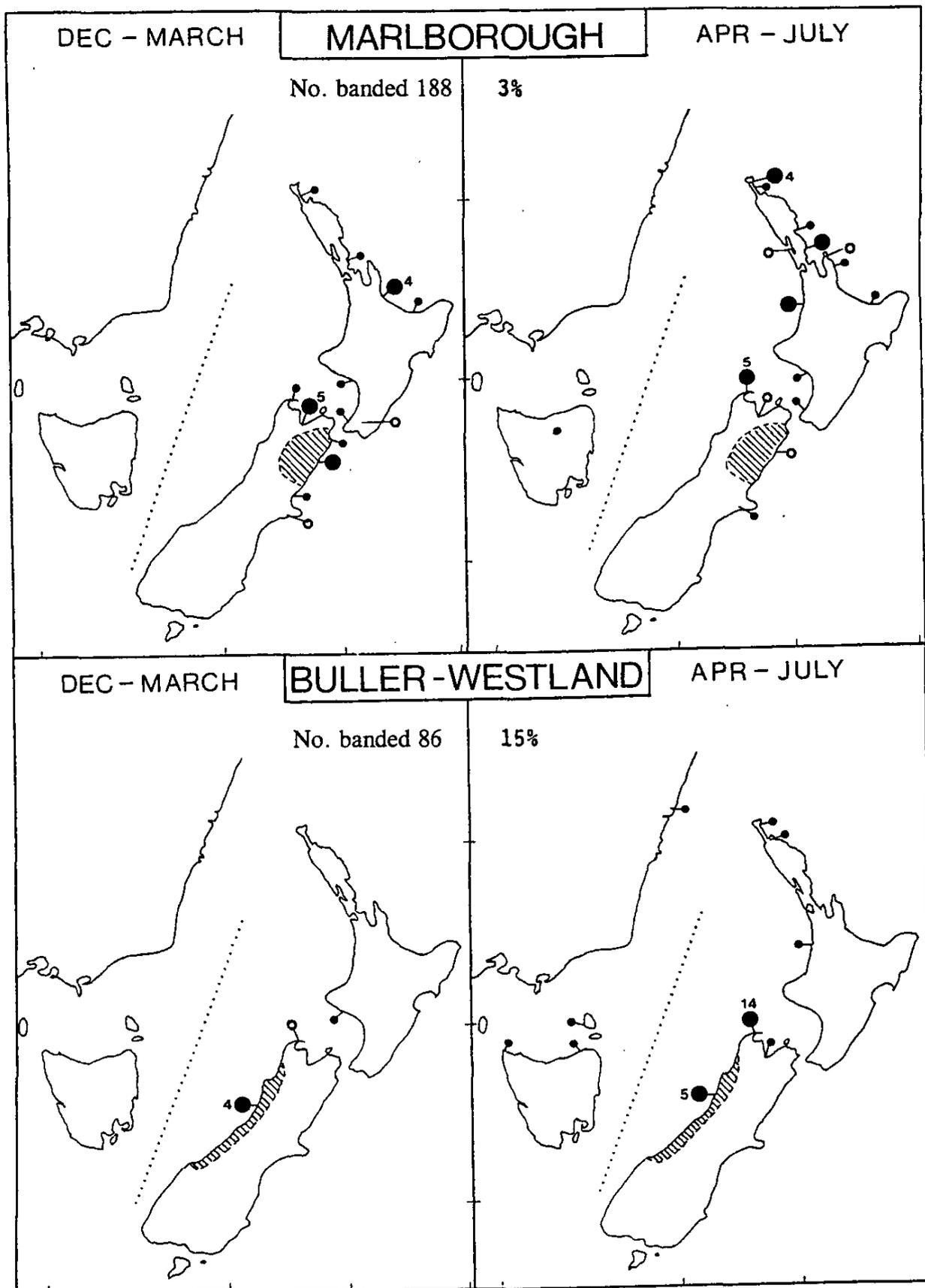


FIGURE 4 – Post-breeding (December-March) and wintering (April-July) sightings of colour-banded Banded Dotterels from Marlborough and Buller-Westland.

(L71A) on 4 January 1989. There were three instances of southward dispersal in December-March. They were Conway River (L39) to Ashley Rivermouth (90 km), Conway River to Lake Ellesmere (140 km) and upper Waiau River (L40) to Lake Ellesmere (130 km).

Of 31 wintering individuals recorded, only two were found in the Marlborough region (both coastal). Twenty (65%) were found in the North Island, especially Northland, and five at Farewell Spit. A Hurunui (L38) male was seen at Lake Ellesmere in June 1989, and a Kaikoura (L41) female was seen at Longford, Tasmania, in August 1987.

Buller-Westland

Four of the seven birds sighted in the post-breeding period were near the breeding grounds in Westland. Some movement to Farewell Spit occurred by late December and one bird was in the Far North by early February. Of 27 winter sightings, 14 (52%) were at Farewell Spit with smaller numbers in Australia and the North Island (Fig. 4).

