AT-SEA FORAGING DISTRIBUTIONS OF RADIO-MARKED CASSIN'S AUKLETS BREEDING AT TRIANGLE ISLAND, B.C., 2000

John L. Ryder[2], W. Sean Boyd[1], Steven G. Shisko[1], and Douglas F. Bertram[1,2]

[1] Pacific Wildlife Research Centre, Canadian Wildlife Service, Environment Canada,
RR#1, 5421 Robertson Road, Delta, British Columbia V4K 3N2

[2] Department of Biological Sciences, Simon Fraser University,
8888 University Drive, Burnaby, BC, V5A 1S6

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ABSTRACT

We conducted a radio-telemetry study to determine the at-sea foraging distributions of Cassin's Auklets (*Ptychoramphus aleuticus*) breeding at Triangle Island, British Columbia, as a follow up to a similar project in 1999. During the chick-rearing period from late May to June 2000, we captured 37 adults and attached radio-transmitters to them. We conducted aerial surveys to locate the radio-marked birds during two survey periods, 31 May-1 June and 15-16 June. We found the majority of marked birds concentrated in a relatively small area 30-60 km southwest of Triangle Island in waters >1000 m deep. Distributions were similar across the two survey periods, and also across days during the second period. We detected 91% of the radio-marked birds at-sea on at least one occasion. Males foraged significantly closer ($p<0.01$) to the colony than females. Birds from different areas of the colony had similar at-sea patterns of distribution. From 1999-2000, the patterns in Cassin's Auklet pelagic distribution showed remarkable similarity and birds were concentrated 50-60 km southwest of Triangle Island in both years. Our findings will be useful for future marine conservation efforts, and can assist decision-makers in mitigating anthropogenic threats to seabirds from non-renewable resource exploration and development, fisheries impacts, and other environmental impacts such as oil spills.

RÉSUMÉ

Nous avons mené une étude de radiomesure afin de déterminer la répartition de stariques de Cassin (*Ptychoramphus aleuticus*) à la recherche de nourriture en mer. Cette étude, qui portait sur des individus nichant à l'île Triangle, en Colombie-Britannique, faisait suite à des travaux semblables effectués en 1999. Durant la période de l'élevage des jeunes, de la fin mai jusqu'en juin 2000, nous avons capturé 37 adultes que nous avons munis d'émetteurs radio. Nous avons effectué des relevés aériens pour localiser ces adultes au cours de deux périodes, soit les 31 mai et 1er juin et les 15 et 16 juin. La majorité de ces oiseaux étaient concentrés dans une zone relativement peu étendue, à une distance de 30 à 60 kilomètres au sud-ouest de l'île Triangle, où l'eau a plus de 1 000 mètres de profondeur. La répartition des oiseaux suivis était comparable d'un jour à l'autre durant la seconde période de relevés et d'une période de relevés à l'autre. Nous avons localisé 91 % des oiseaux surveillés en mer à au moins une occasion. Les mâles cherchaient la nourriture beaucoup plus près ($p < 0,01$) de la colonie que les femelles. Le profil de la répartition pélagique des stariques de Cassin présente une remarquable similarité entre 1999 et 2000, les oiseaux étant concentrés à une distance de 50 à 60 kilomètres au sud-ouest de l'île Triangle les deux années. Les résultats obtenus seront utiles pour les futurs travaux de conservation des ressources marines et pourront aider les décideurs à réduire les menaces que font peser sur les oiseaux de mer les activités d'exploration et de mise en valeur des ressources non renouvelables et les pêches ainsi que les effets sur l'environnement d'autres phénomènes, comme les déversements d'hydrocarbures.

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INTRODUCTION

To facilitate the protection of seabirds in British Columbia, information is needed on their at-sea foraging distributions during the breeding season (Drever 1999, Burger *et al.* 1997, Gaston 1996). Marine Protected Areas (MPAs) have been proposed in areas where marine species congregate in high numbers (Petrachenko and Thompson 1998, Dunn and Morgan 1999). The Scott Island group is the most important site for breeding seabirds in British Columbia and was nominated by the Canadian Wildlife Service (CWS) as an Important Bird Area (IBA) in 1997 (Drever 1999). The islands support an estimated 2.2 million breeding seabirds (Rodway *et al.* 1990, 1992), including ca. one million pairs of Cassin's Auklets (*Ptychoramphus aleuticus*) or 55% of the world's population (Rodway *et al.* 1990, Canadian IBA database 1998). Surveys in 1989 estimated 548 000 breeding pairs of Cassin's Auklets on Triangle Island (Rodway *et al.* 1992). The at-sea distribution of Cassin's Auklets in the area was the subject of much speculation until a telemetry project in 1999 provided the first data on the distributional patterns of known breeders from Triangle Island (Boyd *et al.* 2000).

In 2000, we continued our investigation of the at-sea foraging distributions of breeding Cassin's Auklets at Triangle Island. A second year was required to examine inter-annual variation in at-sea distributions of individuals. Such information will be useful to stakeholders when delineating MPA boundaries for the Scott Island group. Cassin's Auklets were selected because they are one of the focal species for research, their burrow sites are readily accessible, they forage offshore during the daytime (Vermeer *et al.* 1985, Ainley *et al.* 1996) and they tolerate handling. An additional consideration was that Cassin's Auklets provision chicks primarily with zooplankton (Vermeer 1981, Burger and Powell 1989, Bertram *et al.* 2001) and collaborative investigations on the distribution and abundance of zooplankton species have been undertaken with Fisheries and Oceans Canada since 1998.

METHODS

Study area

Triangle Island (50? 52’N; 129? 05’W) is off the northwest tip of Vancouver Island, 46 km off Cape Scott. It is the outermost island in the Scott Islands chain (Figs. 1A and B). Port Hardy (50? 42’N; 127? 25’W) on the north-east coast of Vancouver Island was used as the base camp for the telemetry flights (Fig. 1A).

Maximum detection distance of individual transmitters

On 22 May, we determined the maximum detection distance for each transmitter prior to deployment on birds (Table 1). We estimated the maximum detection distance (i.e. the horizontal distance) from the research station (Fig. 2) to each transmitter present in a zodiac boat positioned in South Bay. We activated transmitters, separated them by a distance of 5-10 cm, and taped them to a paddle. One person in the zodiac boat held the paddle vertically while another person navigated a transect line south from South Bay toward the open ocean using a handheld GPS unit (Garmin model 12XL; Garmin Corp.? , Olathe, Kansas). Two people stationed on-shore used ATS receivers connected to H-antennae to continuously scan for each transmitter. We scanned a transmitter at the maximum limit of its range for 10-15s to confirm that its signal could no longer be detected. Following this confirmation, we recorded the Universal Transverse Mercator (UTM; zone 9 / spheroid NAD 83) location of the boat by GPS. We used these data to determine if a positive relationship existed between a given transmitter’s maximum horizontal detection distance and the number of times it was detected during the aerial surveys.

