

At-sea distribution of Gibson's and Antipodean wandering albatrosses, and relationships with longline fisheries

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Abstract Satellite telemetry was used between 1994 and 2004 to identify the distribution of 2 closely-related species of wandering albatross, Gibson's (*Diomedea gibsoni*) and Antipodean (*D. antipodensis*), which breed in the New Zealand subantarctic. Trials of methods of attaching transmitters revealed that harnessed transmitters decreased foraging efficiency and increased mortality, whereas transmitters glued or taped on birds had little effect. There was some overlap in the species foraging ranges, but *D. gibsoni* mostly foraged in the Tasman Sea and *D. antipodensis* in the Pacific Ocean east of New Zealand. For both species the range of non-breeding birds was larger than that of breeders, but the core areas used by both breeders and non-breeders were similar. Non-breeding male *D. antipodensis* had the largest range, foraging off the coast of Chile, Antarctica and in the tropical South Pacific. In comparison, the range of *D. gibsoni* was small, with non-breeding male and female birds foraging westward to the south-eastern Indian Ocean but avoiding Antarctic waters. Individuals of both species and all stages of maturity had preferred but large foraging areas which lasted many years. Some seasonal trends in distribution were found. Both species preferred to forage at the outer edge of shelves and over seamounts, particularly where there were strong currents or eddies and productivity was enhanced, as well as over deep water. Over the past 40 years, longline fisheries used a minimum 89% and 53% of the range over which our study tracked *D. gibsoni* and *D. antipodensis* respectively. Of 18 *D. gibsoni* and 35 *D. antipodensis* banded birds recovered dead since 1971, 22% and 83% respectively were related to fisheries. The areas where closures of fisheries would be most likely to reduce bycatch are identified.

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INTRODUCTION

New Zealand, a relatively small landmass surrounded by a great deal of ocean, has a large and diverse seabird fauna, including 2 endemic species of wandering albatross, Gibson's wandering albatross (*Diomedea gibsoni*) and Antipodean wandering albatross (*D. antipodensis*) (Fig. 1). These 2 species are closely related, with recent genetic work suggesting they should be regarded as a single species (Berg & Croxall 2004). *D. gibsoni* breeds in the Auckland Is, whereas *D. antipodensis* breeds mostly on Antipodes I (Fig. 2). Both island groups are uninhabited and rarely visited. Over the past few decades, both species have been a regular and sometimes substantial bycatch of longline fisheries (Murray *et al.* 1993; Robertson *et al.* 2004) and this has drawn attention to their vulnerable and threatened conservation status (Croxall & Gales 1998; Hitchmough 2002).

Wandering albatrosses regularly follow boats (Croxall & Prince 1994) and are opportunistic scavengers (Nel *et al.* 2002). In some trawl fisheries,

albatrosses occasionally collide with cables when feeding on discarded offal (Bartle 1991), though the number killed in trawl warps may be underestimated because birds may be pulled underwater out of sight (Baird 2001). Albatrosses are also attracted to squid and fish baits used on long lines set from both demersal and pelagic fishing boats, and some are hooked and drowned in such fisheries (Alexander *et al.* 1997). There have been significant trawl and longline fisheries in the seas around New Zealand since the 1960s (Murray *et al.* 1993), but it was not until the early 1990s that the development of satellite transmitters allowed the at-sea distribution of albatrosses and their spatial overlap with important fisheries to be mapped.

Since 1990 there have been many satellite tracking studies of the oceanic distribution of albatrosses. However, most studies have followed the movements of breeding birds only; these return regularly to land to incubate eggs or feed chicks. Few juvenile and non-breeding wandering albatrosses have been tracked by satellite because of the difficulty of keeping transmitters attached for long

Table 1 The extent of satellite tracking of *Diomedea gibsoni* and *D. antipodensis* during different life-history stages, 1994 to 2004.

Taxon	Sex	Life-history stage	No. of birds	No. of breeding seasons	Total days locations received	Satellite uplinks
<i>D. gibsoni</i> (n=46)	♂♂ (n=23)	Post-breeding/ failed-breeder	13	5	656	3315
		Courting	5	2	159	1007
		Incubating	15	3	146	2261
		Hatch/guard	5	2	59	253
		Chick-rearing	4	2	208	741
	♀♀ (n=23)	Post-breeding/ failed-breeder	9	4	773	3010
		Courting	3	2	82	366
		Incubating	16	4	167	1516
		Hatch/guard	4	3	61	292
		Chick-rearing	4	2	163	633
<i>D. antipodensis</i> (n=65)	♂♂ (n=32)	Post-breeding/ failed-breeder	11	5	604	2961
		Courting	3	1	72	569
		Incubating	21	5	217	1266
		Hatch/guard	10	3	132	694
		Chick-rearing	7	3	294	1758
	♀♀ (n=33)	Fledgling	2	1	342	1439
		Post-breeding/ failed-breeder	10	4	375	1610
		Courting	3	1	57	246
		Incubating	24	5	281	2246
		Hatch/guard	12	4	106	602
		Chick-rearing	6	2	281	1044
		Fledgling	1	1	224	592

periods of time. More than half of any wandering albatross population is not breeding at any one time, so mapping the at-sea distribution of these birds and relating it to the distribution of various fisheries has long been recognized as a priority (Prince *et al.* 1998; Weimerskirch 1998).

This paper presents the results of a satellite-tracking study which aimed to determine the location and characteristics of the oceanic areas most important to *D. gibsoni* and *D. antipodensis* at all stages of their lives. A secondary aim was to assess the risk of incidental capture in fisheries by comparing longline fishing effort and albatross distribution. Direct links between the trajectories of albatross populations and the effects of fisheries are difficult to establish without comprehensive coverage by fisheries observers which is lacking in most parts of the Southern Ocean. As a substitute, recoveries of banded individuals were examined for cause of death.

The New Zealand subantarctic islands are visited so briefly and infrequently that some form of long-term transmitter attachment had to be devised. Hence much time was spent developing a method of long-term transmitter attachment which would not harm the birds. Harnessed back-packs which self-released when the transmitter's batteries were expended were developed and tested, and their effects were compared with those of glue and tape attachments.

Table 2 Error of satellite locations (km) of birds at known locations. Class, location class.

Class	Mean error	SD	Range	n
3	0.90	0.82	0.20-4.82	46
2	0.73	0.55	0.05-2.77	80
1	1.09	1.20	0.06-13.72	212
0	3.86	5.14	0.08-39.31	150
A	2.34	2.88	0.08-15.78	117
B	18.30	48.11	0.09-343.73	114
Z	89.33	87.92	1.69-235.24	5

METHODS

Satellite telemetry

Between 1994 and 2004 we attached satellite transmitters that used the Argos® system to 46 adult *D. gibsoni* (23 ♂♂; 23 ♀♀) and 62 adult and 3 juvenile *D. antipodensis* (32 ♂♂; 33 ♀♀) (Table 1). Birds were tracked at most stages of breeding and during their "sabbatical" years; many individuals followed for short periods during incubation, and fewer individuals followed for longer periods after fledging, when courting, during chick-rearing, failed-breeding, and sabbatical periods. The distribution of tracking effort varied between seasons and years (Fig. 3). Ten individual *D. gibsoni* and 3 *D. antipodensis* were followed while breeding, and then later in the same season after their nest had failed. One female *D. gibsoni* followed as a breeder and a male followed immediately after successfully breeding were both



Fig. 1 (A-G) (A) Adult *D. antipodensis* female (left) and male (right); (B) Adult *D. gibsoni* male (left) and female (right); (C) *D. gibsoni*; (D) Transmitter being taped to adult female *D. gibsoni*; (E) Pico transmitter with a single side battery, showing 1 tape "sandwich" of feathers above and 2 below, plus feathers taped directly to transmitter; (F) The same transmitter, once feathers are smoothed back in place; (G) The harness package used 1997-2000 - a Pico transmitter with a battery on either side and timed-release mechanism at the front, a soft cord extension and bungy-cord harness.

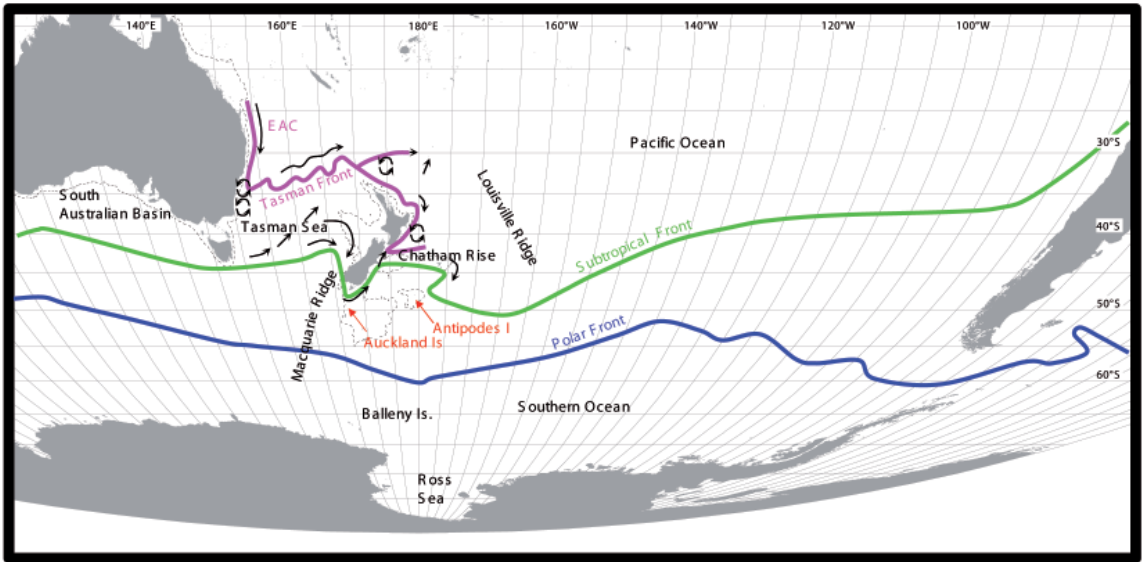


Fig. 2 Location of Auckland and Antipodes Is, and major frontal features affecting marine productivity in the seas used by *Diomedea gibsoni* and *D. antipodensis*. Arrows, major currents; circling arrows, semi-permanent eddies. Position of 1000 m isobath around New Zealand and Australia indicated.

widowed a few years later and tracked subsequently as non-breeders. Three male *D. gibsoni* were tracked while breeding during 2 breeding seasons. In total, 34 breeding and 22 non-breeding *D. gibsoni*, and 45 breeding and 20 non-breeding adults and 3 juvenile *D. antipodensis* were tracked. Almost all *D. gibsoni* used in the tracking study came from a study colony just west of Amherst Stream on the southern slopes of Adams I (Walker & Elliott 1999), and all *D. antipodensis* from a study colony on the north-eastern plains on Antipodes I (Walker & Elliott 2005).

In 1994–97, we used ST10 transmitters, manufactured by Telonics®, each weighing about 140 g with attachment cords, and 2 Nano® transmitters with an external Lithium AA battery (total 40 g) and 3 PTT100s (140 g), both manufactured by Microwave Telemetry Inc. During this period most transmitters transmitted continuously and lasted only 1 month before the batteries required replacing. However, for most of the study period (1998–2005) we used Pico® transmitters manufactured by Microwave Telemetry, which had a duty cycle of 6.5 h on and 24.5 h off to conserve battery life. Between 1998 and 2000 the transmitters were packaged with a Lithium AA battery on each side of the transmitter, a quick-release mechanism and a harness (Fig. 1(g)) and weighed c. 108 g. Between 2001 and 2004 the Pico® transmitters were packaged with a Lithium AA battery on 1 side, had no release mechanism or harness, and weighed only 42 g. Even the heaviest (140 g) transmitter package used was only 2.4% of the lowest weight recorded for a female, and so was unlikely to affect flight performance. However, the

weight of taped and glued transmitters was still important, because heavier packages were more likely to break the feathers supporting the transmitters and lead to early transmitter loss.

Transmitter attachment trials

Glue or adhesive tape was used to attach transmitters to the back feathers in the early years of the study, harnesses during the middle years and a more complex taping system in the final years. Transmitters were glued to the backs of 3 *D. gibsoni* in 1994, 16 *D. gibsoni* in 1995, and 1 *D. antipodensis* in 1996. One *D. antipodensis* in 1996 and 8 in 1997 had transmitters attached by cloth adhesive (Tesa®) tape. Birds were held for less than 5 min during attachment using either glue or simple adhesive tape. Harnesses were used to attach transmitters for short periods to 14 *D. antipodensis* in 1996, 3 in 1997, 10 in 1998 and to 10 birds of both species in 1999. Harnesses were used to attach transmitters for longer periods to 8 birds of both species in 2000. It took < 10 min to attach the standardized harnesses used in 1995–96, and 20 min to attach the individually-fitted harnesses used in 1997–2000. In 2001–04, the transmitters of 13 *D. gibsoni* and 9 *D. antipodensis* were attached by a more sophisticated version of adhesive taping (Fig. 1(d–f)), as described to us by D. Anderson (pers. comm.), but designed by Fernández (1999). Our variation of this method required the birds being held for 30–40 min.