Southern North Island

In the post-breeding period, 31 of the 142 banded birds were seen, mostly in the southern North Island, especially at Lake Wairarapa (L59) where 22 (71%) of sightings were made (Fig. 5). Short distance movements of 10-45 km took place from January onwards. Long distance dispersal started in February, and peaked in March - April. Of 58 birds seen in winter, 30 (52%) were in the southern North Island, again mostly at Lake Wairarapa. The rest were scattered widely on harbours of the northern half of the North Island. One bird was seen in Australia, a Ruamahanga River (L59) adult at Port Stephens, New South Wales, in July 1987.

Hawkes Bay

In the post-breeding period, only 17 of the 246 banded birds were found, mostly in Hawkes Bay and the Bay of Plenty (Fig. 5), long-distance shifts of over 200 km being recorded from February onwards.

Of the 49 wintering birds that were found, 44 (84%) were recorded from Bay of Plenty and Kawhia Harbour (L 77) north to Parengarenga Harbour (L86). One bird was seen in Australia, a Tutaekuri River (L66) female at Altona, Victoria, in June 1987.

Volcanic Plateau

In the post-breeding period, 20 of the 58 banded birds were found. These included birds flocking near the main breeding grounds at Lake Rerewhakaaitu (L72) and the Rangipo Desert (L73). At Lake Rerewhakaaitu, flocks contained banded birds mainly from that lake, but also from Mt Tarawera (9 km away) and the Rangipo

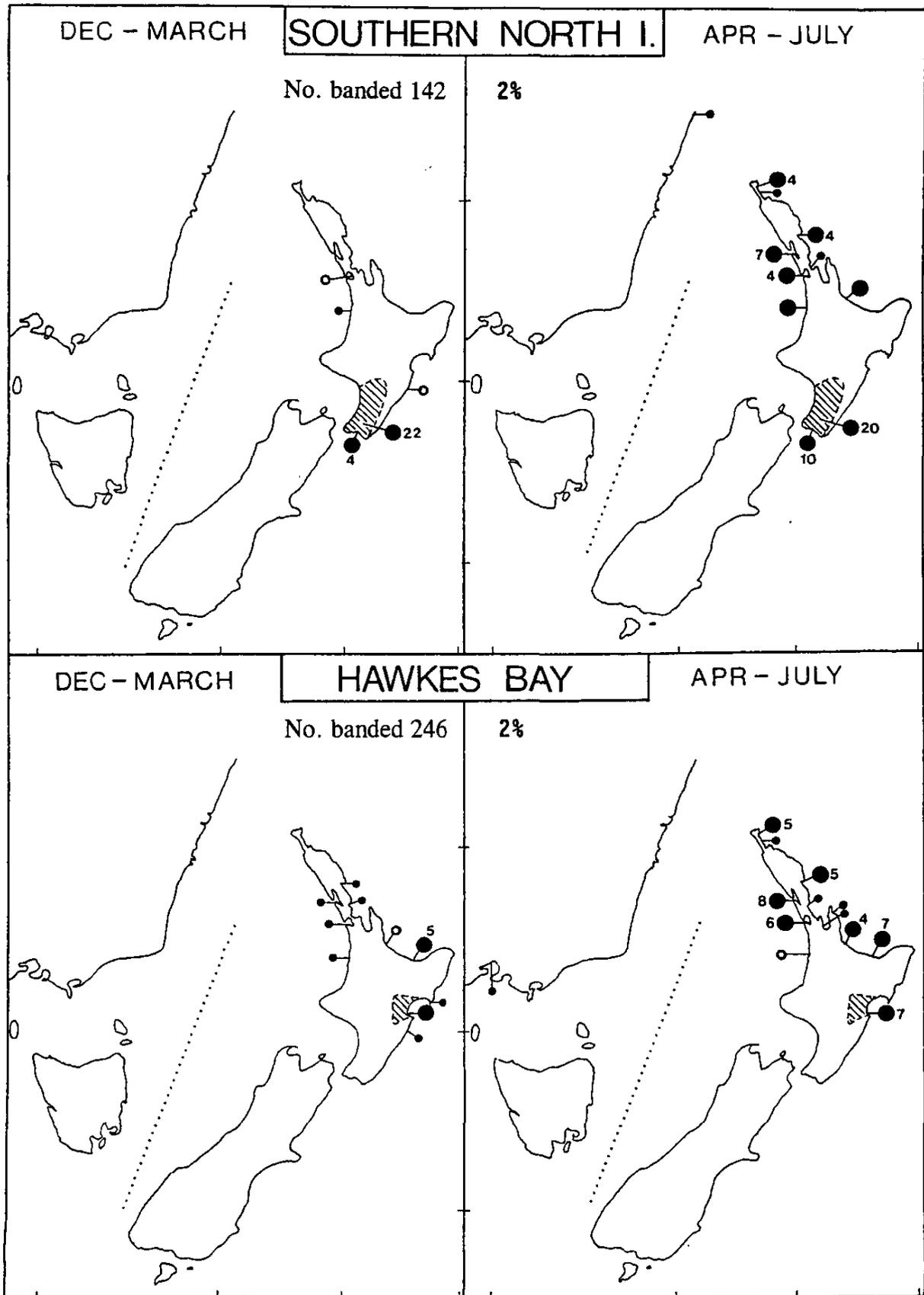


FIGURE 5 – Post-breeding (December-March) and wintering (April-July) sightings of colour-banded Banded Dotterels from Southern North Island and Hawkes Bay.