Adult capture and transmitter attachment

From 23 May to 19 June, 2000, we captured and banded 37 adult Cassin’s Auklets at three locations in West Bay (Fig. 2) and fitted them with radio-transmitters. Our capture dates were timed to match the breeding phenology (i.e. similar chick rearing stage) of 1999. We used two capture methods: 1) adults removed from burrows by hand, and 2) adults captured by a stationary net as they returned to the colony. We affixed transmitters to birds using the protocol described in Newman *et al.* (1999). We used Advanced Telemetry Systems (ATS) transmitters with subcutaneous anchors (Model 394; Advanced Telemetry Systems? , Isanti, Minnesota). Each transmitter weighed approximately 2.2 g (or < 2% of mean adult mass; Vermeer 1981) and had an expected lifespan of approximately 45 d. We used a sterilized 18-gauge hypodermic needle to perforate a small hole through the interscapular epidermis for anchor insertion. To limit handling time, we did not anesthetize birds during the procedure. We applied marine epoxy (Marine epoxy #332? , Titan Corporation, Lynnwood, Washington) to the transmitter and back feathers to hold the transmitter in place below the anchor site. This protocol has been used successfully on Cassin's Auklets at Triangle Island, and on Marbled Murrelets in Desolation Sound, B.C. (Boyd *et al.* 2000, Lougheed 2000, Hull *et al.* 2000).

From 23-27 May and on 6-7 & 19 June, we removed and radio-marked 21 adults from burrows containing nestlings. One parent from each burrow was radio-marked. Nestlings at these burrows were at approximately the mid-point of the 39-45 d development period. We captured birds from two plots in West Bay: 16 were captured from plot A and 5 from plot B (Fig. 2). In plot A we attempted to recapture individuals that were successfully radio-marked in 1999 and were rearing chicks in 2000. We captured all birds from both plots between the hours of 23:32 to 02:25, subsequent to their return to the colony. We returned birds to the burrow immediately after transmitter attachment. We monitored the nestlings from these known location burrows for the duration of the study to determine their individual fates.

From 27-28 May and on 12 June**,** we captured 16 adults using soft plastic "pheasant" nets between the hours of 22:52 to 23:41 as they returned to the colony to deliver food-loads to nestlings. We only radio-marked adults carrying food-loads. We erected the net (approximately 15 m x 3 m) vertically between two guyed plastic poles at the net capture site (Fig. 2). We attempted to recapture individuals that were successfully radio-marked in 1999 by using the same capture location.

We assigned gender to adults from bill depth measurements according to the criteria developed by Knechtel (H. Knechtel, SFU, unpubl. data). We classified individuals with bill depth > 9.9 mm as male and < 9.7 mm as female; we did not attempt to assign sex when bill depth was between 9.7-9.9 mm.

Colony detection of radio-marked individuals

We positioned a remote telemetry recording system (DCC II, Model D5041; Advanced telemetry systems Ltd.?, Isanti, Minnesota) at the north end of West Bay on Triangle Island (Fig. 2) from 24 May to 7 July, 2000, to monitor the attendance behaviour of radio-marked birds at the colony prior to the chick fledging period. We linked the DCC II to a receiver (Model R4000; Advanced Telemetry Systems Ltd.?, Isanti, Minnesota) and an H-antenna, and it was powered by a 12V deep-cycle battery connected to a solar panel (Model SM75, Siemens Solar Industries?, Camarillo, California). We scanned frequencies at 5-10 s intervals to monitor arrival times. Following detection of a specific frequency, the DCC II reduced the scan time to 15 min intervals until the bird departed the colony. We used a tadiran lithium inorganic reference transmitter (164.613) recording at 15 min intervals to confirm that the equipment functioned properly during the study.

Aerial detection of radio-marked individuals

We conducted aerial telemetry surveys over two periods, 31 May-1 June and 15-16 June, 2000. During each survey, we flew at ca. 3000 m altitude and at ca. 130-140 km h^{-1} in a single-engine Dehaviland Beaver on floats. Each survey lasted ca. 4.5 h, including transit time to and from the base camp. We conducted surveys during daylight hours when adult birds were foraging at sea. We arranged telemetry grid transects primarily in east-west directions.

We flew the initial survey on 31 May from 14:00 to 17:15h, at first along the shelf break southeast of Triangle Island (Fig. 3A). Large numbers of Cassin's Auklets had been seen during boat-based surveys 3-4 weeks earlier in this area (Dave Mackas, DFO, pers. comm.). In the late afternoon, we flew through the area where most marked birds were found in 1999. Using the information from 31 May, we flew a wider grid pattern on the morning of 1 June from 09:00 to 13:30h starting north of Triangle Island and working east-west (Fig. 3B). The line transects were separated by a distance of 15 km on this survey. After re-fueling, we flew a more focused grid pattern on the afternoon of 1 June from 15:00 to 19:00h to survey the area where we found most marked birds in the morning (Fig. 3C). The line transects were separated by a distance of 7.5 km on this survey. In the afternoon of 15 June from 14:30

to 19:30h we flew the same grid pattern as the morning of 1 June to determine if the at-sea distribution of marked birds changed across the 2-week period (Fig. 4A). On 16 June from 09:45 to 14:30h we flew the same grid pattern as the afternoon of 1 June survey (Fig. 4B).

We used four-element Yagi antennae mounted to the aircraft struts for all surveys. We scanned radio frequencies at 2 s intervals using an ATS scanner/receiver (Model R4000; Advanced Telemetry Systems Ltd.? , Isanti, Minnesota). When a transmitter was detected, its signal strength and direction (with respect to flight path) were recorded along with the location (latitude, longitude) of the aircraft using GPS. We did not attempt to pinpoint the exact location of each transmitter (eg., by circling at low altitude) because such a procedure would have consumed too much fuel and time. Instead, we recorded all detections for each radio-marked bird and determined its most likely location from the available data (Fig. 5).

Estimating the error in determining at-sea locations

We attached two test transmitters (164.982 and 164.993) to a fixed buoy in South Bay on 12 June (Fig. 6A). Our goal was to evaluate the accuracy of our at-sea positioning protocol used in 1999-2000 by comparing inferred location estimates from aerial telemetry to a known fixed location on the ocean. We deployed the transmitters from 12 to 16 June and we estimated their inferred locations during the aerial surveys conducted on 15 and 16 June. We anchored the buoy approximately 1 km from shore to provide an unobscured line of sight for the telemetry flights (e.g. equal probability of detection from any position on the survey grid without ground interference from the island). To minimize potential survey bias, we did not inform the flight crew that these test transmitters were attached to the buoy. We used a differential GPS (DGPS) antenna to estimate the buoy location in South Bay. The horizontal accuracy of the DGPS system is ? 10m (95% of the time). The differential ground station that we used for this exercise was located at Amphitrite Point, B.C. (48? 55'N; 125? 33'W) on frequency 315 KHz. We used the distance from the inferred location to the fixed location to provide an estimate of the error in our positioning. The test transmitters in South Bay were not bracketed within the aerial telemetry grids, and were located approximately 4 km east of the primary survey transects on both dates (see Fig. 4).

Additionally, we estimated the locations for two adults (164.823 and 164.863) present in burrows on the morning and afternoon of 1 June surveys for an aerial to ground evaluation of our positioning accuracy (Fig. 6B). We reported the accuracy of our positioning protocol in 1999 using this technique (Boyd *et al.* 2000). These transmitters were approximately 4 km east of the primary survey transects on this date, similar to the 15 and 16 June flights (see Figs. 3B,C).