In 1995–96 harnesses were made from soft cord and in 1997–2000 from narrow elastic rubber “bungy” cord. They consisted of 1 loop around the bird’s neck and another around the belly just behind the wings, with the 2 loops joined at the belly and at

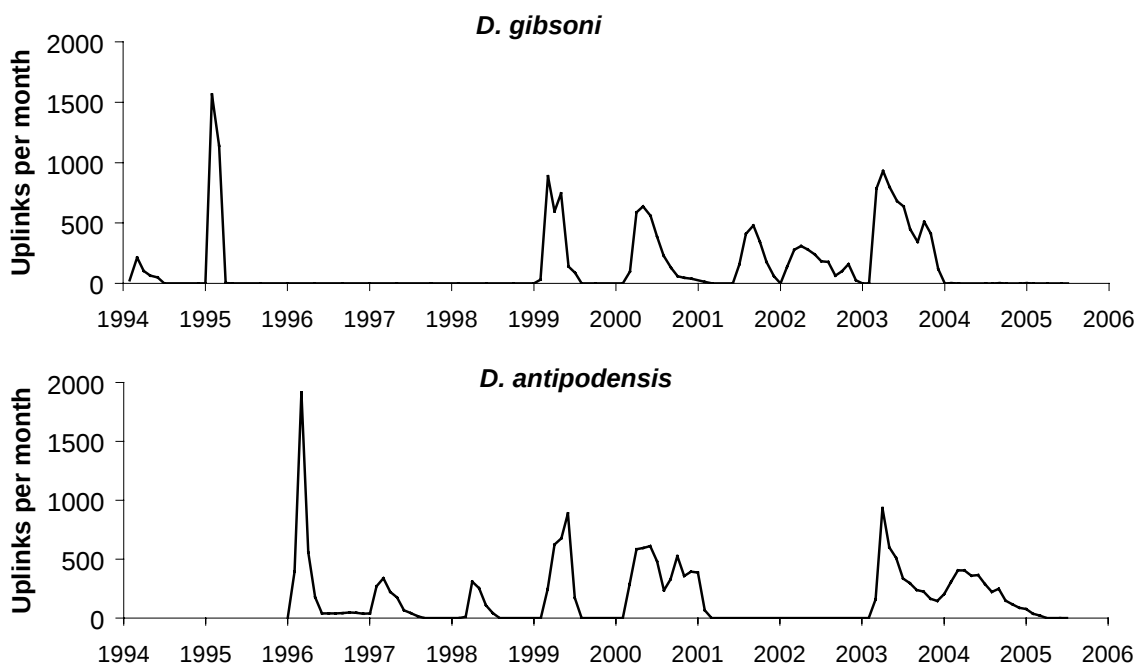


Fig. 3 Within and between-year distribution of satellite tracking effort (measured as number of uplinks) for *Diomedea gibsoni* and *D. antipodensis* between 1994 and 2005.

the transmitter (Fig. 1(g)). To ensure that the transmitter sat as low on the bird's back as possible, a 150 mm-long soft cord with a rubber tube insert extended from the front of the transmitter, before connecting with the neck loop. The length of the harness cord was adjusted as the transmitters were being attached, to allow an optimal fit for each bird. From 1997 all harnessed transmitters included a mechanism that released the harness and transmitter from the bird at a pre-set time, if the equipment had not already been removed. The mechanism comprised a timer and a small detonator which released all 4 cords simultaneously. It was tested on domestic geese (*Anser* sp.), then on 5 *D. antipodensis* chicks ready to fledge, and finally on 13 adult *D. antipodensis* foraging during early incubation and was found to be effective, with no sign that the birds were stressed when the detonator fired.

The bird's responses to the transmitter load and attachments were compared by measuring flight durations and weight gains of birds with transmitters that were attached by harness, or were glued or taped on, and those without transmitters. Most trials were done using *D. antipodensis* during the 1996–98 breeding seasons, but some *D. gibsoni* were monitored in 1995 and 2000. During the trials, the duration of foraging trips during early incubation was recorded by daily visits to marked nests to record the departure and return dates of birds with

and without transmitters. To measure the average changes in weight of birds without transmitters during early incubation, a sample of 11 incubating *D. antipodensis* were weighed every 2nd day that they were on the nest between mid Jan and Mar in 1996; a further 25 birds were weighed regularly in 1997, and 21 in 1998. Over the same period, a much smaller number of birds wearing transmitters or dummy transmitters were weighed when the transmitters were attached, which generally was just before their departure to sea after being relieved at the nest by their partner. For those birds that continued to incubate after the transmitter had been attached and the bird weighed, or which returned from foraging and incubated for a day before being re-weighed, the presumed weight on departure or return was estimated by application of the standard daily weight loss of the large sample of incubating birds without transmitters.

Flight durations and weight gains between birds with transmitters attached by the 3 methods and birds without transmitters were compared by 2-way analysis of variance to remove the confounding effect of the year and species. For this analysis, glued and taped-on transmitters were pooled, because of their small sample sizes and the similarity of the 2 methods.

An incubating male *D. gibsoni* tracked wearing a glued-on transmitter in 1995, was tracked again using a harnessed transmitter during the incubation

period in 1999. Two male incubating *D. gibsoni* were tracked in 1995 wearing glued-on transmitters, then again during chick rearing in 2001 wearing taped-on transmitters. Likewise an incubating female *D. gibsoni* tracked in 1994 with a glued-on transmitter was followed again as a widowed non-breeder with a taped-on transmitter in 2002, and a post-breeding male *D. gibsoni* tracked in 1994 with a glued-on transmitter was followed again with a taped-on transmitter as a widowed non-breeder in 2003. Although the main aim was to investigate changes in preferred destination of individuals, these re-deployments also helped in the assessment of the effect of different methods of attachment.

Analysis of tracking data

On the basis of transmitter signal strength, the Argos® system assigns each location to 1 of 7 classes (from most to least accurate: 3; 2; 1; 0; A; B; Z). To examine the accuracy of locations received in each of the accuracy classes, we compared 724 locations received from birds sitting on their nests with the actual location of the nests, as measured by GPS (Table 2).

Class Z locations were so erroneous and so rare in our data that we excluded them from subsequent analysis. To further eliminate the few unacceptably erroneous fixes from amongst the remaining Argos® locations, we excluded those that implied unrealistically high flying speeds. The maximum speed predicted and recorded for wandering albatrosses by Pennycuik (1982) and Jouventin & Weimerskirch (1990) was 80 kmh⁻¹, but even small errors in successive Argos® fixes recorded only a few min apart can lead to flight speed estimates of more than 80 kmh⁻¹. We therefore excluded fixes which implied that birds flew at more than 80 kmh⁻¹ only when they appeared to have flown more than 100 km, because errors of < 100 km would have little effect on our interpretation of the bird's movements given the large distances they fly.

Bathymetry data was obtained from the GEBCO Digital Atlas (IOC *et al.* 1994), and the depth of ocean below each satellite uplink was taken to be the depth of the nearest 500 m bathymetric contour. To determine whether albatross foraging patterns represented selective or random use of the oceans with respect to depth, the observed depth distribution of albatross satellite uplinks for both species was compared with the distribution of depths within their ranges. The bird's ranges were approximately defined by drawing a polygon around the periphery of the distribution of satellite uplinks for each species.

As a measure of the distance from breeding islands at which breeding birds of both species foraged, the maximum distance from its breeding island was calculated for each bird during each of its flights during the incubation period.

The ranges of subsets of the birds we tracked were characterised using the area of sea (land was excluded) contained within the 95% contours of kernel density distribution maps. Because the smoothing parameter (*h*) can affect area estimation by kernel analysis greatly (Nicholls *et al.* 2004), we used the same value of *h* (0.14) for all the areas we estimated. Kernel density distribution maps were derived using the Home Range Extension for ArcView Version 3.2a.

Fishing interactions

Data on the distribution of longline fishing effort in the Australasian and South Pacific region of the Southern Ocean over the period of the study was provided by Dr Geoff Tuck (CSIRO, Hobart, Australia) from sources described by Tuck *et al.* (2003). Effort data were not collated for the areas north of 30°S, but only 0.1% of *D. gibsoni* and 0.5% of *D. antipodensis* uplinks were from that area. No information was available from illegal, unreported, and unregulated fishing vessels. *D. gibsoni* and *D. antipodensis* have been a regular and substantial reported bycatch only of pelagic longline fisheries (Murray *et al.* 1993; Klaer & Polacheck 1997; Gales 1998; Baird 2001a, 2001b; Robertson *et al.* 2004), so only effort from pelagic longline fleets was mapped.

Fishing effort was reported on a coarse longitude/latitude grid (5° squares). Fishing effort data from 1990-98 was overlaid with the more finely-detailed albatross distribution maps. To identify areas with the highest potential for interaction between birds and fishers (i.e. where there were either many birds and some fishers, a few birds and many fishers, or many of both) a potential interaction-index was calculated by multiplying the average number of hooks in each 5° square by the proportion of total uplinks from either *D. gibsoni* or *D. antipodensis* in that square (Cuthbert *et al.* 2005).

To explore whether the differences in population trajectory observed between *D. gibsoni* and *D. antipodensis* (Elliott & Walker 2005) were attributable to differences in the (mostly unreported) bycatch of these 2 species, we attempted to estimate the total bycatch using 2 methods:

1. *Interaction method* We assumed that the bycatch rate (birds caught/hooks set) in each 5° square was proportional to the interaction index estimated for each square. We used the average ratio between bycatch rate and interaction index in fishing areas in which bycatch rates were reliable in the New Zealand Exclusive Economic Zone (EEZ) between 1996 and 1998 to estimate the ratio between our interaction index and bycatch rate, and we multiplied this ratio by the interaction index in each 5° square to estimate the bycatch rate. We then estimated the total bycatch in each 5° square

Table 3 Distribution of satellite locations amongst Argos® location classes.

Location class	<i>n</i>	%
Not recorded	3214	
3	264	1.0
2	652	2.6
1	2290	9.1
0	11387	45.2
A	4926	19.5
B	5697	22.6

by multiplying our estimated bycatch rate by the number of hooks set in that square (from Tuck *et al.* 2003).

2. *Fixed catch rate method* We assumed that the bycatch rate of albatrosses was the same in all 5° squares, and was equal to the average bycatch rate recorded in the New Zealand EEZ between 1996 and 1998. We then estimated the total bycatch in each 5° square by multiplying this fixed bycatch rate by the number of hooks set in that square (from Tuck *et al.* 2003).

We used bycatch data from the New Zealand EEZ between 1996 and 1998 (Baird 1997, 1999; Bartle 2000; Robertson 2000) because until then most wandering albatrosses reported by fisheries observers were not identified correctly, with many simply classified as “wandering albatross”, and because there was an almost 100% observer coverage of tuna longline sets in the Japanese charter fleet fishing around New Zealand in those years. Since 1999 this fleet has been replaced by a large domestic fleet, mostly lacking observers (Baird 2001a, 2001b).

To further explore ways in which the information on albatross distribution might be used to reduce their incidental bycatch, we estimated the reduction in bycatch that would be achieved by the exclusion of fishing from areas of ocean with high interaction indices.

To obtain an estimate of the extent to which albatrosses may have come in contact with longline fisheries over the past 45 years, the total number of 5° squares used by longline fleets between 1960 and 1998 was compared to the total number of 5° squares used by *D. gibsoni* and *D. antipodensis* between 1994 and 2005, on the assumption that albatross at-sea distribution remained more or less constant over this period. This assumption was supported, for *D. gibsoni* at least, by at-sea observations by J.A.F. Jenkins during the 1960s (Gibson 1967).

Banding

On Adams I 644 birds (105 chicks; 539 adults) were marked with numbered metal bands in 1969–1985 (C.J.R. Robertson, pers. comm.) with a further 5026 birds (1947 chicks; 3079 adults) banded in 1991–2006, (Walker & Elliott 1999; unpubl. data), a total of 5670 banded birds.

On Antipodes I, 20 chicks were banded in 1950 and 793 birds (37 chicks; 756 adults) in 1969 (Warham & Bell 1979), 1200 birds (1096 chicks; 104 adults) in 1978 (Bell 1979), and 4660 birds (3444 chicks; 1222 adults) in 1994–2005 (McClelland *et al.* 2001; unpubl. data), a total of 6679 banded birds.

Since 1997 large, individually numbered, coloured plastic bands have been attached in addition to the metal bands, making identification of live birds at sea possible without their capture.

RESULTS

Performance of the tracking system

Low battery voltage in the transmitters carried by 5 chick-rearing *D. gibsoni* in late 2001 and poor signal strength from transmitters carried by 3 non-breeding female *D. antipodensis* between Jul and Sep 2003 resulted in only sporadic usable signals from these transmitters, but the rest of the transmitters performed well. Omitting the erroneous locations, we recorded an average of 7.59 ($SE_{\text{mean}} = 0.576$) signals/transmitter/day from those running continuously before 1997, and 3.11d⁻¹ ($SE_{\text{mean}} = 0.152$) for those running for 6 h d⁻¹ from 1997 onwards. The distribution of locations amongst the Argos® location classes is presented in Table 3.

Effect of transmitters on birds

During incubation, birds with taped or glued transmitters had flight durations and weight gains similar to birds without transmitters, but all these birds had significantly shorter flight durations ($F_{2,253} = 6.49$, $P = 0.001$) and greater weight gains ($F_{2,82} = 3.69$, $P = 0.029$) than did birds with harnessed transmitters (Table 4).

D. antipodensis wearing harnessed transmitters while rearing chicks in 2000 made fewer, significantly longer ($t = 3.7$, $df = 6$, $P = 0.01$) foraging trips than did *D. gibsoni* wearing taped-on transmitters while rearing their chicks in 2001 (Table 5). The difference may have resulted from inter-year and interspecies differences, rather than the effects of the different transmitter attachment methods.