Desert (130 km). A few had also moved north to the Bay of Plenty (n=6) and harbours of the Auckland area (n=3, Fig. 6). In winter, the 18 birds found were all on the coast from the eastern Bay of Plenty north to Mangawhai (L83), and Kawhia, Manukau and Kaipara Harbours. Despite searches, none was found in the Volcanic Plateau, Far North or Australia.

Bay of Plenty

Post-breeding birds were found within the Bay of Plenty and 400 km to the north-west at Mangawhai (L 83). Wintering birds were found within the Bay of Plenty (n=4) and at Mangawhai and Coromandel Peninsula (L80), 400 and 150 km from their respective banding sites (Fig. 6).

Auckland - Northland

Of four adults banded at Whatipu (L78), three wintered at the same beach. At least six of 11 adults banded at Karikari Bay (L85) wintered on paddocks and lagoons within 7 km of Karikari Bay.

Chatham Islands

None of the four birds banded were seen, but no specific searches were made on Chatham Island in autumn and winter.

Factors modifying regional patterns of movement

Habitat

Data from Canterbury and Southland provide the best comparison of the influence of local habitat; birds breeding on inland riverbeds tended to undertake long-distance migrations, whereas those breeding at coastal lagoons and estuaries and on some lowland pasture were mainly sedentary (Table 2).

Most Southland riverbed birds wintered in Australia (74% of sightings) whereas only a few coastal birds did (13% of sightings) ($\chi^2 = 7.31$, $P < 0.01$, d.f.=1).

In Canterbury, 84% of riverbed breeders were found either in Australia or central-northern New Zealand, whereas birds breeding at coastal lagoons, lake-edges and estuaries and on pasture were mainly sedentary, only 12% being found in Australia ($\chi^2 = 24.1$, $P < 0.001$, d.f.=1).

Sighting data may be biased in favour of sightings of coastal birds wintering at their coastal localities because of better monitoring of these locations than elsewhere. To test for this bias, the banding totals from each riverbed and coastal habitat were used to calculate the ratios of birds expected to be found wintering in other regions, assuming random movements. The observed values for riverbed birds in Southland exceeded expected values ($\chi^2 = 4.3$, $P < 0.05$, d.f.=1), indicating that more birds