Estimating the area of telemetry survey coverage

We derived an estimate of aerial survey coverage from the maximum detection distances from the aircraft to the inferred locations of birds at-sea for both the morning of 1 June and 15 June surveys. We used this estimate to calculate the area covered by telemetry for all survey dates (Figs. 7 and 8). For each transmitter, we measured the distance from the inferred location to the outermost detection event recorded at the aircraft. We calculated the mean maximum detection distance from these estimates. This distance represents the mean horizontal distance from the aircraft to inferred locations rather than the diagonal (or hypotenuse) distance from the aircraft to the inferred location. We used a paired t-test to determine if these detection distances were significantly different across survey periods. We also estimated maximum detection distances for the two fixed location test transmitters on 15 and 16 June for comparison.

Mapping and analyses of foraging locations

We plotted at-sea locations in lat/long coordinates and later converted them to Albers projection for mapping and analysis using Arcview GIS software (Version 3.2; Environmental Systems Research Institute Inc.? , Redlands, California). We determined the inferred location of each radio-marked bird by plotting aircraft location and transmitter signal strength/direction. Position accuracy was related to the quantity and strength of detections recorded for each transmitter (eg., individuals with >10 strong signals were likely positioned more accurately than birds with only one or a few weak signals). Our assumptions were that (1) individuals did not move during each survey, and (2) all transmitters had an equal probability of detection. The factors that can lead to violation of these assumptions are discussed below.

We estimated “modified” Jenrich-Turner home ranges for marked birds on the morning of 1 June and 15 June using the Arcview GIS Animal Movement Analysis Extension (Jenrich and Turner 1969, Hooge and Eichenlaub 1997). Typically, home range analyses generate polygons for specific individuals detected on multiple occasions over time. In our “modified” approach, we used the inferred location of each marked bird as the sampling unit to calculate the arithmetic mean centre of activity for all birds. Distributions with 50% and 95% probability ellipses were generated and compared. The grids flown on the afternoon of 1 June and 16 June were too small (i.e. focused and limited coverage) to warrant this type of analysis.

RESULTS AND DISCUSSION

Colony detections

We found that 27 of 37 radio-marked birds (73%) regularly attended the colony on a daily or bi-daily basis (11 males, 7 females, and 9 undetermined, Table 2). We radio-marked 2 of these 27 birds after the aerial surveys had concluded. We recaptured 2 of 37 birds from burrows where they were radio-marked and banded in 1999 (cross reference frequencies 164.173 and 164.124 from 1999 with 164.411 and 164.423 for 2000, respectively). In both cases, we found no evidence that the birds had been radio-marked the previous year (e.g. no anchor and no scar tissue was present at the anchor site). We did not recapture any birds that were radio-marked and banded at the net site in 1999.

We did not detect 3 of 35 birds that were radio-marked prior to the aerial surveys (9%), either at the colony or during the at-sea surveys (Table 2). Their transmitters may have failed, the birds may have died, or they may have left the study area. The nestlings from two of these adults (164.411 and 164.544) were emaciated and left the burrows under-developed; we could not determine the fate of the third nestling as the adult was captured at the net and its burrow was not located. Of note, the estimated failure rate of the same ATS transmitters attached to Marbled Murrelets in Desolation Sound, B.C., was 5-6% in 2000 (R. Bradley, SFU, pers. comm.).

We detected 6 birds during the at-sea surveys that had abandoned the colony (see Table 2). We caught 3 of these 6 birds in burrows; two of the burrows successfully fledged chicks and the third chick (adult 164.912) left the burrow under-developed. We could not determine the fates of the other 3 nestlings as the adults were captured at the net, and their burrows were not located. Most birds that we radio-marked returned to the colony within 1-2 days following radio attachment, with the following exceptions: DCC data showed that adult 164.793 was absent from 28 May to 4 June and adult 164.802 was absent from 28 May to 7 June, but the birds returned nightly after this period. We caught both these individuals at the net. These periods of absence may be indicative of an initial handling effect or the birds may have been non-breeders with irregular attendance patterns (colony attendance patterns for all individuals will be treated elsewhere).

We activated the DCC prior to the aerial surveys, and it was used to confirm which adults were present at the colony during the flights. We also conducted manual (hand-held) scans on 31 May and 1 June to validate the DCC results. We confirmed that no adults were present at the colony from scans conducted on 31 May at 13:00h. We confirmed that 2 adults (164.823 and 164.863) were present at the colony on both scans conducted on 1 June at 13:37h. DCC data showed that no adults were present at the colony on 15 and 16 June.

We tested for the effect of capture technique and handling time on subsequent detection of individuals at the colony. We found that for birds detected at the colony, the proportion of returning adults taken from burrows (0.71 ? 0.21) was not significantly different than for adults caught at the net (0.75 ? 0.23 (95% C.I)) (2-tailed t-test, t = 0.27, df = 35, p = 0.81). Handling time did not appear to affect attendance behaviour. Average handling time was 28 min for each bird removed from the burrow (range 20-35 min) and 66 min for birds captured at the net (range 19-113 min). We compared the subsequent colony detections of adults that were handled for ? 30 minutes to adults handled for > 30 minutes. We found no significant difference in the proportion of adults that returned to the colony that were handled for ? 30 min. (0.72 ? 0.22) compared to those handled for > 30 min. (0.68 ? 0.22) (2-tailed t-test, t = 0.27, df = 35, p = 0.79).

At-sea detections

We detected 32 of 35 (91%) birds that were radio-marked prior to the aerial surveys on at least one occasion at-sea (Table 2). Of these, 26 attended the colony and we detected all of them at-sea on at least one occasion. An example of high quality/quantity telemetry data collected for one bird (164.912) on 16 June is provided in Figure 5. The relative signal strength and direction from the transect line for each detection are shown along with the inferred location of the bird. We did not detect the anticipated positive relationship between the number of detections and transmitter quality (as determined from the maximum horizontal detection distance for each transmitter), except on the morning of 1 June survey (Fig. 9). Contrary to what we expected, relative transmitter signal strength (e.g. strong versus weak) did not result in differences in the number of detections during a given survey (Fig. 10). This suggests that our survey design was robust in that we detected all radios with equal frequency, and that factors other than transmitter quality per se were more likely to influence the probability of at-sea detection.

The patterns found on morning of 1 June (Fig. 11B) and 15 June (Fig. 12A) represent the at-sea distributions of Cassin's Auklets during the chick rearing period at Triangle Island in 2000. We flew large replicated survey grids on these two dates, and the extensive area covered around Triangle Island facilitated a robust comparison of distributions across days. On the morning of 1 June, we detected 15 of 23 (65%) marked birds at-sea (Fig. 13A; mean distance from Triangle Island = 37 km (SE=4), maximum = 56 km). We detected two of these individuals only once (Fig. 10A). Nine birds were male, 3 female, and 3 undetermined (Fig. 14A). On 15 June, we detected 25 of 35 (71%) marked birds at-sea (Fig. 13B; mean distance = 41 km (SE=3), maximum = 67 km). We detected two of these individuals only once (Fig. 10B). Ten birds were male, 7 female, and 8 undetermined (Fig. 14B).