Birds wearing harnessed transmitters were significantly more likely to desert than birds wearing glued-on or taped-on transmitters (Fisher's Exact test; $P = 0.001$). Of 87 harness-wearing birds, 21 (24%) deserted, whereas only 1 (6%) of 18 birds wearing glued-on transmitters and none of the 27 birds wearing taped-on transmitters deserted. Six (29%) of the 21 desertions by birds wearing harnessed transmitters happened after the transmitter had been attached to birds that had just been relieved at the nest by their mate. Four (19%) occurred 7–10 days after the transmitter had been attached, when the incubating bird was relieved at the nest by its mate; the remaining 11 (52%) birds deserted 1–6 months after the transmitter was

Table 4 Average foraging trip length (d) during early incubation, and average daily weight gain (g d⁻¹) during the trips, of *Diomedea gibsoni* and *D. antipodensis* wearing taped, glued, or harnessed transmitters, or no transmitter (No PTT). Sample sizes in parentheses.

Year	1995	1996	1997	1998	2000	
Taxon	<i>D. gibsoni</i>	<i>D. antipodensis</i>	<i>D. antipodensis</i>	<i>D. antipodensis</i>	<i>D. gibsoni</i>	Mean
Glued	14.8 d (12)	10.5 d (1)				12.7 d
	0.09 g d ⁻¹ (3)	0.02 g d ⁻¹ (1)				0.06 g d ⁻¹
Taped		10.5 d (1)	8.7 d (6)	13 d (1)		10.7 d
		0.06 g d ⁻¹ (1)	0.04 g d ⁻¹ (6)	0.06 g d ⁻¹ (1)		0.05 g d ⁻¹
Harnessed	13.3 d (6)	19.2 d (6)	12.3 d (5)	17.5 d (13)	19 d (7)	16.3 d
	0.02 g d ⁻¹ (4)	0.01 g d ⁻¹ (6)	0.04 g d ⁻¹ (5)	0.04 g d ⁻¹ (4)		0.03 g d ⁻¹
No PTT		13 d (11)	11.6 d (214)	13.5 d (128)	15.9 d (86)	13.5 d
		0.06 g d ⁻¹ (11)	0.06 g d ⁻¹ (25)	0.08 g d ⁻¹ (21)		0.07 g d ⁻¹

Table 5 Total number of foraging trips and average duration of trips made over a 12-week period between 16 Jun and 7 Sep, during chick rearing, by 4 *Diomedea antipodensis* in 2000 and 4 *D. gibsoni* in 2001.

Year and taxon	Sex	Attachment	No. of trips	Average duration
2000 <i>D. antipodensis</i>	2 ♂♂; 2 ♀♀	Harness	28	13.17 d
2001 <i>D. gibsoni</i>	1 ♂; 3 ♀♀	Tape	45	6.74 d

Table 6 Total area of ocean (×10⁶ km²; 95% kernel contours) used by 23 male and 23 female *Diomedea gibsoni* and 32 male and 33 female *D. antipodensis*.

Species and sex	Life history stage		
	Incubation & chick-rearing	Hatch/guard	Non-breeding
<i>D. gibsoni</i> females	3.0	0.8	7.5
males	5.1	0.7	7.5
<i>D. antipodensis</i> females	6.1	0.7	8.6
males	14.5	5.0	25.5

attached, and involved mainly *D. gibsoni* in the 1999 and 2000 breeding seasons.

Birds wearing a transmitter harness were also significantly more likely to die during the year they were wearing the harness than were birds wearing glued-on or taped-on transmitters (Fisher's Exact Test; $P = 0.000$). Of 89 birds wearing harnessed transmitters or dummy transmitters, 29 (38%) were not seen again, whereas only 1 (3%) of 29 birds wearing taped-on transmitters and none of the 20 birds wearing glued-on transmitters disappeared.

The single bird tracked first with a glued-on transmitter then subsequently with a harnessed transmitter, went to the same general area on both occasions, as did all 4 birds tracked first with glued-on transmitters then in later years with taped-on transmitters. When all records from birds with taped-on and glued-on transmitters (i.e. birds which appeared indistinguishable in foraging behaviour from birds without transmitters) were mapped and compared with those from birds wearing harnessed transmitters, at-sea distributions were very similar, irrespective of the method of attaching the transmitter.

Satellite tracking

All locations of *D. gibsoni* and *D. antipodensis*

tracked during this study are shown in Fig. 4. *D. gibsoni* foraged mostly in the Tasman Sea, whereas *D. antipodensis* foraged mostly in the Pacific Ocean. The taxa overlapped in their distribution along the eastern coast of New Zealand, particularly between Kaikoura and East Cape, and along the edge of the Chatham Rise; there was a little mixing in both the Tasman Sea and the western Pacific.

Distribution of *D. gibsoni*

The at-sea distribution of *D. gibsoni* is shown in Fig. 4. Birds ranged from 24°S to 57°S in the Tasman Sea, to the south-western tip of Australia at 112°E and east of the Chatham Is at 161°W. They made very little use of the ocean south of the Auckland Is, and none travelled eastward of the Louisville Ridge. Most non-breeders foraged in similar areas to the breeding birds (Fig. 5). However, in 2003, 3 non-breeding adult birds spent long periods off southern and south-western Australia, an area not often visited by breeding birds. Females spent more time in the central and eastern Tasman Sea, whereas males spent more time off the southern coast of New South Wales and off Tasmania and along the Chatham Rise (Fig. 6).

When chicks hatched between late-Mar and mid-Apr, breeding birds made only brief (2-4 day) trips

but most birds still travelled to the southern-mid Tasman Sea to feed, and a few foraged just south of Adams I along the edge of the Auckland–Campbell shelf (Fig. 7). Between Jan and Apr widowed adults that were spending time on Adams I courting new mates, foraged in similar areas to those of parents feeding recently-hatched chicks on the island. They made relatively brief foraging trips to the edge of the Auckland shelf, just south-west of Adams I, or to the south-western Tasman Sea (Fig. 8).

The area of ocean used by both sexes of *D. gibsoni* at various life-history stages are shown in Table 6.

Distribution of D. antipodensis

The at-sea distribution of *D. antipodensis* is shown in Fig. 4, with separate maps for breeding and non-breeding birds presented in Fig. 5 and for males and females in Fig. 6. Birds ranged from 24°S, just south of the Fiji and Society Is in the central Pacific, to 73°S near the Balleny Is and the Ross Sea off Antarctica, and west to the Great Australian Bight (134°E) and east to the coast of Chile (77°W). One of the 9 non-breeding adult females tracked was the only bird to forage off Tasmania and South Australia, though several other females briefly visited the central Tasman Sea, but 6 of the 12 male non-breeders that were tracked foraged off Chile. Between these extremes, almost all females and many male non-breeders foraged in the western Pacific basin, along with breeding birds. In contrast to *D. gibsoni*, breeding, non-breeding and even courting birds made substantial use of the ocean south of Antipodes I, but only males used these southern waters. Most females (Fig. 6a) spent all their time to the east of New Zealand, particularly off the edge of the Chatham Rise and between North Island and the Louisville Ridge. Males had much larger foraging ranges than females (Table 6), venturing well to the south (23% of all males used Antarctic waters), east to South America, and a few birds even foraged well north of New Zealand (Fig. 6b).

During Apr and May, as the chicks hatched, breeding birds mostly made only brief (1–4 day) trips and their foraging range contracted (Table 6). Many birds still fed along the edge of the Chatham Rise, but they also used areas even closer to Antipodes I, particularly the northern edge of the Campbell Plateau and Bollons Seamount, and the edge of the Bounty Platform (Fig. 7). Widowed adults courting on Antipodes I between Feb and Apr also used these shelf edges, but several males also made longer trips to Antarctic waters during this period (Fig. 8).

Three juveniles, which on the basis of their sizes were presumed to be 2 males and 1 female, were tracked for the 1st 9–13 months after fledging. They were all initially blown to the south-east of Antipodes I, but subsequently spent the whole year in waters north of 50°S (Fig. 9). The female's range was

indistinguishable from that of adult females, but the 2 males consistently used more northern waters than did adult males (mean latitude: 2 ♂ chicks = 40.6°S, non-breeding adult ♂♂ = 45.9°S, Mann-Whitney $U = 1.02 \times 10^6$, $P = 0.000$). One spent most of the year in the southern central Pacific Basin, an area visited occasionally by adult males, and briefly visited the shelf off central Chile, while the 2nd male used waters from the central Pacific to the central Tasman Sea.

Individual foraging areas

All birds that were tracked on multiple flights, either in the same year or in different years, appeared to have individual preferences in foraging areas. This was most obvious in non-breeding and juvenile birds, because their flight patterns were not obscured by repeated trips back to the island, and in males because they used larger areas of ocean than females. The patterns were the same for both species. The individual foraging areas still usually encompassed large areas of ocean (Fig. 10).

The preference for a specific foraging area seems to start early in life and persist through many years. The only 3 juvenile *D. antipodensis* tracked from fledging each went to separate areas and remained there throughout the 8–13 months they were tracked (Fig. 9). A banded 3-year-old female *D. gibsoni* started visiting the coast off Kaikoura (South Island, New Zealand) in 1998, and has been located in the same area several times every year ever since. All 5 birds which were tracked on subsequent occasions, 4–8 years apart, foraged in the same area on each occasion (2 birds illustrated in Fig. 11).

Characteristics of preferred foraging areas

Both species foraged in oceans of similar depths (Fig. 12). Both used waters up to 6000 m deep, with a small peak of activity at 1000 m, and a larger peak at 4500 m for *D. gibsoni* and 5000 m for *D. antipodensis*. When ocean depths used were compared to those available, breeding and non-breeding birds of both species showed non-random ($4 \chi^2$ tests, $\chi^2 > 1155$, $df = 12$, $P = 0.000$) use of the ocean waters, which changed depending on whether or not the birds were breeding. While breeding, both species spent more time in waters ≤ 1000 m deep, presumably partly because they commuted frequently over the shallow shelf waters around the breeding islands. When not breeding they foraged more frequently in deeper water.

The apparent preference for depths of the order of 1000 m results from clusters of uplinks over the high seamounts of the Louisville Ridge, and the shelf break off Chile, South Australia, Tasmania and New Zealand. This relationship is spectacular along the edge of the Chatham Rise (Fig. 13). Concentrations of uplinks coincided with areas where strong currents, fronts, and rugged bathym-

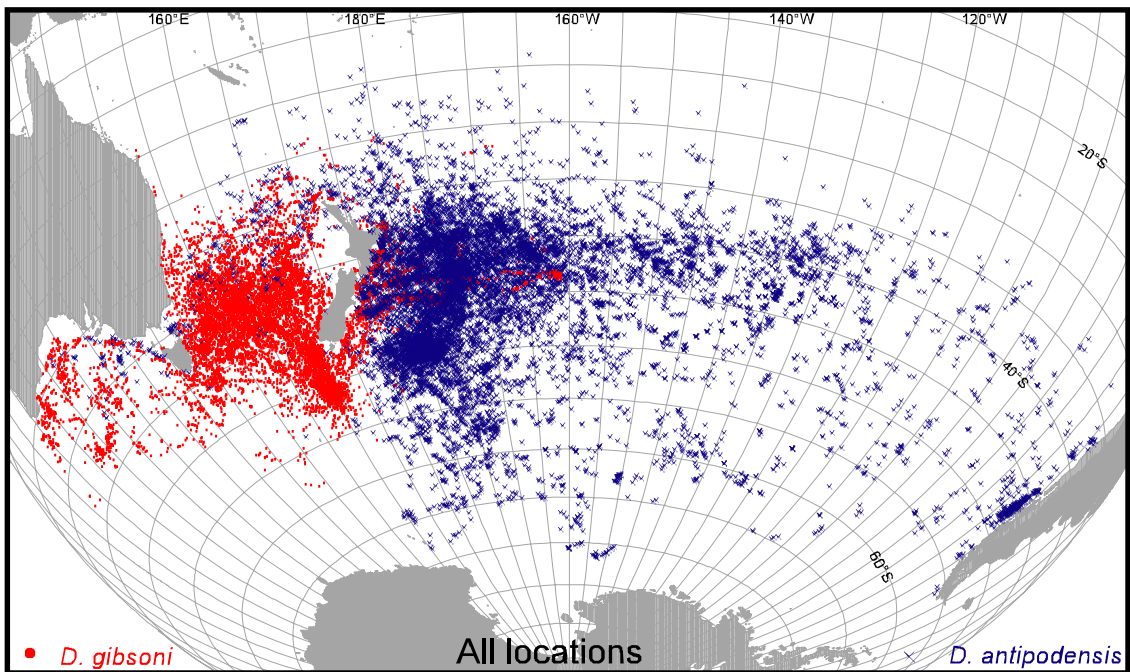


Fig. 4 All 13,403 uplinks from 46 *Diomedea gibsoni* tracked between 1994 and 2003 and all 15,027 uplinks from 65 *D. antipodensis* tracked between 1996 and 2005.

etry were combined. One of these areas was off the south-western coast of New Zealand's South Island, where nutrient-rich waters of the subtropical convergence moving east suddenly meet the very steep shelf edge off Fiordland, and are forced to the south. Another was the south-eastern end of the Chatham Rise, where the Subtropical Front meets the steeply sloping flanks of the shelf, which block the northerly flow of the frontal waters and pin them in a predictable position all year. Permanent eddies, with accompanying enhanced productivity, that form where the warm East Australian Current meets colder subantarctic waters off New South Wales (Fig. 2), and eddies in the Tasman Front at North Cape and East Cape, New Zealand, were other sites associated with clusters of uplinks.

The apparent favouring of depths of 4500–5000 m results from the extensive use of the mid-Tasman Sea by *D. gibsoni*, and the South Pacific Basin by *D. antipodensis*. Both are areas of relatively subdued seafloor topography, but still relatively high productivity because of the convergence of subtropical and subantarctic waters (Fig. 2).

D. gibsoni foraged mostly to the north of the Subtropical Convergence, whereas *D. antipodensis* also used subantarctic waters between the Subtropical Convergence and the Polar Front, and even the Southern Ocean.