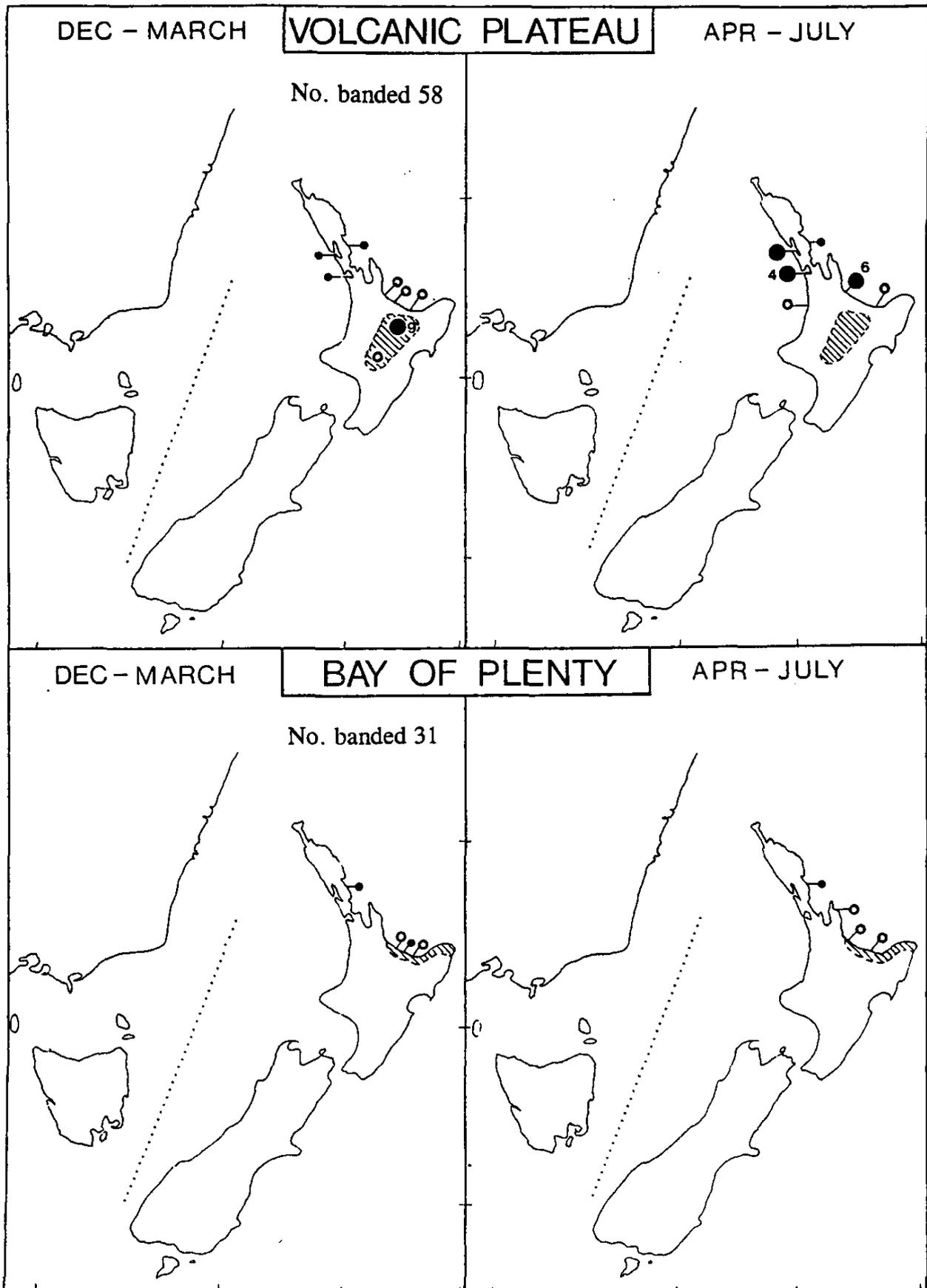


FIGURE 6 - Post-breeding (December-March) and wintering (April-July) sightings of colour-banded Banded Dotterels from Volcanic Plateau and Bay of Plenty.

TABLE 2 – Distances moved by birds from different nesting habitats

REGION	HABITAT	n	DISTANCE MOVED (km)			
			1-10	11-100	101-1100	+1600
Southland	Rivers	23	0	4	2	17 (74%) ¹
Southland	Lagoons	16	14	0	0	2 (13%)
Canterbury	Rivers	64	2	8	21	33 (52%)
Canterbury	Lagoons	19	12	0	3	4 (21%)
Canterbury	Coastal lake	23	18	2	3	0 (0%)
Canterbury	Estuary	13	8	2	1	2 (15%)
Canterbury	Pasture	50	39	4	1	6 (12%)

1. Percentages refer to proportion of observed sampled that moved to Australia.

than expected were found away from their inland breeding areas. This trend was also apparent for Canterbury riverbed birds ($\chi^2 = 3.2$, $P < 0.1$, d.f. = 1).

Age and sex-related differences

In the MacKenzie Basin, families of Banded Dotterels separate in the period from immediately before to about two weeks after young flew first (Pierce 1989). Juveniles departed from the breeding grounds earlier than adults; a Southland bird moved earliest. (c. 12 km on 29 November 1985). Useful data on juvenile movements were obtained from Southland, MacKenzie Basin and estuaries of Canterbury. From December to February most juveniles had moved over 10 km from their natal area whereas most adults were still within 10 km of their nest sites ($\chi^2 = 17.3$, $P < 0.001$, d.f. = 1) (Table 3).

No evidence of different timing of movements was found for males and females, but Lake Wairarapa provided a variation in one year: a predominance of females in January-February 1989 was replaced by a dominance of males in March, but this pattern did not repeat in 1990.

No differences in general winter destination was found amongst juveniles, adult males or adult females. For trans-Tasman movements, for example, females comprised 66% of the 1008 birds banded in southern New Zealand and 67% of the 127 birds sighted in Australia.

Birds had high wintering site fidelity, with many instances of juveniles and adults returning in later years to the same roosts which they had used previously. Of 43 individually marked birds, 41 were found at the same roost sites between years, for a total of 90 out of 93 inter-year records, representing wintering site fidelity of over 95%. Low tide feeding territories were also frequently the same between years, with the same individuals defending approximately the same intertidal space each year. At Parengarenga Harbour, for instance, four individuals were found in 2 - 3 successive years on the same general feeding area. Once recorded at a particular harbour, few cases were found in which a bird subsequently wintered at a different harbour - the longest shift recorded in New Zealand was 30 km between Parengarenga and Houhora Harbours (L86).