At-sea distributions on the afternoon of 1 June (Fig. 11C) and 16 June (Fig. 12B) are presented for comparison. On the afternoon of 1 June, we detected 18 of 23 (78%) marked birds at-sea (mean distance = 41 km (SE=2), maximum = 57 km). Eight of these individuals were male, 6 female, and 4 undetermined (Fig. 15A). On 16 June, we detected 28 of 35 (80%) marked birds at-sea (mean distance = 46 km (SE=2), maximum = 74 km). Eleven of these individuals were male, 8 female, and 9 undetermined (Fig. 15B). At-sea distributions for the 31 May test flight are also presented (Fig. 11A). We detected sixteen marked birds on this date, but only one was located in the area southeast of Triangle Island where concentrations of Cassin's Auklets had been seen during the ship surveys in early May.

We detected more birds in the smaller survey grids (afternoon of 1 June and 16 June) relative to the larger survey grids (morning of 1 June and 15 June). This is due to the fact that the transects were closely spaced on these surveys, and the more focused survey coverage increased the probability that we would detect a marked bird inside the grid.

There were apparent sex-specific differences in the patterns of distribution across survey periods. For the morning of 1 June and 15 June surveys pooled, we found 15 males significantly closer to the colony (mean distance of 37 km ? 9 km (95% C.I.)) than 8 females (mean distance of 54 km ? 4 km (95% C.I.)) (Mann-Whitney U test, ?^{2} = 7.35, df = 1, p = 0.0067).

We found no apparent within-survey differences in the distributions of birds captured from the two separate plots (Fig. 16). This confirmed that birds from different areas of the colony had similar at-sea patterns of distribution. We found that birds that were no longer attending the colony had similar distributions to birds that were provisioning nestlings (Fig. 17). We detected 1 of 2 recaptured and re-marked adults from 1999 on all survey dates in 2000. This individual was found in the same general area in both years, but was closer to the colony in 2000 (Fig. 18).

Accuracy of estimating at-sea locations

During the aerial surveys, we detected the test transmitters 164.982 and 164.993 on 9 and 13 occasions on 15 June and on 6 and 15 occasions on 16 June, respectively. Distances from the estimated (or inferred) locations to the true locations on 15 June were 2.9 km for 164.982 and 4.8 km for 164.993. For 16 June, the distances were 2.4 km for 164.982 and 3.2 km for 164.993. These errors are relatively low given the fact that the test transmitters anchored in South Bay were outside the primary aerial telemetry survey grids. We expect that the true location would have been estimated more accurately had the buoy been inside the survey grids.

We also estimated the locations for the two birds present in burrows on 1 June during the aerial surveys. We detected frequency 164.823 on both the morning and afternoon surveys on 2 and 3 occasions, respectively. We detected frequency 164.863 on the afternoon survey on 5 occasions. The distance from the estimated location to the true location on the morning of 1 June was 3.2 km for 164.823. For the afternoon of 1 June, distances were 2.8 km for 164.823 and 2.2 km for 164.863. The differences between the estimated and true locations from this ground comparison are also relatively low given the fact that Triangle Island was outside the primary aerial telemetry survey grid.

The above findings suggest that the accuracy of plotting the inferred locations for birds detected ? 2 times on a given day would be high if the assumptions of (1) no individual movement, and (2) equal probability of detection for all transmitters were met. For all survey dates combined, we detected 94% of birds ? 2 times.

Aerial survey coverage

The mean maximum horizontal detection distance from the aircraft to inferred locations was 28 km ? 8 km (95% C.I.) for both the morning of 1 June and 15 June surveys pooled. We found no significant difference in the mean maximum detection distances for 10 birds found on both dates (paired t-test, $t = 1.64$, $df = 9$, $p = 0.13$). The mean and maximum areas covered on the morning of 1 June and 15 June were 2.4 million and 2.9 million hectares, respectively. For the afternoon of 1 June and 16 June, the areas were 1.7 million hectares (max = 2.2) and 1.8 million hectares (max = 2.3), respectively. The area covered on the 31 May test flight was 1.9 million hectares (max = 2.4). The confirmed mean maximum horizontal detection distance from the aircraft to the test transmitters anchored in South Bay at Triangle Island was 30 km (range 18-60 km) for the 15 and 16 June surveys, showing good agreement with the maximum estimate obtained from the inferred locations.

Foraging ranges and distributions

In general, we found that most birds detected at-sea on the morning of 1 June and 15 June were concentrated in an area 30-60 km southwest of Triangle Island, and the distributions were similar across the two survey periods. We also observed similar distributions on the afternoon of 1 June and 16 June. A concurrent telemetry study conducted at San Miguel Island, California, from 1999-2000 found that Cassin's Auklets were concentrated approximately 10-25 km from their colony and utilized the same general area in the California Bight in both years (J. Adams, USGS-BRD, unpubl. data). Other planktivorous auklets such as the Least Auklet in the Bering sea region had foraging radii of 5-56 km (Obst *et al.* 1994); Least Auklets have been detected 25-50 km from their colonies foraging close to fronts (Russell *et al.* 1999). Hunt *et al.* (1993) found that Crested Auklets foraged between 55-110 km from St. Lawrence Island and King Island in the Bering Sea. Foraging distributions for piscivorous seabirds such as Common Murres, Razorbills and Atlantic Puffins were reported to range from 2 to >10 km from colonies (Wanless *et al.* 1990). Thick-billed and Common Murres foraged at distances of 50-80 km from colonies in the Chukchi Sea (Hatch *et al.* 2000). Marbled Murrelets in British Columbia commuted 12-102 km from nest sites to foraging sites in 1998 (Hull *et al.* 2000).

The Jenrich-Turner ellipses differed in area covered but were centred over approximately the same area of open ocean. The 95% probability ellipse for the morning of 1 June covered an area of 524 293 ha with an arithmetic mean point 33 km southwest of Triangle Island (Fig. 19A). The 95% probability ellipse for 15 June covered an area of 473 264 ha with an arithmetic mean point 39 km southwest of Triangle Island (Figs. 20A). Hence, between the morning of 1 June and 15 June the centre of distribution shifted only 6 km to the northwest (Figs. 19 and 20).

The majority of marked Cassin's Auklets foraged 5-40 km seaward of the 200 m shelf break isobath. On the morning of 1 June and 15 June, we found only 5 of 15 (33%) and 4 of 25 (16%) adults at the continental shelf margin between the coast and the 200 m isobath, respectively. We found one adult on each date between the 200 m and 1000 m isobaths. All other marked birds were in water 1500-2000 m deep. In contrast to our findings, other studies in California (Briggs *et al.* 1987, Ainley *et al.* 1996, J. Adams, USGS-BRD, unpubl. data), Alaska (Sanger, 1987) and British Columbia (Vermeer *et al.* 1985) suggested that Cassin's Auklets foraged near the continental shelf break during the breeding season. Previous studies have documented aggregations of Cassin's Auklets and other seabirds in the vicinity of offshore seamounts (Vermeer *et al.* 1985, Haney *et al.* 1995); however, no such features occur where we located marked birds.

We detected nine radio-marked birds on both the morning of 1 June and 15 June (Fig. 21). These birds moved mean and maximum distances of ca. 23 km (SE=5) and 59 km, respectively, between periods. As with the Jenrich-Turner home range distributions discussed above, the area over which these marked birds were distributed was similar for both dates. We detected 16 radio-marked birds on both the afternoon of 1 June and 16 June for dates with focused survey coverage (Fig. 22). These birds moved mean and maximum distances of ca. 26 km (SE=3) and 53 km, respectively, between periods. We observed a shift in distribution from west to southwest of Triangle Island (seaward of the 1000 m isobath) for most birds across this period. Across days (from 15 to 16 June), the movements of 25 marked individuals were less pronounced. Mean and maximum distances moved were 17 km (SE=2) and 42 km, respectively (Fig. 23).