Both species travelled similar distances from their breeding islands during incubation (*D. antipodensis* = 1625 km, *D. gibsoni* = 1553 km, $t = -0.55$, $df = 96.9$, $P = 0.58$) though the excursions made by *D. antipodensis* varied more (*D. antipodensis* 248–4189 km, $SD = 835$ km, cf. *D. gibsoni* 435–2705 km, $SD = 486$ km).

Seasonal and annual variation in ocean-use

Despite the few birds tracked, the individual foraging areas, and the uneven tracking effort between seasons, it was possible to discern seasonal differences in the distribution of both species (Fig. 14; Table 7).

The most obvious trend in Fig. 14 was the movement by *D. antipodensis* away from Antarctic waters in colder months when the seas froze over. Although some male *D. antipodensis* foraged as far south as 70°S from mid to late summer (Feb–Apr), during the rest of the year they foraged only to 60°S, the approximate northern limit of pack ice (Table 7).

Both species also exhibited a more general north-south seasonal shift. During the warmer months (Dec–May) most *D. gibsoni* foraged between 40°S and 45°S in the Tasman Sea, but during Jun to Nov they moved north of 40°S. *D. antipodensis* showed a similar pattern of movement in the Pacific Ocean (Table 7). *D. gibsoni* also shifted during spring (Sep–Nov) from the eastern to the western Tasman Sea (Fig. 14; Table 7).

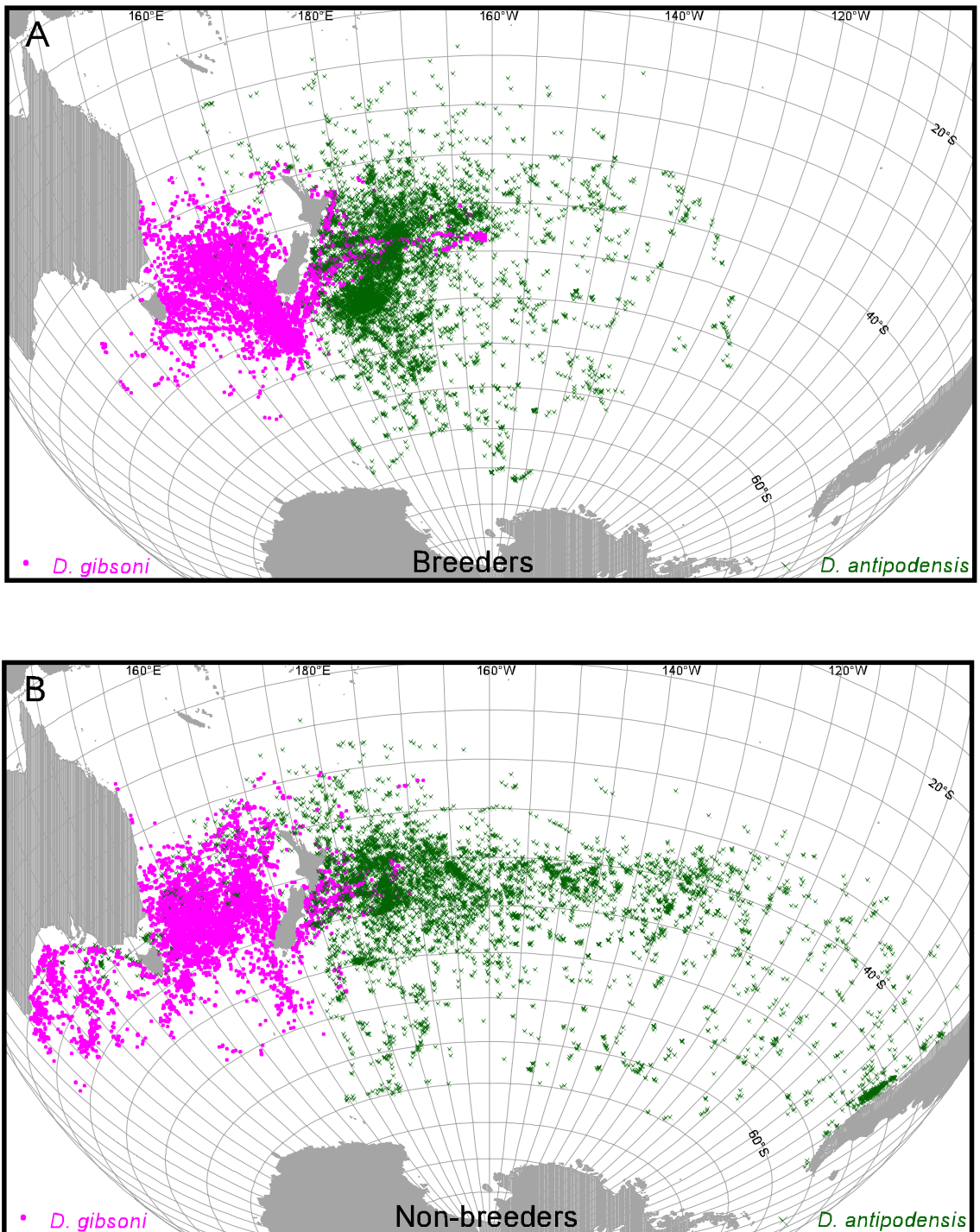


Fig. 5 (A, B) All uplinks from (A) 35 breeding *Diomedea gibsoni* and 45 breeding *D. antipodensis*, and (B) 30 non-breeding adult *D. gibsoni* and 27 non-breeding adult and 3 juvenile *D. antipodensis* that were tracked between 1994 and 2005.

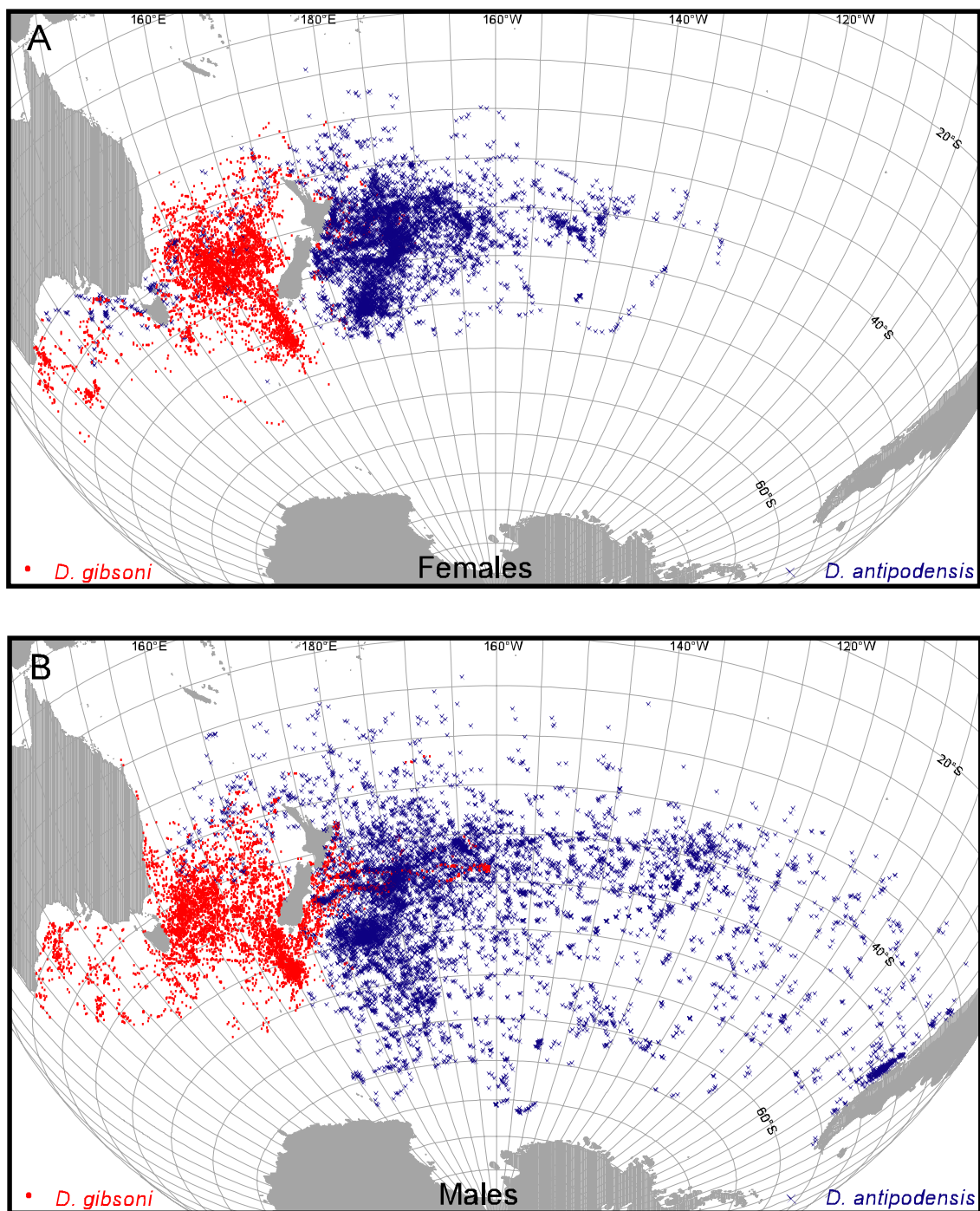


Fig. 6 (A, B) All uplinks from (A) 23 female adult *Diomedea gibsoni* and 31 female adult *D. antipodensis*, and (B) 23 male adult *D. gibsoni* and 30 male adult *D. antipodensis* tracked between 1994 and 2004.

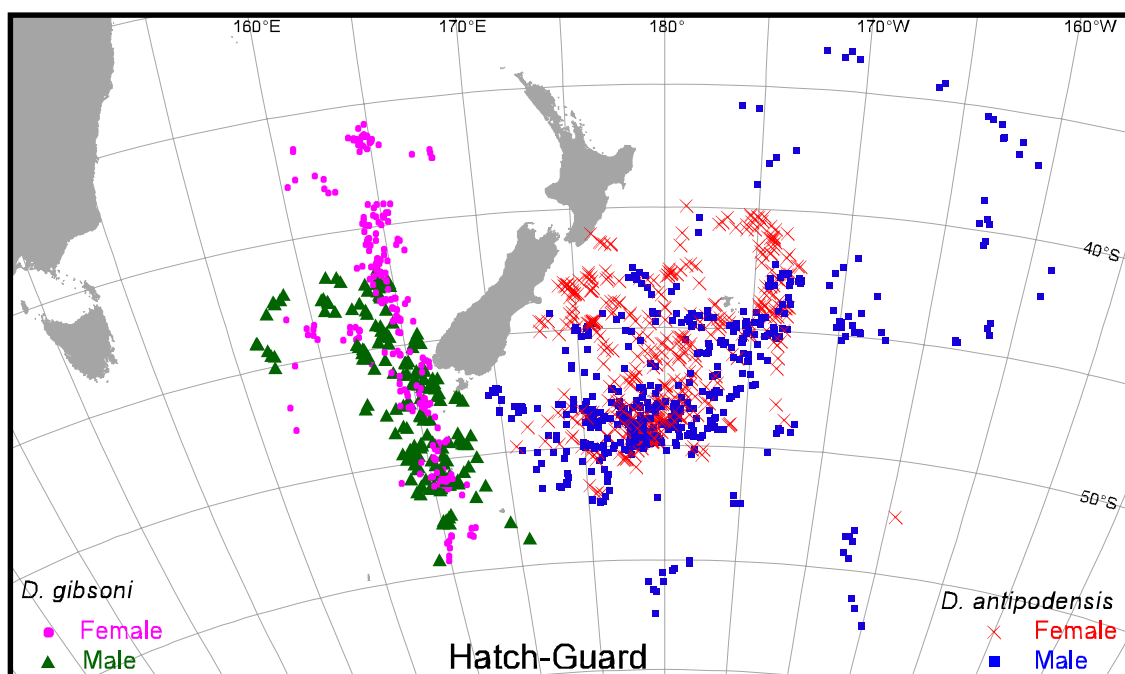


Fig. 7 All uplinks of 5 male (▲) and 4 female (●) breeding *D. gibsoni* tracked for periods during the hatch/guard stage 31 Mar-1 May in 1994, 1999-2000; and 10 male (■) and 12 female (×) breeding *D. antipodensis* tracked for periods during the hatch/guard stage 1 Apr-29 May in 1997-2000.