TABLE 3 – Post-breeding sightings of adults and juveniles December - February in relation to breeding ground proximity

REGION	Birds Banded		Distance Moved			
			0-10km		over 10km	
	n	Juvs	n	Juvs	n	Juvs
Southland	91	14(15%)	53	5(10%)	38	9(24%)
MacKenzie 1986	121	14(12%)	85	5(6%)	36	9(25%)
Canterbury Estuaries	49	5(10%)	41	2(5%)	8	3(38%)
TOTAL	251	33(13%)	180	12(7%)	82	21(26%)

Regional composition of birds at different wintering areas

Because banding effort was not constant across New Zealand, only qualitative comparisons can be made of source of birds wintering in different parts of New Zealand and Australia. Despite this limitation it is clear that the regional composition of wintering birds varied markedly.

Wintering in Australia

The pattern of sightings of birds banded on New Zealand birds was similar in each of Tasmania, Victoria and New South Wales. In each state most banded birds came from the MacKenzie Basin, Canterbury, Central Otago and Southland (Fig. 7).

Wintering in New Zealand

Lagoons in each of Southland and Canterbury held mainly local birds in winter, whereas Farewell Spit birds came mainly from Westland, Marlborough and Canterbury (Fig. 7). There was no evidence that Farewell Spit formed a staging ground for further migration as nearly all band combinations seen in December-January were seen there again in autumn or winter. Despite a March 1985 check of 1,200 birds at the spit, an ideal month to check for potential migrants *en route* to Australia, no individually colour-banded passage migrants were found.

Birds at Lake Wairarapa were mainly from the rivers and coast of the Wairarapa (L57 and L59). Harbours in the Bay of Plenty and the Auckland area north to Whangarei contained mainly birds which bred in the North Island, with birds from Hawkes Bay being the most frequently observed, followed by birds from the southern North Island and Volcanic Plateau regions. In the Bay of Plenty, many South Island (especially Marlborough) birds were observed in January-February, but few were found later (Fig. 4). In the Far North (L85/86), the general pattern for North Island harbours was broken with South Island birds predominating on the three harbours – Parengarenga, Houhora and Rangaunu. Some 59% of the 27 banded migrants found were from the South Island, contrasting with only 22% of 99 migrants found at all other North Island harbours combined ($\chi^2 = 8.2$, $P < 0.01$, d.f. = 1).