Factors that can influence the probability of detection at-sea

Our ability to accurately estimate a single best location is complicated by a number of factors that can affect the quantity and quality of signals received, including: transmitter strength, position of antenna on the bird, submerged (diving) activity, atmospheric conditions, signal interference from ship traffic, and the spatial coverage of survey grids. Bird locomotion and behaviour can also introduce variation into the probability of at-sea detection (i.e. if the antenna of a strong transmitter is partially submerged due to preening or other activity it can substantially reduce the signal strength). These compounded sources of variation likely led to highly variable detection probabilities, even for a single transmitter.

One example of the effects of these sources of error on positional accuracy can be found in our analysis of within-day movements for 1 June. We found that twelve radio-marked birds moved mean and maximum distances of ca. 24 km (SE=4) and 57 km, respectively, between the morning and afternoon surveys (Fig. 24). In general, the distributions shifted from an area southwest of the colony to a more concentrated area west of the colony. However, a portion of the apparent movement might be explained by differences in our sampling design and/or other factors discussed above rather than being solely attributable to individual movements. We recorded fewer and weaker detections on the morning survey when area coverage and transect separation distances were higher. In this case, focused survey coverage and less spatial separation between transects on the afternoon survey likely resulted in improved accuracy in estimating locations relative to the morning survey.

The tradeoff in the design of sampling grids is that large grids provide extensive survey coverage, but there is a reduced probability of either a) detecting an individual, or b) plotting the location of an individual accurately. Our survey grids are designed to cover large areas of ocean, and exact locations are difficult to pinpoint as we would have to break transect and circle individual marked birds at low altitude. As discussed earlier, this latter approach to pinpoint individuals is not feasible for long distance offshore flights when fuel and time are limited. Although our protocol is subject to the above sources of error, we argue that our location accuracy is sufficient for examining broad scale patterns in distribution, particularly given the short duration of our surveys.

It is, however, important to consider these potential sources of error when estimating locations. We are considering further evaluation of our positioning protocol accuracy by flying identical morning and afternoon sampling grids in 2001 and pinpointing a small sub-sample of marked birds (by flying tight circles around them) on both occasions. This will allow us to better refine our inferred location estimates, and to further quantify within-day movements. This exercise will be useful for comparing inferred locations to exact locations under conditions when assumptions (1) and (2) cannot be met for most individuals (assumptions are discussed on p. 6).

Summary

We found the majority of marked birds concentrated in a relatively small area 30-60 km southwest of Triangle Island in waters >1000 m deep in June 2000. Distributions were similar across the two survey periods, and also across days during the second period. We detected 91% of the radio-marked birds at-sea on at least one occasion. We found that males foraged significantly closer to the colony than females. We observed no differences in the patterns of distribution for adults captured from the two study plots. This finding confirmed that birds from different areas of the colony had similar at-sea patterns of distribution. We found that birds that had abandoned the colony had similar distributions to birds that attended the colony. Data from a single recaptured adult from 1999 showed that it was closer to the colony in 2000. Our positioning protocol was highly accurate in predicting a fixed at-sea location when the assumptions of 1) no individual movement, and 2) equal probability of detection were met under controlled conditions. At-sea, we detected some movement of individuals between the morning and afternoon survey periods on 1 June 2000 (mean distance of 24 km moved between surveys for 12 individuals), and further research is required to quantify the effect of these movements on our positional accuracy. However, on a large geographic scale we argue that these localized individual movements are insignificant in the context of identifying key areas for marine conservation.

The patterns in Cassin's Auklet pelagic distribution showed remarkable similarity from 1999-2000, and birds were concentrated 50-60 km southwest of Triangle Island in both years. Our findings will be useful for future marine conservation efforts, and can assist decision-makers in mitigating anthropogenic threats to seabirds from non-renewable resource exploration and development, fisheries impacts, and other environmental impacts such as oil spills.

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Table 1: Maximum horizontal at-sea detection distances of individual transmitters determined from ground station in South Bay on 22 May 2000.

Frequency[1]	Maximum detection distance (km)			
	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 - 2.5
.173	x			
.185	x			
.802	x			
.812	x			
.823	x			
.154		x		
.782		x		
.793		x		
.114			x	
.192			x	
.411			x	
.423			x	
.454			x	
.462			x	
.473			x	
.513			x	
.775			x	
.833			x	
.843			x	
.932			x	
.943			x	
.993			x	
.523				x
.544				x
.553				x
.573				x
.592				x
.863				x
.873				x
.882				x
.893				x
.912				x
.923				x
.951				x
.964				x
.973				x
.982				x

[1] Frequency prefix is 164 (Mhz)

Table 2: Summary of transmitter attachment dates and post-release detections.

Frequency[1]	Capture date and time		Capture Plot	Capture method	Adult Sex	Detected at colony[2]	Detected on ocean	
						Detected (x)	Detected (x)	Detection date(s) May to June
.114	23 May	23:32	A	BUR		x	x	31,1,15,16
.154	24 May	00:19	A	BUR		x	x	31,1,15,16
.173	24 May	00:52	A	BUR	F	x	x	1
.185	24 May	01:27	A	BUR	F		x*	1,16
.192	25 May	00:04	A	BUR	F	x	x	31,1,15,16
.411	25 May	00:55	A	BUR☞	M			
.423	25 May	01:34	A	BUR☞		x	x	31,1,15,16
.454	25 May	02:15	A	BUR	F		x*	1,15,16
.462	25 May	23:46	A	BUR	M	x	x	31,1,15,16
.473	26 May	01:00	A	BUR	M	x	x	31,1,15,16
.513	26 May	01:40	A	BUR	M	x	x	31,1
.523	26 May	02:05	A	BUR		x	x	31,1,15,16
.544	26 May	23:50	A	BUR	M			
.553	27 May	22:52	A	NET	M	x	x	31,1,15,16
.573	27 May	00:40	A	BUR	M	x	x	1,15,16
.592	27 May	22:58	A	NET	F	x	x	31,1,15,16
.775	27 May	23:08	A	NET	M		x*	1
.782	27 May	23:09	A	NET	M		x*	1
.793	27 May	23:10	A	NET	M	x	x	1,16
.802	27 May	23:10	A	NET	M	x	x	31,1,15,16
.812	28 May	23:00	A	NET	F	x	x	31,1,15,16
.823	28 May	23:20	A	NET		x	x	31,15,16
.833	28 May	23:21	A	NET	M	x	x	31,1,15,16
.843	28 May	23:21	A	NET	M	x	x	31,1,15,16
.863	28 May	23:23	A	NET	M	x	x	31,15,16
.873	06 Jun	23:55	B	BUR	M	x	x	15,16
.882	07 Jun	00:30	B	BUR	F	x	x	15,16
.893	07 Jun	01:03	B	BUR		x	x	15,16
.912	07 Jun	01:38	B	BUR	M		x*	15,16
.923	07 Jun	02:25	B	BUR		x	x	15,16
.932	12 Jun	23:25	A	NET		x	x	15,16
.943	12 Jun	23:30	A	NET		x	x	16
.951	12 Jun	23:36	A	NET	F		x*	15,16
.964	12 Jun	23:41	A	NET	F			
.973	12 Jun	23:23	A	NET	F	x	x	15,16
.982?	19 Jun	01:30	A	BUR	F		N/A	N/A
.993?	19 Jun	00:01	A	BUR	F	x	N/A	N/A

1 frequency prefix is 164 (Mhz)

2 colony detection of radio-marked individuals based on data collected from 24 May to 7 July, 2000. Individuals undetected at ?1d post-attachment were considered to have abandoned the colony and/or the transmitter failed (detected = x).