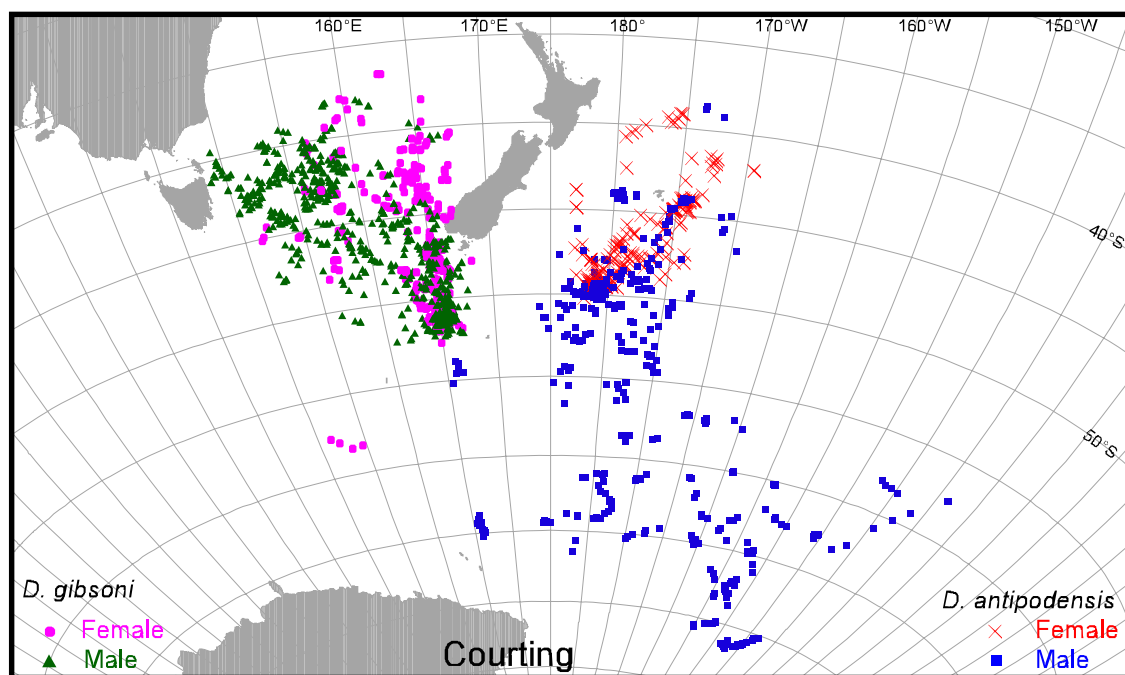


Fig. 8 All uplinks of 5 male (▲) and 3 female (●) courting *Diomedea gibsoni* tracked in-between courting sessions on Adams I from mid-Jan to mid-May in 2002 and 2003; and 3 male (■) and 3 female (×) courting *D. antipodensis* tracked in-between courting sessions on Antipodes I between 20 Feb and 30 Apr 2003.

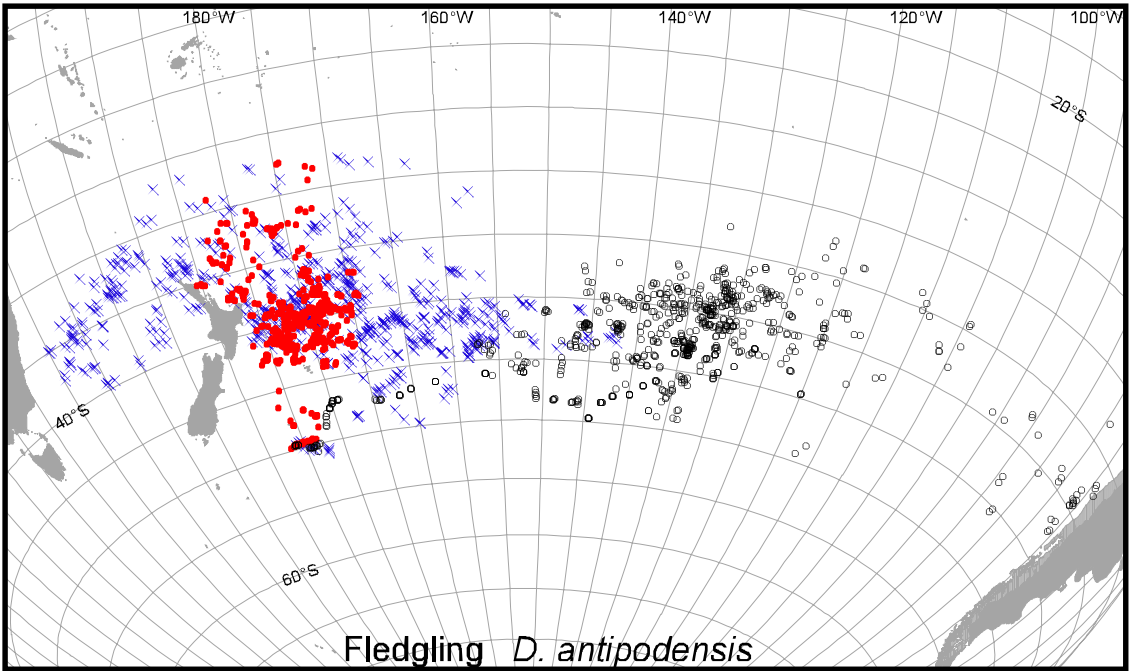


Fig. 9 All uplinks from 3 juvenile *Diomedea antipodensis* satellite-tracked after they fledged from Antipodes I. The female (●) was tracked 27 Jan–8 Sep 2004, a male (○) from 16 Jan–29 Nov 2004, and a 2nd presumed male (×) from 16 Jan 2004–23 Feb 2005.

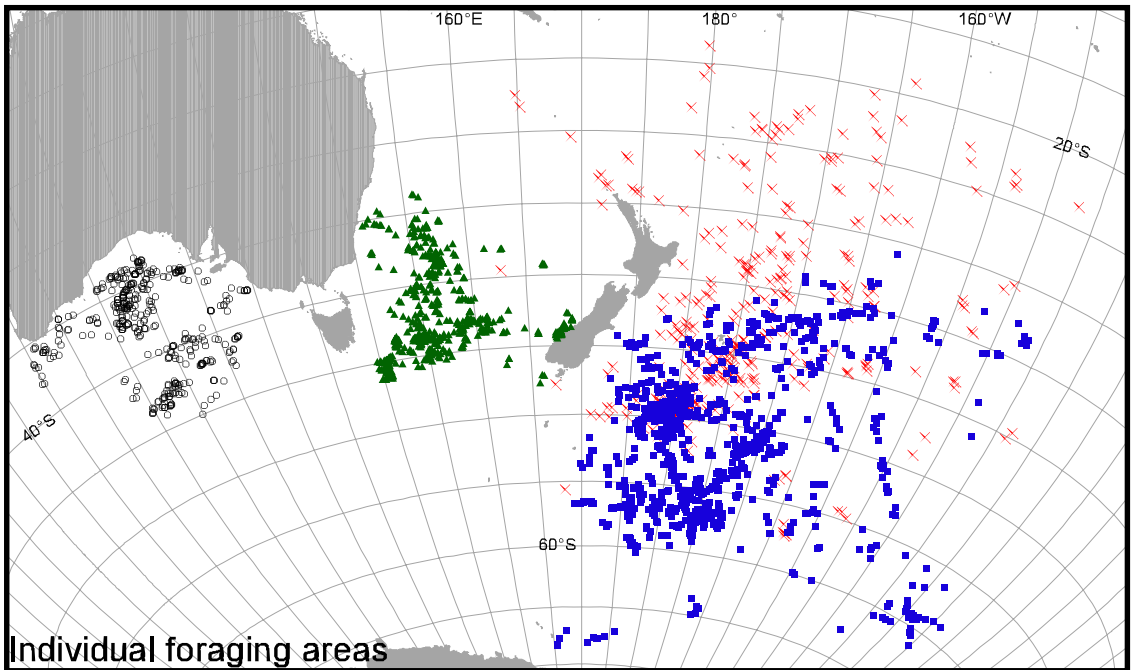


Fig. 10 All uplinks received during 7 months tracking of 2 adult non-breeding male *Diomedea gibsoni* from the end of courting on Adams I in mid-Mar to mid-Oct 2003, during which time they used 1.5 (○) and 1.2 (▲) × 10⁶ km² of ocean respectively; and 11 months tracking of 2 adult breeding male *D. antipodensis* regularly returning to Antipodes I during incubation and chick-rearing from early Feb 2000 to early Jan 2001 during which time they used 6.9 (■) and 11.7 (×) × 10⁶ km² of ocean respectively.

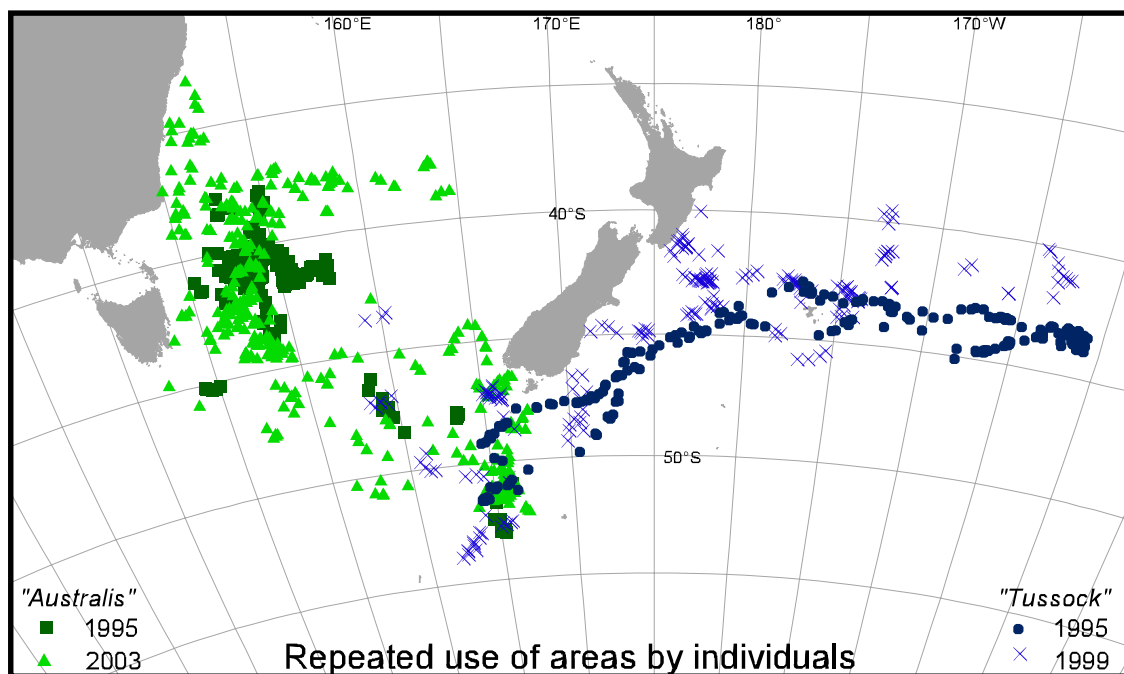


Fig. 11 All uplinks from 2 male *Diomedea gibsoni*: the 1st bird (green symbols) tracked as a post-breeder from 2 Jan-13 Feb 1995 (■), then again while courting from 2 Feb-17 May and as a non-breeder 17 May-17 Oct 2003 (▲); and the 2nd bird (blue symbols) during incubation from 21 Jan-18 Feb 1995 (●), and again during incubation and later nest failure between 10 Feb and 25 Apr 1999 (×).

Birds used the Chilean coast mainly between late summer and mid-winter (Feb-Jul). No banded or tracked birds were recorded there between Nov and Jan, and all the male *D. antipodensis* we tracked visiting South America had returned to the west by Aug. However, unbanded *D. antipodensis* have been seen, and several bands recovered from there in Sept and Oct (D. Nicholls pers. comm.; Latham *et al.* 2004).

The core areas used by both species (central and lower Tasman Sea for *D. gibsoni*; western Pacific Basin for *D. antipodensis*) remained the same in every year of our study. However, the more distant areas such as the west coast of South America, Antarctica, and south-western Australia were visited in some years and not in others. We recorded birds near the south-western coast of Australia in 2000 and 2003 only, and in 1999 *D. gibsoni* and *D. antipodensis* both remained close to New Zealand. However, the sample sizes of birds tracked at the same stage in the same season in different years were insufficient for us to be confident that these apparent differences represented inter-annual differences in the range of the species, rather than just individual differences in preferred foraging area.

Band recoveries

Between 1971 and 2006, 35 banded *D. antipodensis* and 18 banded *D. gibsoni* were recovered dead

away from the breeding islands. Given the numbers banded previously, these values represent band recovery rates of 0.53% and 0.33% respectively.

Twenty-nine (83%) of the *D. antipodensis* recovered had died in association with fishing boats: 16 (55%) on longlines; 8 were "killed on fishing boats at sea"; 1 hit a net-sonde cable; 2 were caught in fishing nets; and 1 was shot from a fishing boat (data from the New Zealand Banding Office, Department of Conservation). Thirteen of these birds were juveniles and 16 were adults.

Four (22%) of the 18 *D. gibsoni* recovered dead had been killed in association with fishing boats: 3 on longline hooks; and 1 was caught in fishing net. The remaining 14 (9 juveniles; 5 adults) were recovered along the south-eastern coast of Australia and north-western and north-eastern coasts of New Zealand (Fig. 15). Judging from their injuries and their proximity to large fishing fleets, a few of these birds may not have been victims of storms but rather drifted ashore after being cut free or thrown overboard after capture by fishing vessels.

The distribution of recoveries largely reflected the distribution of albatrosses tracked with transmitters. The biggest gaps were the absence of any band recoveries in the Great Australian Bight, and from near Antarctica.

Overlap with longline fisheries

The major longline fisheries with which the foraging distributions of New Zealand wandering albatrosses overlap are: the Japanese, Taiwanese, New Zealand and Australian fleets fishing for southern blue-fin tuna (*Thunnus maccoyii*) in the Tasman Sea and to the south and east of Australia and New Zealand; Korean and Taiwanese fleets in the central Pacific, which mostly target the more northerly distributed albacore tuna (*T. alalunga*); Chilean artisanal and industrial demersal fleets off South America that fish for ling (*Genypterus blacodes*), hake (*Merluccius hubbsi*) and Patagonian toothfish (*Dissostichus eleginoides*); New Zealand demersal fleets fishing to the east and south of the country for ling; and Australian and New Zealand boats fishing for Patagonian toothfish in the Southern Ocean (Tuck *et al.* 2003). Most parts of the ranges of *D. gibsoni* and *D. antipodensis* were used by longline fisheries at some stage between 1960 and 1998. Over the past 40 years, longline fishers have used 92% of the 5° squares occupied by *D. gibsoni*, and 54% of those visited by *D. antipodensis*. Fig. 16 shows the distribution of fishing effort 1990–98 in comparison to the distribution of individual albatrosses we tracked between 1994 and 2004.