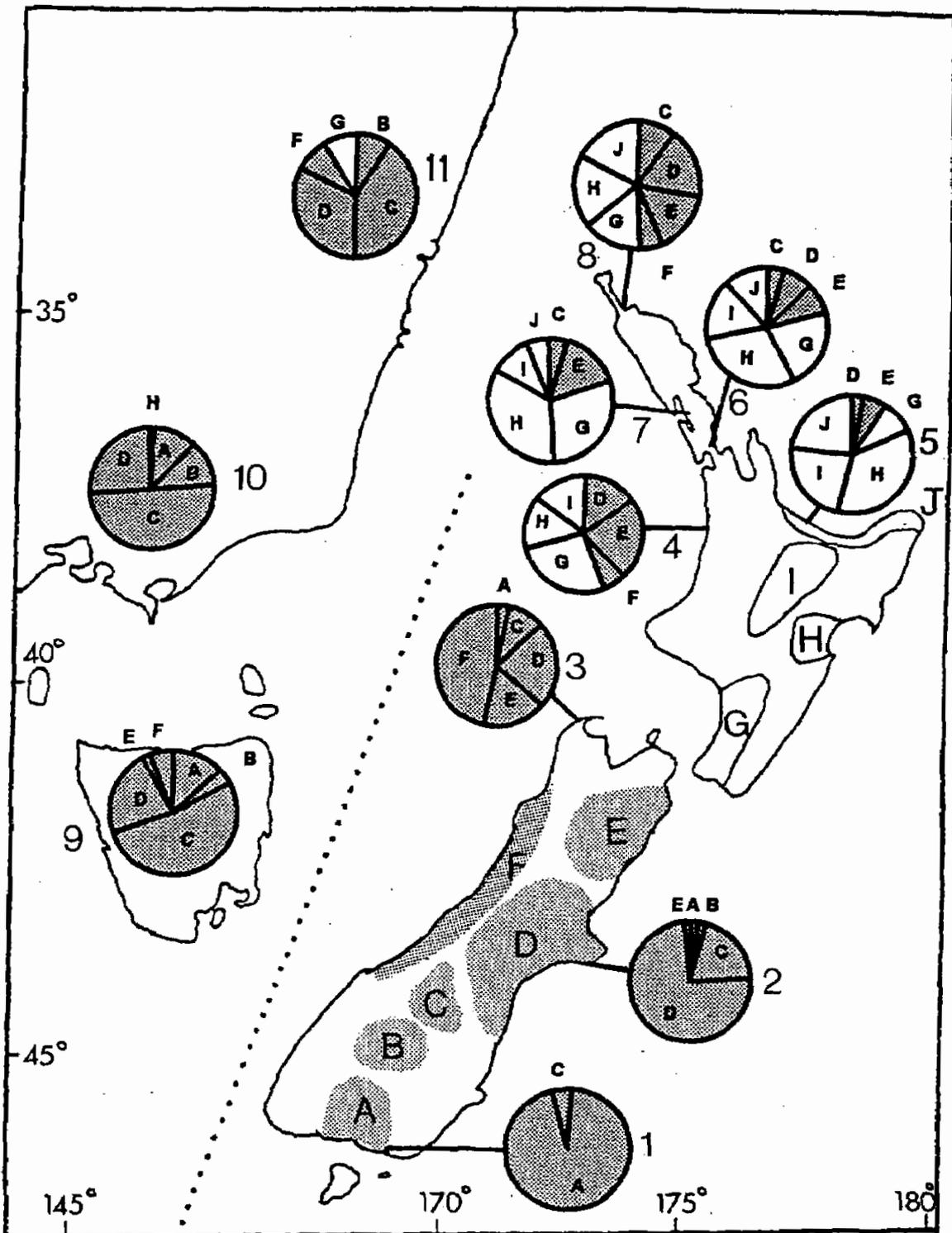


FIGURE 7 - Breeding source of banded birds found at 11 different wintering sites.

Note 1: Pie diagrams denote proportion of total banded birds sighted coming from different breeding grounds (A-G).

Note 2: The wintering sites are: 1 = Southland lagoons, 2 = Lake Ellesmere, 3 = Farewell Spit, 4 = Kawhia/Aotea, 5 = Bay of Plenty harbours, 6 = Manukau-Firth of Thames, 7 = Kaipara-Whangarei harbours, 8 = Far North harbours, 9 = Tasmania, 10 = Victoria, 11 = New South Wales

Five of seven individually colour-coded birds found at Northland and Auckland harbours in December-March were relocated there in April-July.

The return to the breeding grounds

Unlike post-breeding movements, pre-breeding shifts were directly from the wintering to breeding grounds and took place over a short period of time – mostly in August from both Australian and New Zealand wintering areas. Localities which in summer and autumn had attracted many colour-banded birds from other localities, supported only local birds during late winter. The earliest return was of a Cape Palliser (L57) male which wintered annually at Auckland Airport (L78) and which had returned the 515 km to the breeding grounds by 7 July.

DISCUSSION

Banded Dotterels exhibit a wide range of seasonal movements including sedentary behaviour, latitudinal migration and trans-Tasman migration. Birds on breeding grounds separated by short distances may display strikingly different post-breeding behaviour, e.g., coastal Southland birds are sedentary, but birds from rivers 20-50 km away generally undertake a long migration to Australia.

The northern limit to trans-Tasman migration is effectively North Canterbury, with only six birds from north of this area (three from Marlborough and one each from Buller, southern North Island and Hawkes Bay) being seen in Australia. Moreover, trans-Tasman migrants stage at areas in inland or coastal areas not far from their breeding grounds, rather than in the northern South Island or North Island.

With such a definitive pattern of migration, the immediate questions are:

1. Why do Banded Dotterels from some sites migrate whereas at other sites most birds are resident?
2. What are the functional explanations of the differential winter distribution and hence migration patterns of this species?

Although migratory behaviour is partially under genetic control in birds, environmental parameters modify that genetic control (Berthold 1984, 1995). In Banded Dotterels four key parameters influencing wintering destinations are likely to be:

1. Habitat quality - the extent and quality of food offered by potential wintering habitat, primarily extensive intertidal flats and coastal lagoons and pasture.
2. Cost of living - essentially the climate of a potential wintering area and how this can affect energetics, e.g., Piersma (1994).
3. Prior occupancy - whether local Banded Dotterels or other potential competitors are already present and occupying the prime habitat.
4. Distance from breeding grounds to potential wintering sites and the associated energy costs and risks (Barter & Minton 1987, Piersma 1994).

Each one of these parameters can be regarded as having an associated hypothesis to explain the observed distribution pattern of Banded Dotterels. Thus “birds will winter in an area if”:

1. The habitat quality and food availability is high; and/or
2. the climate is warm; and/or
3. there are few, if any, prior occupants; and/or
4. the migration distance is minimal.

Table 4 summarises these parameters for each potential wintering area in relation to each of the breeding regions. The parameters are qualified in terms of lower, similar or higher values than those at the breeding grounds during the non-breeding season. Preferred wintering options by Banded Dotterels are also indicated for each breeding region.

Birds breeding in coastal areas of Southland and Canterbury have locally available habitat of a moderate-high quality, they have a moderate cost of living (mean winter temperatures of 5-10°C) and few prior occupants to contend with. Not surprisingly, most of these birds are sedentary, with few undertaking an energy-demanding migration.

Birds breeding in inland areas of Southland, Central Otago, MacKenzie Basin and Canterbury have additional problems. Few of these regions currently have high quality winter feeding habitat and these are generally small e.g., on the deltas fringing lakes where there are concentrations of mudflat food (Child 1967, Pierce 1983). Some areas have snow cover for a month or more of the year, and for the majority of inland breeders migration is obligatory. However, some birds do winter inland regularly, indicating that mean daily winter temperatures of 3-4°C (or lower in some years) – at Lake Tekapo for example – are not prohibitive of local wintering; Black Stilts (*Himantopus novaezelandiae*) also overwinter (Pierce 1983).