☞ recaptured adult from 1999

* adult detected on ocean following confirmation it had abandoned the colony (no longer feeding the nestling)

? transmitters deployed after flights had ended

N/A = not available / attached to birds after flights had ended on 16 June

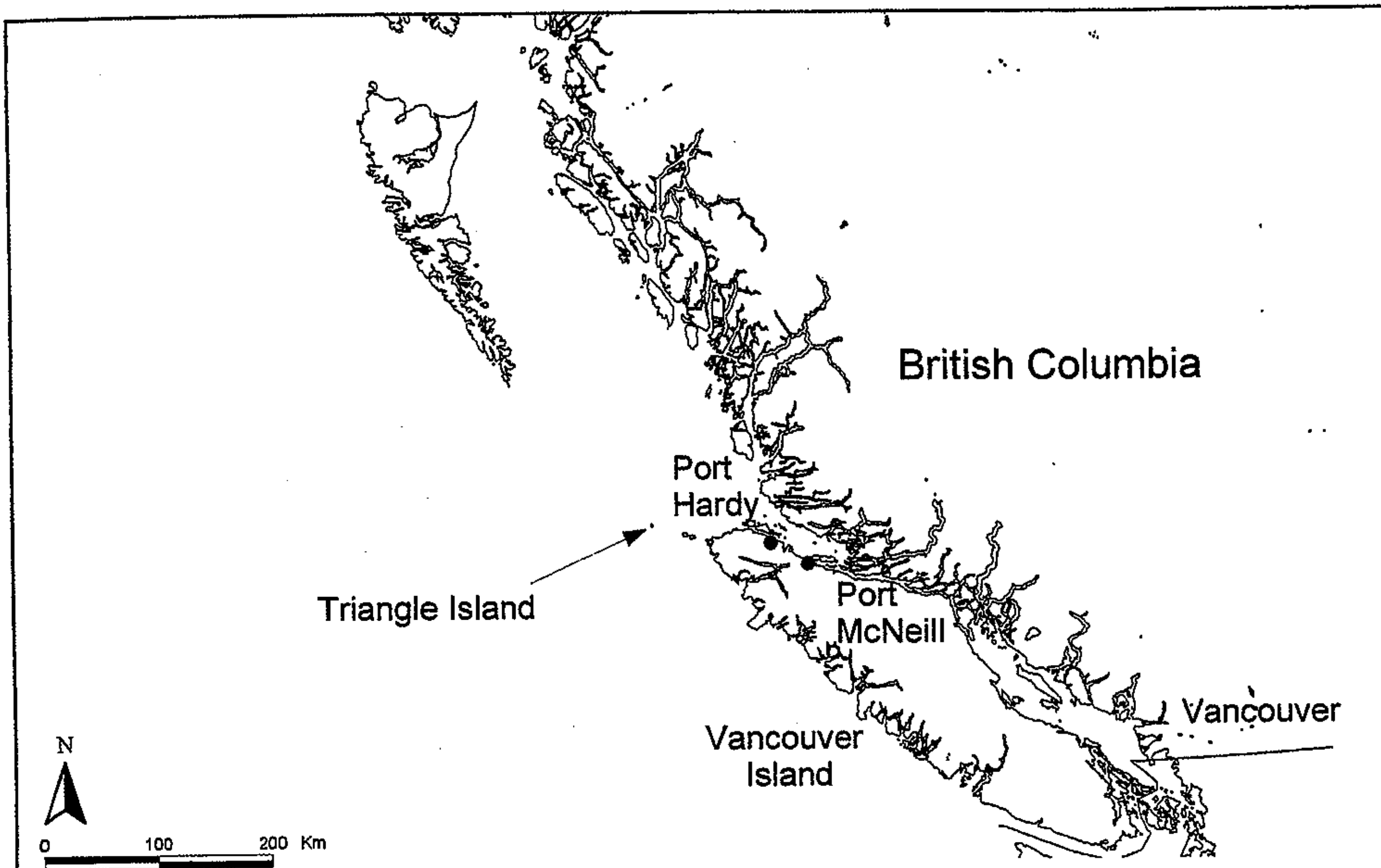


Figure 1A. Map of British Columbia showing Vancouver Island and Triangle Island (50 52N, 129 05W).