The index of potential interaction between wandering albatrosses and longline fisheries shows that for *D. gibsoni*, the south-western and western coasts of the South Island, the central Tasman Sea and eastern Tasmanian waters were areas with high levels of potential interaction in the 1990s (Fig. 17a). Areas with the highest potential for conflict in the 1990s for *D. antipodensis* were near East Cape and the east coast of New Zealand, the central Tasman Sea, the east coast of Tasmania, and the mid-west Pacific (Fig. 17b). The reductions in interaction that could be achieved by banning fishing in some 5° squares with high levels of interaction are shown in Fig. 18. Our 2 methods of estimating annual bycatch across the range of both species yielded dramatically different results (Table 8).

DISCUSSION

Effect of transmitters on birds

The duration of foraging trips was on average longer, and weight gains less, for birds wearing harnessed transmitters than for birds with taped-on or glued-on transmitters, or carrying no transmitters at all, but harnesses did not affect all birds equally. Four *D. antipodensis* wearing harnessed transmitters for a full 12-month breeding season each successfully fledged a chick. Similarly, a female *D. gibsoni* wearing a harnessed transmitter throughout a failed nesting attempt, put on sufficient condition whilst wearing the transmitter over the following 10 months to return to the island and breed success-

fully the next year. In contrast, some birds with harnessed transmitters deserted their nests, and some died.

Individuals of neither species appeared unduly stressed by the fitting of transmitters; all birds returned immediately to incubation on release. Birds may have deserted as a result of gradual weight loss over several foraging trips caused by the harnesses, not from the stress associated with putting the harnesses on. We may have recorded a particularly high desertion rate because one of the largest deployments of transmitters in harnesses coincided with a season (2000) when *D. gibsoni* had an abnormally low breeding success and a high mortality rate (Elliott & Walker 2005).

The high death rate for birds that were wearing harnessed transmitters took some time to detect, because the birds' absences from the breeding grounds were at first thought to result from poor breeding condition, brought on by wearing the harnesses. Considerable efforts were made to ensure that birds that deserted while wearing a harnessed transmitter were relieved of both harness and transmitter by the action of an automatic release mechanism, to allow them to re-gain lost condition. However, because the birds have never, to our knowledge, returned to the breeding grounds, it seems more likely that transmitter harnesses both impede foraging performance, and entail a much higher risk of catastrophic failure through entanglement of the bird's bill in the harness, before the release mechanism is activated.

Other studies of seabird distributions using satellite telemetry have also shown longer foraging trip durations (~67% of studies summarized by Phillips *et al.* 2003) and higher rates of nest desertion for birds equipped with transmitters, particularly when the transmitters are mounted in harnesses (Falk & Möller 1995; Phillips *et al.* 2003).

Our experience with New Zealand wandering albatrosses was that wearing light (<1% of the birds' body mass) taped-on and glued-on transmitters had no discernable effect on foraging efficiency, or rates of desertion or mortality, whereas transmitters mounted in harnesses affected all three. Harnesses potentially allow long-term deployments of transmitters on birds that do not return to land regularly, but in practice harnesses lead to unacceptable mortality. In addition, the average period of deployment of transmitters in harnesses was actually less than that achieved with transmitters attached by tape.

Because of the effects of transmitter harnesses on the foraging performance of wandering albatrosses, we have not used the data collected in this study to assess foraging effort. However, our comparisons of the locations of foraging birds wearing harnessed transmitters with those with taped-on or glued-

Fig. 12 The distribution of *Diomedea gibsoni* and *D. antipodensis* above oceans of various depths. Shaded bars are breeding birds, un-shaded bars are non-breeding birds and solid lines are the availabilities of depth classes within the ranges of the 2 species.

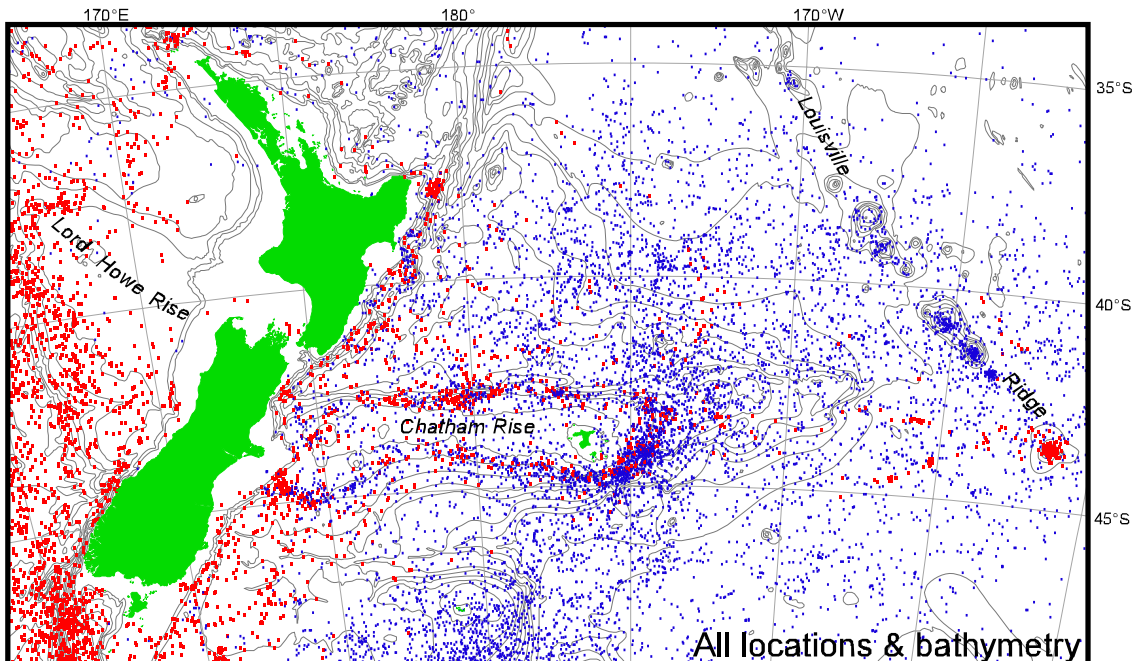
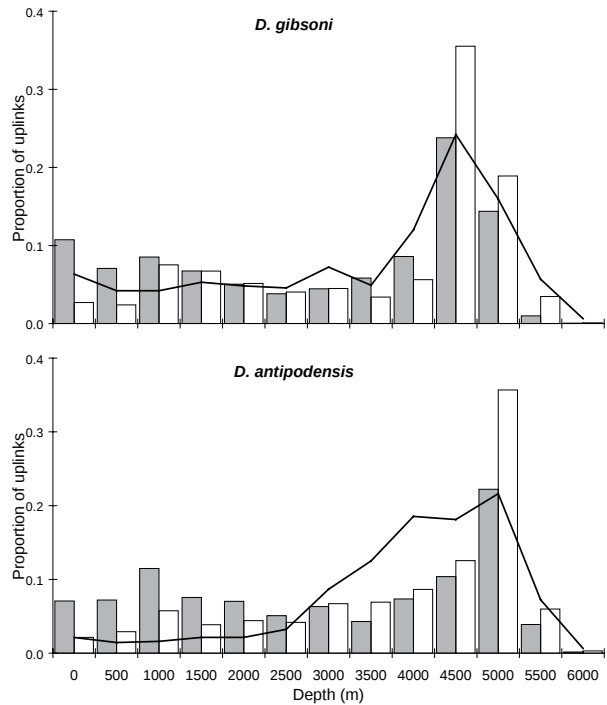


Fig. 13 Relationship of distribution of *Diomedea gibsoni* and *D. antipodensis* to bathymetric features around New Zealand. Note that albatross satellite uplinks are clustered around the breeding island, along the edge of the continental shelf around New Zealand, along the edge of the steeply sloping Macquarie Ridge Complex, along the edge of the Chatham Rise, and around the seamounts of the Louisville Ridge.

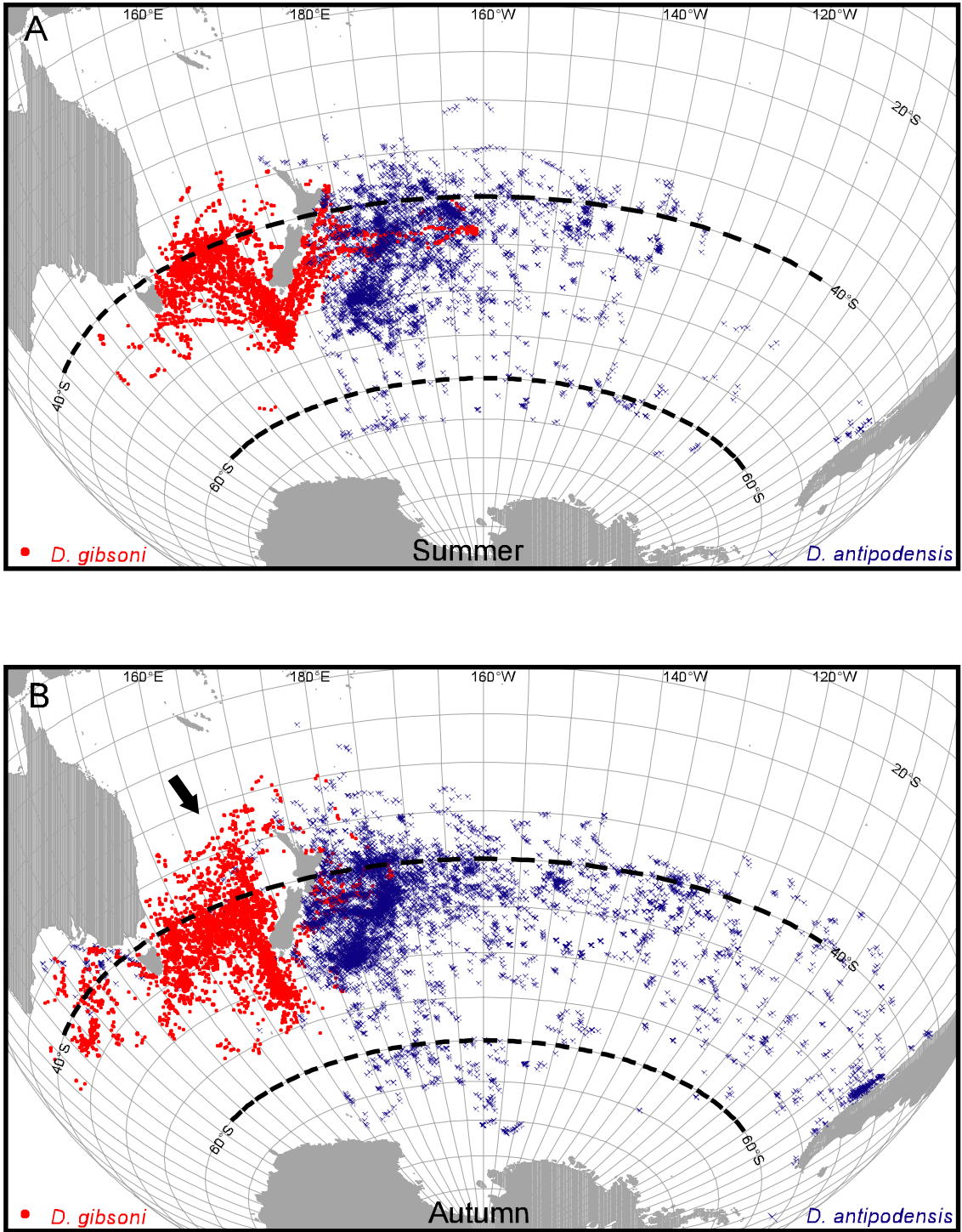
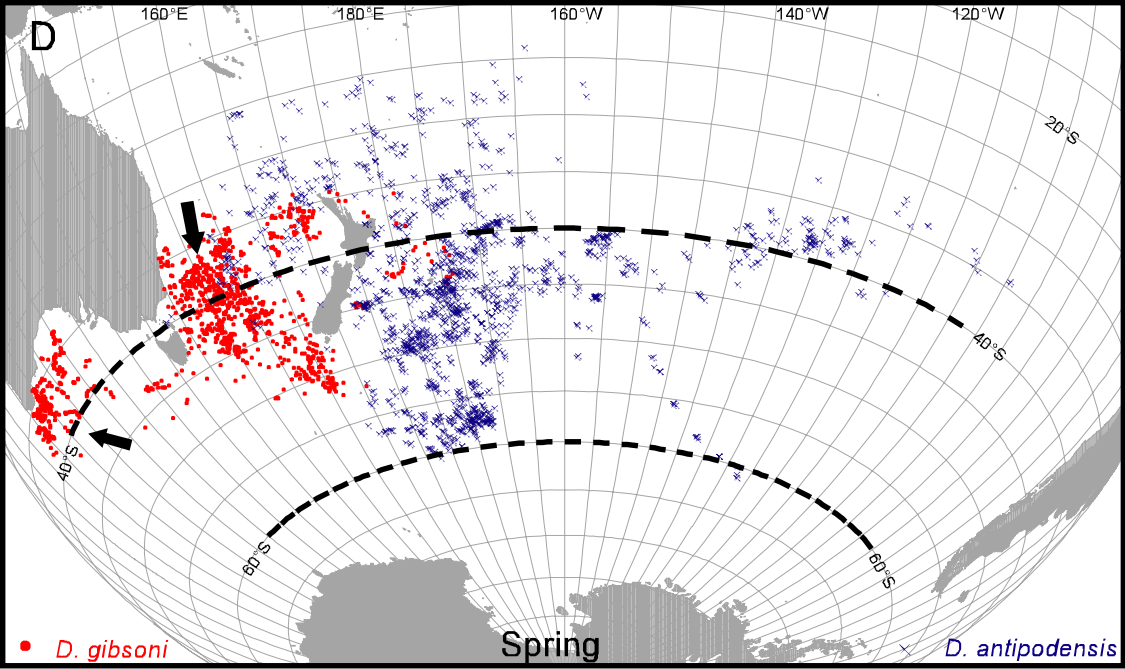
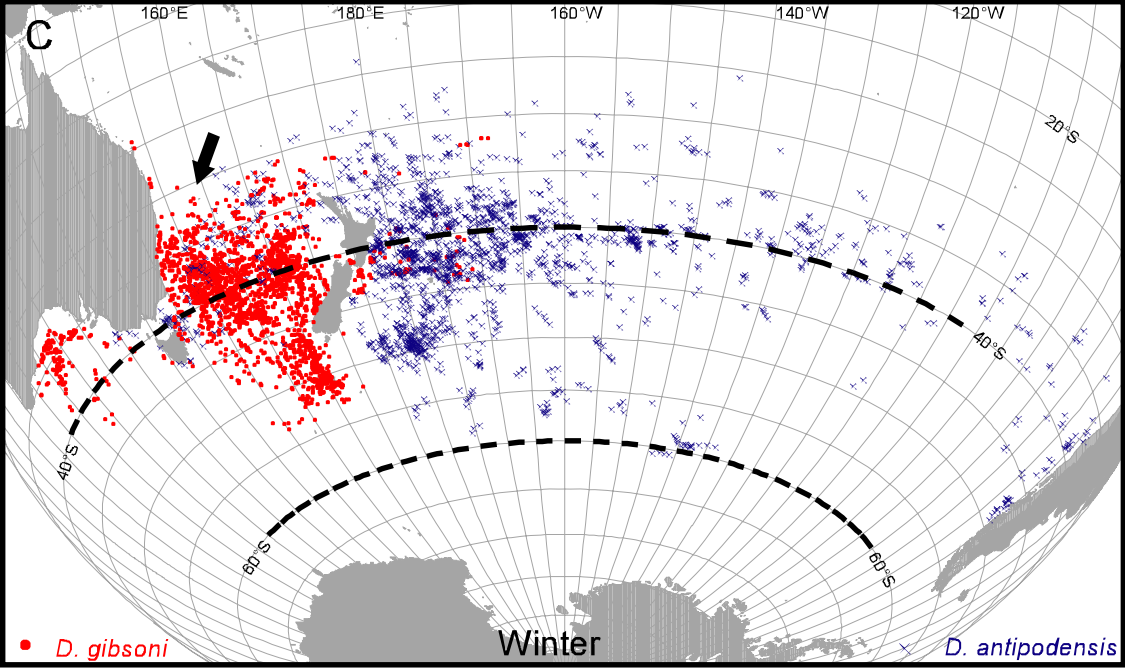