Inland-breeding birds are faced with the need to migrate, but where to? Coastal sites in the southern and eastern South Island have moderate to high quality habitat, but these are limited in size (no large harbours), often have fluctuating water levels (and hence food supply), and in winter the prime areas are already occupied by local residents. Prior occupation is also a feature of the higher quality habitats to the north, e.g., Farewell Spit and many North Island harbours, which are occupied by nearby northern and lowland-breeding birds which have finished nesting earlier than the birds of the inland South Island.

The selected option of coastal south-eastern Australia provides some advantages for high-country Banded Dotterels including slightly higher mean winter temperatures (12-14°C, Australian Bureau of Meteorology) than those of the southern North Island. Additional advantages are the extensive intertidal habitats in Victoria and Tasmania, plus the lack of prior occupancy by other Banded Dotterels. The timing of arrival of Banded Dotterels in south-eastern Australia (March-April) also coincides with the exodus of many northern hemisphere wader species. The main disadvantage is the long migration for which the completion of a full moult of

TABLE 4 Parameters of potential wintering areas in comparison to parameters of breeding grounds in winter

BREEDING GROUND	PARAMETER	WINTERING AREA						
		Coastal South Island	Inland South Island	North & West South Island	South North Island	Volcanic Plateau	North North Island	South-East Australia
Coastal Southland and Canterbury (A5-6, D22, D26-28, D32-36) ¹	Habitat quality ²	Moderate/High	Lower	Similar/Higher	Similar	Lower	Higher	Higher
	Cost of living ³	Moderate	Higher	Lower	Lower	Higher	Lower	Lower
	Prior occupancy ⁴	Moderate	Lower	Higher	Higher	Lower	Similar	Lower
	Distance (km) ⁵	0-50 ◆	100-300	400-600■	500-1000	700-1200	1000-1500■	1700+■
Inland South Island (A2-4, B,C, D23-25, D30,D37)	Habitat quality	Higher	Low	Higher	Higher	Similar	Higher	Higher
	Cost of living	Lower	High	Lower	Lower	Lower	Lower	Lower
	Prior occupancy	Higher	Moderate	Higher	Higher	Similar	Lower	Lower
	Distance (km)	100-300	0	400-500■	500-800	800-1000	1100-1300■	1600+◆
North and West South Island (E,F)	Habitat quality	Lower	Lower	Moderate/High	Lower	Lower	Higher/Similar	Higher
	Cost of living	Higher	Higher	Moderate	Similar	Higher	Lower	Similar
	Prior occupancy	Higher	Higher	Moderate	Higher	Similar	Lower	Lower
	Distance (km)	400-600	400-500	0-300 ◆	200	400	700	1600+
South North Island (G,H)	Habitat quality	Lower	Lower	Higher	Moderate	Lower	Higher	Higher
	Cost of living	Higher	Higher	Similar	Moderate	Higher	Lower	Similar
	Prior occupancy	Higher	Similar	Similar	Moderate	Similar	Lower	Lower
	Distance (km)	500-1000	500-800	200	0-100 ◆	200	500◆	2000+
Volcanic Plateau (I)	Habitat quality	Higher	Similar	Higher	Higher	Low	Higher	Higher
	Cost of living	Lower	Higher	Lower	Lower	High	Lower	Lower
	Prior occupancy	Higher	Similar	Higher	Higher	Moderate	Similar	Lower
	Distance (km)	700-1200	800-1000	400	200	0	100-300◆	2000+
North North Island (J)	Habitat quality	Lower	Lower	Lower	Lower	Lower	High	Similar
	Cost of living	Higher	Higher	Higher	Higher	Higher	Low	Similar
	Prior occupancy	Higher	Similar	Higher	Higher	Similar	Low	Similar
	Distance (km)	1000-1500	1100-1300	700	500	100-300	0◆	2000+

- Notes:**
1. Refer to Table 1 and Fig. 1 for specific regions and localities.
 2. Extent of suitable feeding habitat, especially intertidal flats, in relation to that at breeding grounds.
 3. Inversely related to average winter temperatures at potential wintering sites relative to that at breeding grounds.
 4. Degree of prior occupancy by dotterels in potential wintering areas compared with that at breeding grounds.
 5. Average distances from main breeding sites to main wintering areas.
- ◆ preferred wintering area.
■ Secondary wintering area.
Highlighted = stay at home option

flight feathers and gaining of sufficient fat and protein reserves for the flight are a pre-requisite (Barter & Minton 1987).

Birds from breeding sites in Marlborough, Westland and the North Island exhibit short- to medium-distance movements to wintering sites generally in a northerly direction. That few of these birds opt for a trans-Tasman destination probably reflects some combination of high quality habitat nearby (extensive intertidal flats, c.f. eastern South Island), low cost of living (mean July temperatures of 8-12°C in central and northern New Zealand), low population densities (few residents at central and northern harbours) and shorter distance migration and hence lower energetic costs.