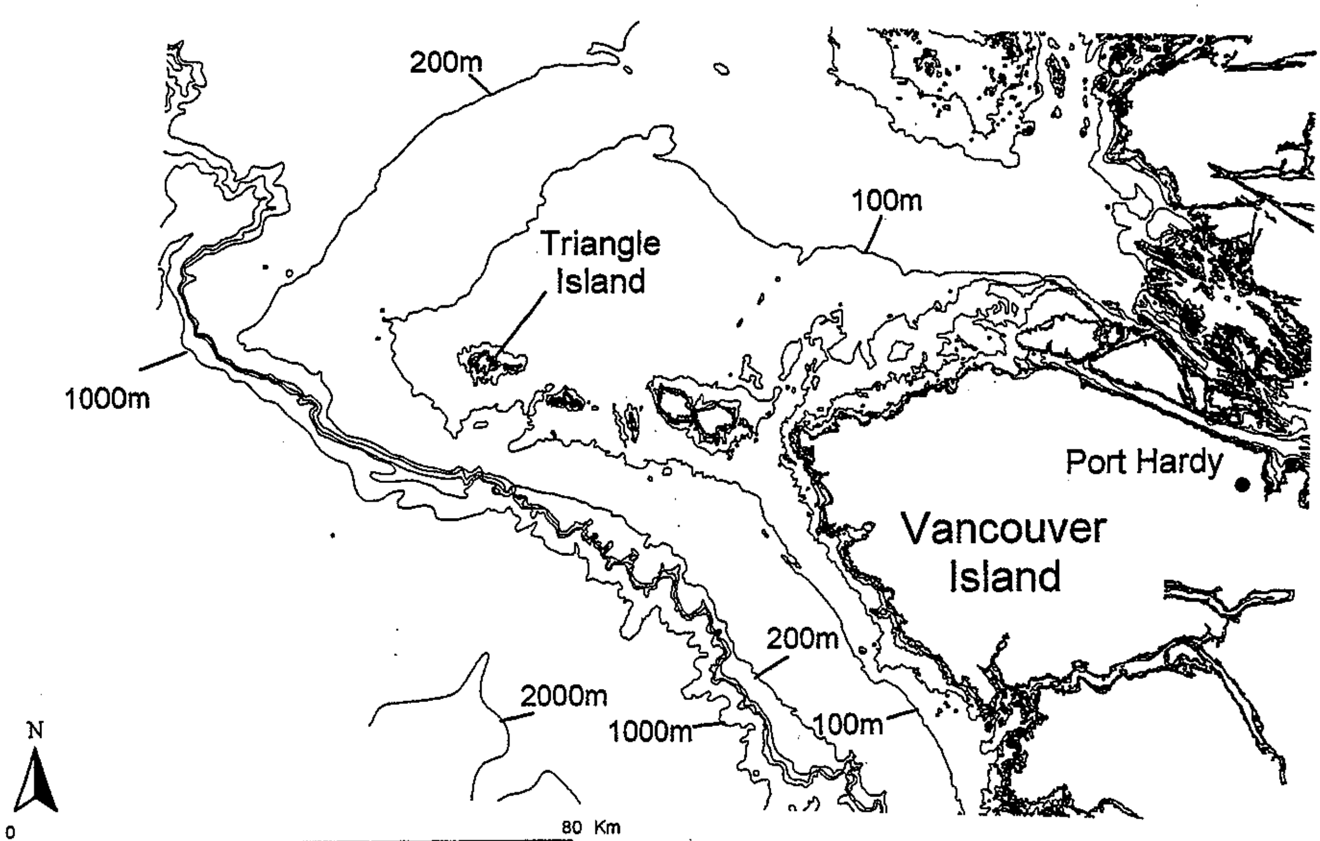


Figure 1B. Map of study area showing the North coast of Vancouver Island, Triangle Island (50 52N, 129 05W) and ocean bottom contours.

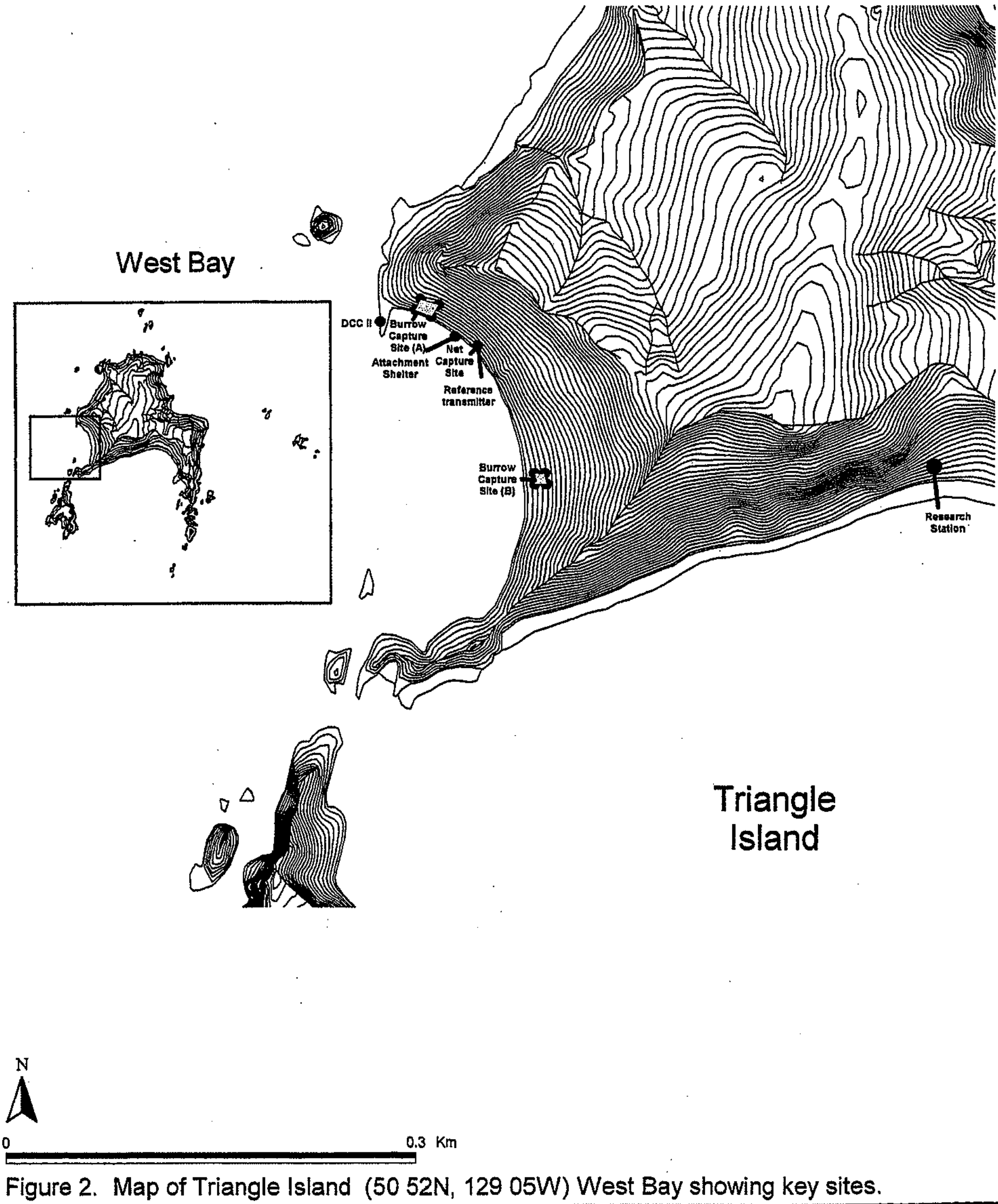


Figure 2. Map of Triangle Island (50 52N, 129 05W) West Bay showing key sites.

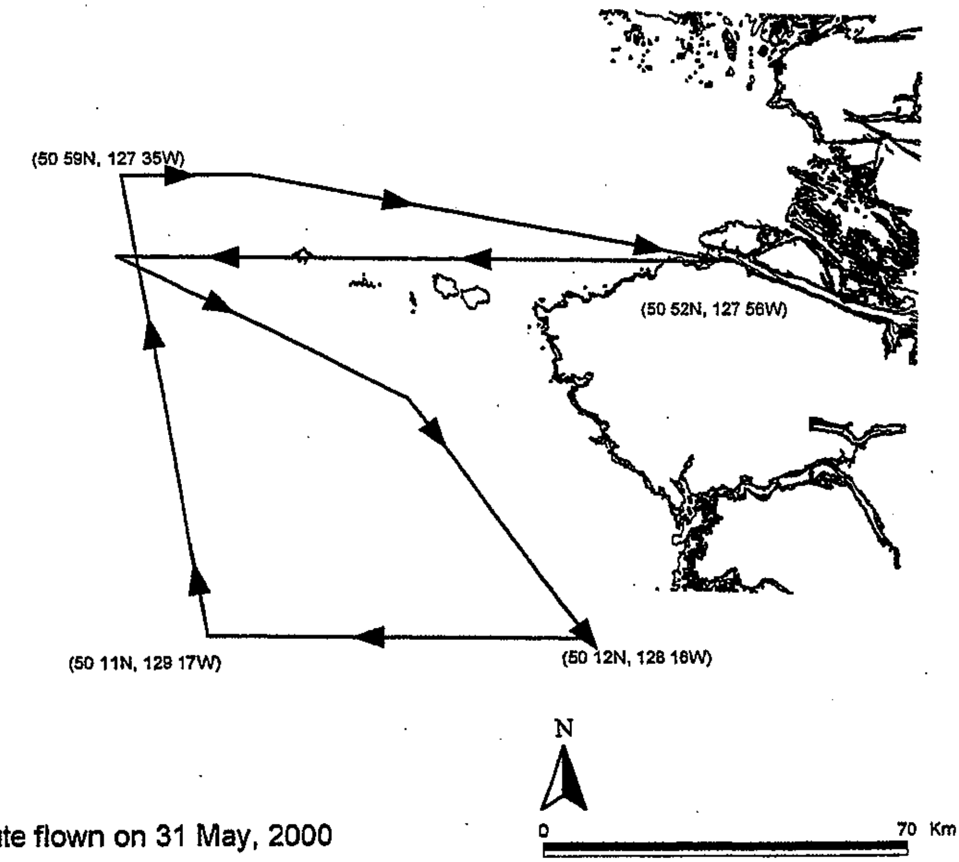


Figure 3A. Telemetry route flown on 31 May, 2000 (14:00h to 17:15h).