Fig. 14 (A-D) All uplinks received from *Diomedea gibsoni* and *D. antipodensis* between 1994 and 2005 in: (this page) (A) summer months (Dec-Feb), (B) autumn months (Mar-May), and (facing page) (C) winter months (Jun-Aug), (D) spring months (Sep-Nov).



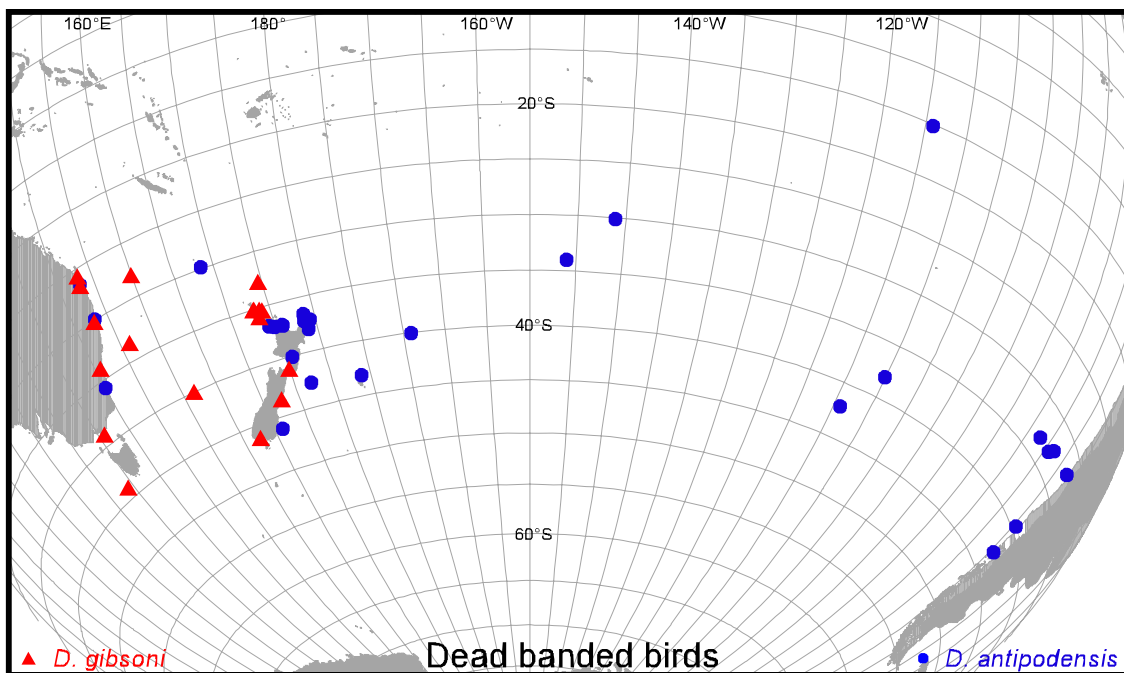


Fig. 15 Distribution of recoveries of 18 *Diomedea gibsoni* (▲) banded on Adams I (50°S, 166°E) and 35 *D. antipodensis* (●) banded on Antipodes Is (48°S, 178°E).

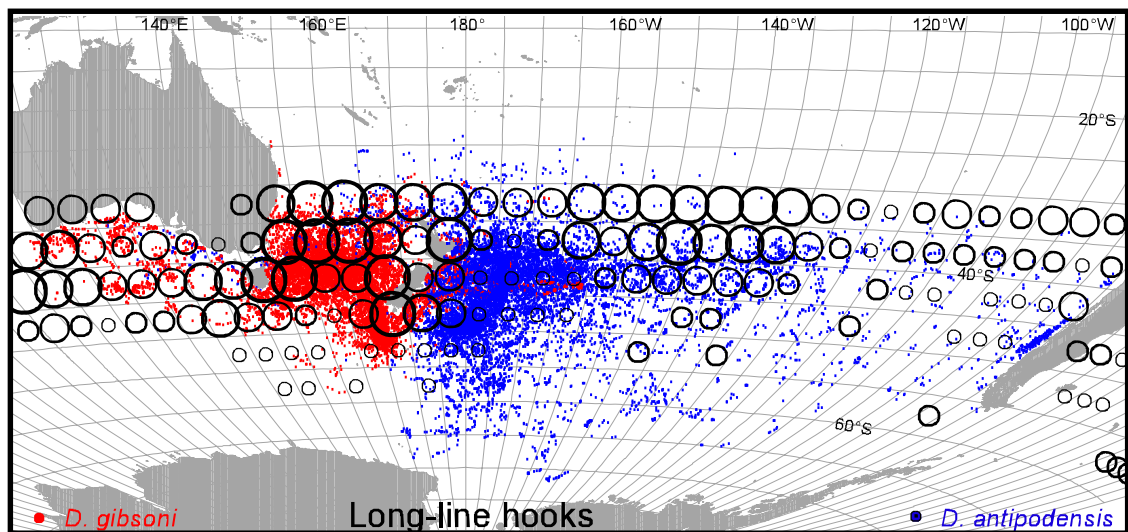


Fig. 16 The distribution of *Diomedea gibsoni* and *D. antipodensis* wandering albatrosses 1994-2004 overlaid by the distribution of pelagic longline fishing effort in 1990-98. Fishing effort is reported as mean annual effort by 5° square. Circles, levels of fishing effort, diameter increases with number of hooks set in 5 classes (1-10,000; 10,000-250,000; 250,000-1,000,000; 1,000,000-4,000,000; >4,000,000) (from Tuck *et al.* 2003).

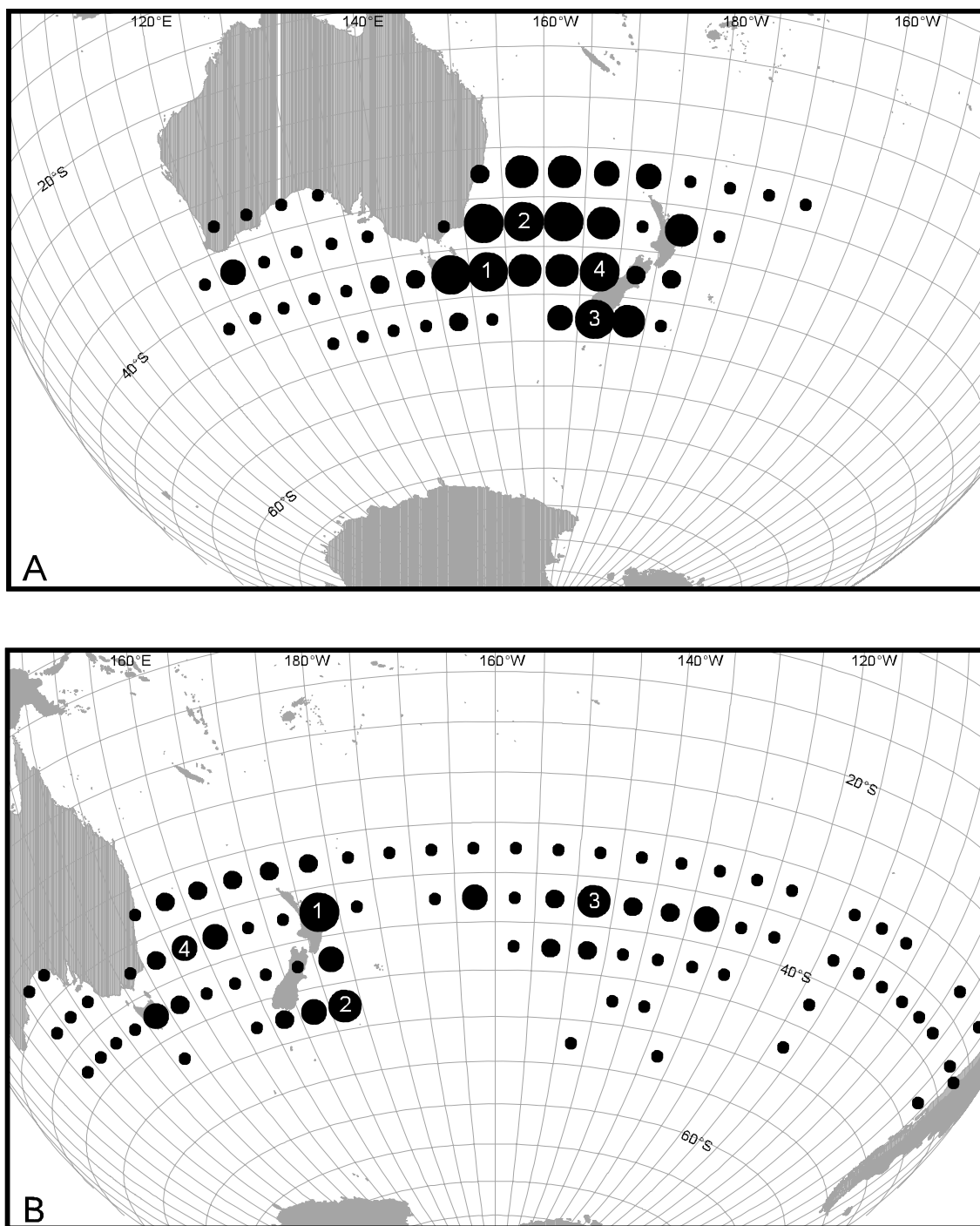


Fig. 17 (A, B) Distribution of potential interaction between longline fisheries and (A) *Diomedea gibsoni* and (B) *D. antipodensis* during the period 1990-98. Circle size increases in proportion to the potential interaction, as measured by the product of the proportion of albatross uplinks during the 1990s in a 5° square and the average number of longline hooks set annually in the square from 1990-98. The squares with the largest interaction indices are labelled (1-4) in decreasing order of importance.

Table 7 Percentage of all satellite uplinks from *Diomedea gibsoni* and *D. antipodensis* in different parts of the southern oceans in different seasons.

Season	Percentage of uplinks			
	<i>D. gibsoni</i> north of 40°S	<i>D. antipodensis</i> north of 40°S	<i>D. antipodensis</i> south of 60°S	<i>D. gibsoni</i> west of 163°E
Summer (Dec-Feb)	13	12	3	42
Autumn (Mar-May)	18	15	4	49
Winter (Jun-Aug)	52	42	0	57
Spring (Sep-Nov)	54	30	0	82

on transmitters or no transmitters at all, suggests that the harnesses did not affect the destination of foraging birds. Other studies of seabirds using taped-on transmitters have also reported circumstantial evidence that suggests that the destination of foraging birds is not affected by wearing a transmitter, even when trip duration is extended un-naturally (Cherel & Weimerskirch 1995; Waugh *et al.* 1999).