The pattern of migration, particularly trans-Tasman migration, lends greatest support to the hypotheses that habitat quality and prior occupancy are, or have been, key factors in Banded Dotterel migration. Thus, birds tend to winter at high quality (intertidal) habitat provided the area is not heavily occupied by other Banded Dotterels. The trans-Tasman migration indicates the lengths that Banded Dotterels are prepared to travel to use high quality unoccupied habitat.

The collection in the Far North (L 85/86) of many South Island breeders is curious. Few, if any, are trans-Tasman birds blown off course because several of these north-bound transitory birds were sighted in Taranaki and Bay of Plenty. Also, these birds began arriving in the North Island from late December onwards, whereas the trans-Tasman migration from the South Island is in late February-April. It seems more likely that these Far North birds initially wander north as juveniles during late summer-autumn (Pierce 1989). It is not clear whether they move well north (c. 1000 km) because of genetic influences, or whether they are forced to the northernmost harbours to find feeding space; the latter has been reported for juvenile Grey Plovers (*Pluvialis squatarola*) in Europe (Townsend 1985). The late but regular arrival of Volcanic Plateau Banded Dotterels at Bay of Plenty and Auckland harbours, however, is inconsistent with a sole explanation of limited feeding space and competition.

It is likely that the trans-Tasman migration of Banded Dotterels was more prevalent during the severe climates of the Ice Ages, when suitable winter habitat would have been more restricted in New Zealand, than in Australia. Recent work on bird migration (Berthold 1998, Pulido & Berthold 1998) indicates that migration direction and destination of Blackcaps (*Sylvia atricapilla*) and other species can change over a few decades as a result of climatic warming. With milder winters and changing habitat quality at many New Zealand wintering sites, it is possible that Banded Dotterels could alter patterns of over-wintering in New Zealand, as birds "experiment" with new wintering grounds. In Banded Dotterels, such experimentation is likely to occur through juveniles which are first to leave the breeding grounds and disperse farthest earliest, even though a parent may be a local resident (Pierce 1989).

Further work to test for long-term changes in Banded Dotterel migration could involve a dual approach: firstly a comparison of historical with current winter census

data, and secondly a repeat of parts of this banding study. The census data likely to be the most useful are those of discrete inland South Island populations, e.g., repeats of 1970s and 1980s counts of Central Otago and MacKenzie Basin sites. Similarly, a repeat banding study of e.g., Central Otago, MacKenzie Basin and Canterbury birds, would enable a comparison with the late 1980s data of the proportions of birds that winter in Australia, northern New Zealand, locally and elsewhere in the South Island.

ACKNOWLEDGEMENTS

A large team of people contributed to this study. People who had their spring and summer weekends consumed by "dotterel banding" included Maida Barlow (Southland), Margaret and Peter Child (Central Otago), Jack Cowie (North Canterbury), Donald Geddes (Mid Canterbury), Jenny Hawkins (Nelson), Barrie Heather (Southern North Island), Peter Howden (Mid Canterbury), Ken Hughey (Canterbury), John Innes (Volcanic Plateau), Richard Maloney (many South Island regions), Derek Onley (Westland), Ray Pierce (most New Zealand regions), Gail Quayle (Nelson), Hugh Robertson (Hawkes Bay, Southern North Island), Paul Sagar (Canterbury), Dave Sim (Southern North Island), Margaret and Wayne Tywdle (Hawkes Bay). The contribution of the late Peter Child to this project was outstanding with many isolated mountain ranges and river valleys in Central Otago being systematically covered. Many other people helped the banding programme in various ways.

Most sightings in New Zealand were provided by the people mentioned above plus Pam Agnew, Peter Anderson, Brian Chudleigh and Graeme Taylor. Most sightings in Australia were provided by VWSG members (particularly Mark Barter, Peter Dann, Brett Lane, Clive Minton and Bob Swindley), and by Ralph Cooper, Alan Fletcher, Priscilla Park (all Tasmania), Joy Pegler (New South Wales) and myself (Tasmania, Victoria). Clive Minton collated Australian sightings before passing them on to OSNZ.

Many people and organisations helped with land and water transport, particularly Ralph Cooper (Tasmania), Department of Conservation staff (New Zealand), Vic Hensley (Northland), Clive Minton (Victoria), Priscilla Park (Tasmania), Betty Seddon (Waikato). Support was provided by the New Zealand and Australian Banding Offices throughout this study and the Ornithological Society of New Zealand provided annual financial support via the Projects Assistance Fund including payment for a visit to search for birds in Australia. My sincere thanks go to all the above people and organisations for their generous provision of time and resources.

Finally, I thank K. Hughey, R. Maloney, T. Piersma, H. Robertson and G. Taylor for constructive comments on this manuscript and E. Conn, B. Lyford, J. Roberts and L. Wells for assistance with typing and graphics.

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