At-sea distribution

Though there were some areas of overlap, *D. gibsoni* and *D. antipodensis* foraged in surprisingly distinctive areas, given that their breeding islands are only 1000 km apart. With some exceptions, *D. gibsoni* used the Tasman Sea and *D. antipodensis* the South Pacific. Although male *D. antipodensis* used Antarctic waters, *D. gibsoni* did not, despite their breeding island's being farther south. *D. gibsoni* has a smaller at-sea range than *D. antipodensis*, and gender and life-history related changes in distribution are thus less spatially distinctive. Females and juvenile *D. antipodensis*, and to a lesser extent female *D. gibsoni*, tended to use more northerly waters than did males, as has been found in other species of wandering albatross (Weimerskirch *et al.* 1993; Weimerskirch *et al.* 2004; Nel *et al.* 2002).

Although *D. gibsoni* and *D. antipodensis* foraged mostly in different oceans, they made similar use of oceanographic features within their ranges. Both species appeared to prefer to forage over shelf breaks and seamounts, and their locations were concentrated at areas where fronts and strong currents met rugged underwater topography. Away from such sites, both species, particularly non-breeding birds, preferred to forage over deep (4–5000 m) water. However, only *D. antipodensis* made significant use of cool subantarctic and cold Antarctic waters.

Throughout the year, *D. gibsoni* and *D. antipodensis* use areas where waters of the Subtropical Convergence Zone are forced as strong currents around land masses such as the eastern Tasmanian coast, the south-western coast of New Zealand, the Chatham Rise, and the seamounts of the Louisville Ridge. These are areas of constant and predictably high productivity (Chang & Gall 1998; Murphy *et al.* 2001). They also make extensive, but seasonally variable, use of mid-oceanic waters such as the

Table 8 Fisheries bycatch of *Diomedea antipodensis* and *D. gibsoni* estimated assuming that bycatch is proportional to the interaction between fisheries and birds (Interaction method) and that bycatch rate is constant throughout the range of the birds (Fixed catch rate method).

	Estimated annual bycatch 1990–1998	
	Interaction method	Fixed catch rate method
<i>D. antipodensis</i>	408	553
<i>D. gibsoni</i>	1593	145

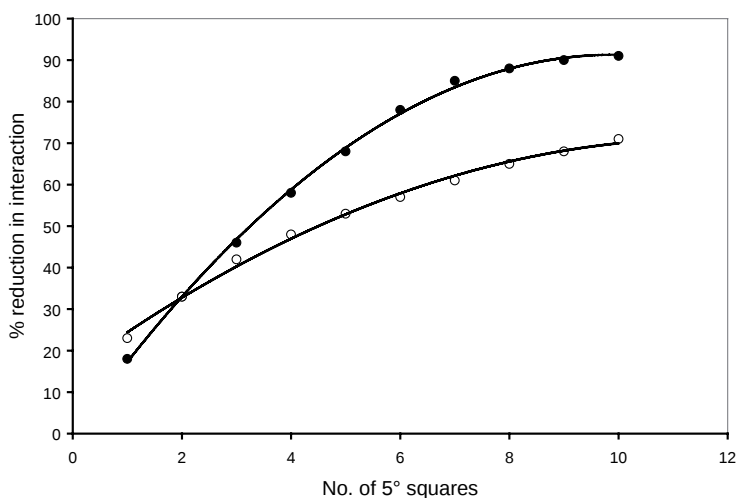
southern Tasman Sea, where productive zones fluctuate spatially and temporally with the changing position of the Subtropical Front (Stanton 1981; Uddstrom & Oien 1999).

The oceanographic conditions in the Tasman Sea and the southern Pacific Ocean can be very different. For example, in the winter of 1999, the Pacific had near-normal (cool) conditions whereas the Tasman Sea experienced significantly more anti-cyclones and higher temperatures than normal (Jones 2000). The unusual winter weather in the Tasman Sea meant that few adult *D. gibsoni* attained adequate condition to lay by Jan 2000, and many that tried failed, and the species had a record low breeding success. In contrast, the breeding success for *D. antipodensis* was high in 1999 (Elliott & Walker 2005). The lack of correlation in breeding success between *D. gibsoni* and *D. antipodensis* can be attributed, at least in part, to the differences in conditions in their (separate) foraging areas.

Relationship with fisheries

Most wandering albatross captures in the South Pacific have been reported from the surface or mid-water horizontal long-line fishery for tuna, particularly southern blue-fin tuna, and for other, tuna-like, species (Brothers 1991; Murray *et al.* 1993; Klaer & Polacheck 1997; Gales *et al.* 1998; Baird 2001). Demersal (bottom) longline fisheries, such as those for ling and Patagonian toothfish, and vertical droplines, seem to result in fewer captures (Baird 2001; Tuck *et al.* 2003), perhaps because the lines are weighted and sink more rapidly (Moreno *et al.* 2004). Our study has also shown that New Zealand wandering albatrosses make relatively little use of

Fig. 18 The potential reduction in interaction between longline fisheries and *Diomedea gibsoni* (filled circles) and *D. antipodensis* (open circles) which could be achieved by the exclusion of longline fishing from 5° squares. Fishing is excluded first from squares with the most potential for interaction, and then from squares in decreasing order of potential for interaction.



the shelf waters where trawling and most demersal fishing occurs, though they potentially overlap on the shelf slope.

If the longline fisheries for billfish north of 30°S and the poorly-known longline fleets of the central and south-eastern Pacific are considered as well, almost all of the foraging range of *D. gibsoni* and 75% of the range of *D. antipodensis* are likely to have overlapped with longline fisheries over the past 40 years. When only the recent (1990s) and reliable data are considered, a minimum 68% and 40% of the ranges of *D. gibsoni* and *D. antipodensis* respectively, overlap with those of longline fisheries. In comparison to *D. gibsoni*, there have been more fisheries-related band recoveries of *D. antipodensis* over the past 30 years, and twice as many *D. antipodensis* (90 against 45) birds were recovered dead from observed fisheries in New Zealand waters in 1988–98. The apparently higher bycatch rate of *D. antipodensis* is probably an artefact of increased opportunity for reporting; more *D. antipodensis* were banded, and *D. antipodensis* individuals spend 48% of their time within the New Zealand EEZ where observer coverage has been relatively high, whereas *D. gibsoni* spend 39%.

Measures of the rate of seabird bycatch come from a small proportion of fishing boats operating in New Zealand and Australian waters; there are almost no measures of bycatch from fishing in the surrounding international waters. The total bycatch therefore, has to be estimated by extrapolation from the small number of boats for which there are adequate observations. Observed bycatch rates are extremely variable, and therefore estimates of bycatch made by extrapolation have large confidence intervals.

In the absence of comprehensive information on the at-sea distribution of birds, estimates of bycatch for other albatross species (e.g. Cuthbert *et al.* 2005;

Lewison & Crowder 2003) have had to assume that the number of birds caught varies only with fishing effort. It clearly makes more sense to assume that the number of birds caught varies with both the density of birds and the fishing effort. The inclusion of albatross distributions in our estimates of bycatch dramatically changed them, but which estimate was best was not clear. Incorporating distribution information yielded results more consistent with population trajectories of the 2 species, as it estimated a high bycatch for *D. gibsoni* (whose population is static or declining), and a low bycatch for *D. antipodensis*, whose population is increasing (Elliott & Walker 2005). The interaction method indicates bycatch may have been substantially under-reported for *D. gibsoni*, and that the unobserved fleets in the central Tasman Sea may be having more effect on the population than assumed from fixed average bycatch rates.

If the assumption that albatross bycatch is proportional to the interaction between fishing effort and the foraging distribution of the birds holds, then an interaction index should provide a useful method of identifying areas of ocean where albatrosses are at the greatest risk of incidental death in fisheries, and where they might usefully be protected by closures of fisheries. We estimate that albatross bycatch might be reduced significantly by closing only 1 or 2 5° squares. A more detailed comparison of the seasonal distribution of albatrosses and fishers might allow the closure of smaller areas for shorter periods to achieve the same reduction in albatross bycatch. If the 3 5° squares that had the highest interaction indices were closed to fishing, 46% of potential interactions between *D. gibsoni* and fisheries and 42% of potential *D. antipodensis*/fisheries interactions would be avoided. For *D. gibsoni*, excluding from the fishery a 5° square off eastern Tasmania would result in

the greatest reduction, followed by a neighbouring square in the western Tasman Sea, and a square off the south-western coast of New Zealand. For *D. antipodensis*, closing the square north-east of New Zealand would be most beneficial, followed by a square in the Bounty Trough, and 1 in the mid-western South Pacific. Four of these 6 squares lie within the New Zealand and Australian EEZ's, making regulatory action potentially possible.

Although *D. antipodensis* overlapped substantially, and *D. gibsoni* significantly, with longline fisheries during most of their adult life-history stages, there is currently little longline fishing for tuna near their breeding islands. There are however, significant demersal and trawl fisheries on both the Campbell Shelf and the Chatham Rise. The high densities of albatrosses around the Auckland and Antipodes Is means these are areas where even a small amount of fishing could result in significant losses of birds, particularly if it was conducted during the courting and hatching period in late summer when birds forage near the islands. *D. antipodensis* have been killed at this time on the Chatham Rise by collisions with fishing equipment (Baird 2001; banding recovery data).

Wandering albatrosses may also have benefited from fisheries discards. There have been occasional reports of *D. antipodensis* foraging on discards from the ling longline fleet in shelf waters of the Chatham Rise (Neville Smith, pers comm.) and fisheries litter (hooks, nylon braid, plastic bags, fresh food scraps) are often found in chick regurgitations on both Adams and Antipodes Is, indicating that both species forage near boats.

Although fisheries constitute an easy food supply, there is also the risk to the birds from consuming dangerous food. Wandering albatrosses (*Diomedea exulans*) from Marion I and South Georgia often scavenge waste from Patagonian toothfish fisheries near their breeding islands (Nel *et al.* 2002; Xavier *et al.* 2004). Such scavenging was most common in years of low availability of natural food (Xavier *et al.* 2004), or during hatching, when birds could not feed far from the breeding island (Nel *et al.* 2002). Despite the increase in availability of offal around Marion I when the toothfish fishery started, breeding success did not increase there, perhaps because the large amounts of fisheries litter consumed by some chicks led to their poor condition and death (Nel *et al.* 2002).

The nature, intensity and timing of fisheries that are potentially harmful to *D. gibsoni* and *D. antipodensis* vary so much that it is difficult to assess their likely effects without the deployment of many more observers than has so far been possible. The arrival of new fisheries such as that for Patagonian toothfish, in previously un-fished areas, highlights the limitations of the "potential interaction index" attempted in this study.

Although fisheries may differ in the threat they pose to albatrosses, the behaviour of wandering albatross themselves is perhaps more predictable. We have tracked sufficient birds of both species for our maps to be likely to reflect their foraging distributions. The seasonal trends in habitat-use that we identified may help in interpreting the seasonably-variable bycatch rates reported in places such as south-eastern Australia (Gales *et al.* 1998). Some findings, such as the individual preferences in foraging area of both breeding and non-breeding birds, have been foreshadowed by earlier banding studies (Tickell & Gibson 1968) that telemetry of breeding *D. exulans* confirmed (Weimerskirch *et al.* 1993). Dietary studies suggested that *D. gibsoni* and *D. antipodensis* depended on different, characteristic, and geographically restricted species of squid, and hence separate foraging areas in the Tasman Sea and South Pacific Ocean (Imber 1992; pers. comm.). These independent studies provide confidence that the distribution patterns of our sample of satellite-tracked birds are representative of those of their species.

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CORRIGENDA

Walker, K.; Elliott, G. 2006. At-sea distribution of Gibson's and Antipodean wandering albatrosses, and relationships with longline fisheries. *Notornis* 53(3): 265-290.

Symbols were corrupted in the captions to several figures; captions with the correct symbols are reproduced below:

Fig. 7 All uplinks of 5 male (▲) and 4 female (●) breeding *D. gibsoni* tracked for periods during the hatch/guard stage 31 Mar-1 May in 1994, 1999-2000; and 10 male (■) and 12 female (×) breeding *D. antipodensis* tracked for periods during the hatch/guard stage 1 Apr-29 May in 1997-2000.

Fig. 8 All uplinks of 5 male (▲) and 3 female (●) courting *Diomedea gibsoni* tracked in-between courting sessions on Adams I from mid-Jan to mid-May in 2002 and 2003; and 3 male (■) and 3 female (×) courting *D. antipodensis* tracked in-between courting sessions on Antipodes I between 20 Feb and 30 Apr 2003.

Fig. 9 All uplinks from 3 juvenile *Diomedea antipodensis* satellite-tracked after they fledged from Antipodes I. The female (●) was tracked 27 Jan-8 Sep 2004, a male (○) from 16 Jan-29 Nov 2004, and a 2nd presumed male (×) from 16 Jan 2004-23 Feb 2005.

Fig. 10 All uplinks received during 7 months tracking of 2 adult non-breeding male *Diomedea gibsoni* from the end of courting on Adams I in mid-Mar to mid-Oct 2003, during which time they used 1.5 (○) and 1.2 (▲) ×106 km² of ocean respectively; and 11 months tracking of 2 adult breeding male *D. antipodensis* regularly returning to Antipodes I during incubation and chickrearing from early Feb 2000 to early Jan 2001 during which time they used 6.9 (■) and 11.7 (×) ×106 km² of ocean respectively.

Fig. 11 All uplinks from 2 male *Diomedea gibsoni*: the 1st bird (green symbols) tracked as a post-breeder from 2 Jan-13 Feb 1995 (■), then again while courting from 2 Feb-17 May and as a non-breeder 17 May-17 Oct 2003 (▲); and the 2nd bird (blue symbols) during incubation from 21 Jan-18 Feb 1995 (●), and again during incubation and later nest failure between 10 Feb and 25 Apr 1999 (×).

Fig. 15 Distribution of recoveries of 18 *Diomedea gibsoni* (▲) banded on Adams I (50°S, 166°E) and 35 *D. antipodensis* (●) banded on Antipodes Is (48°S, 178°E).