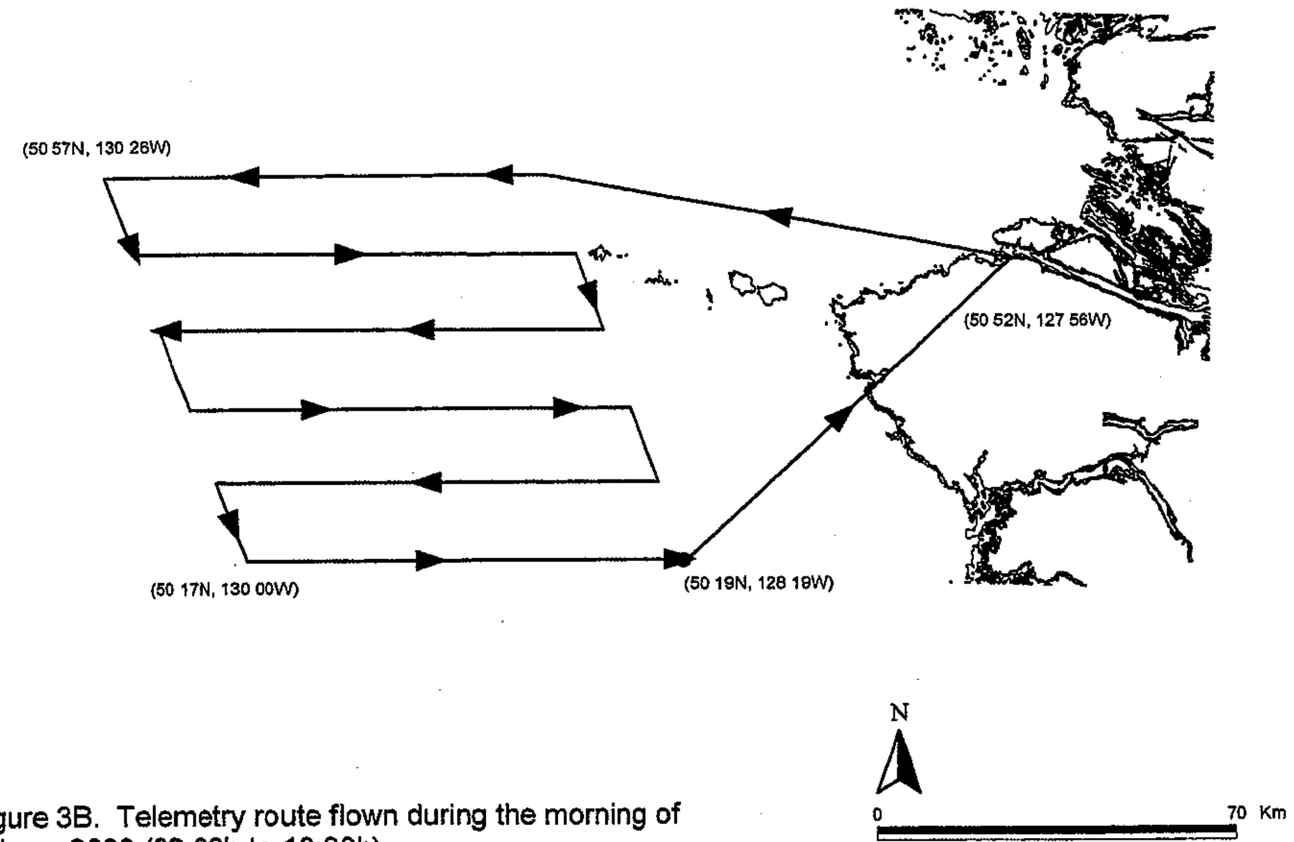


Figure 3B. Telemetry route flown during the morning of 1 June, 2000 (09:00h to 13:30h).

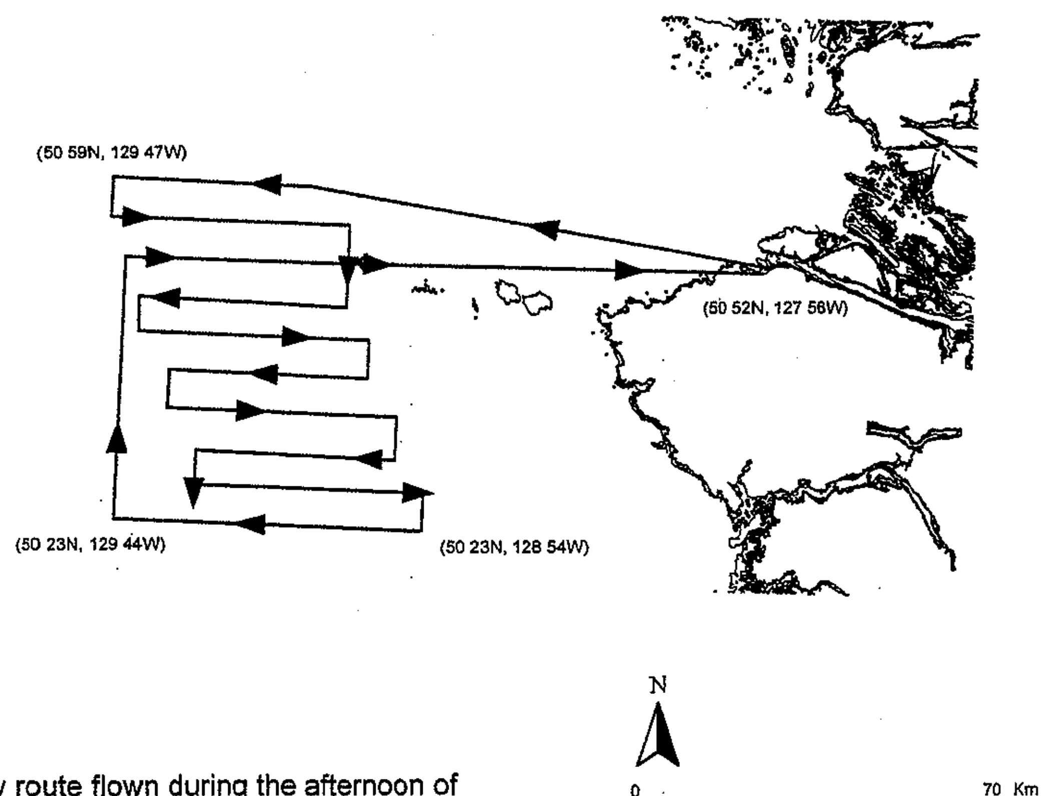


Figure 3C. Telemetry route flown during the afternoon of 1 June, 2000 (15:00h to 19:00h).

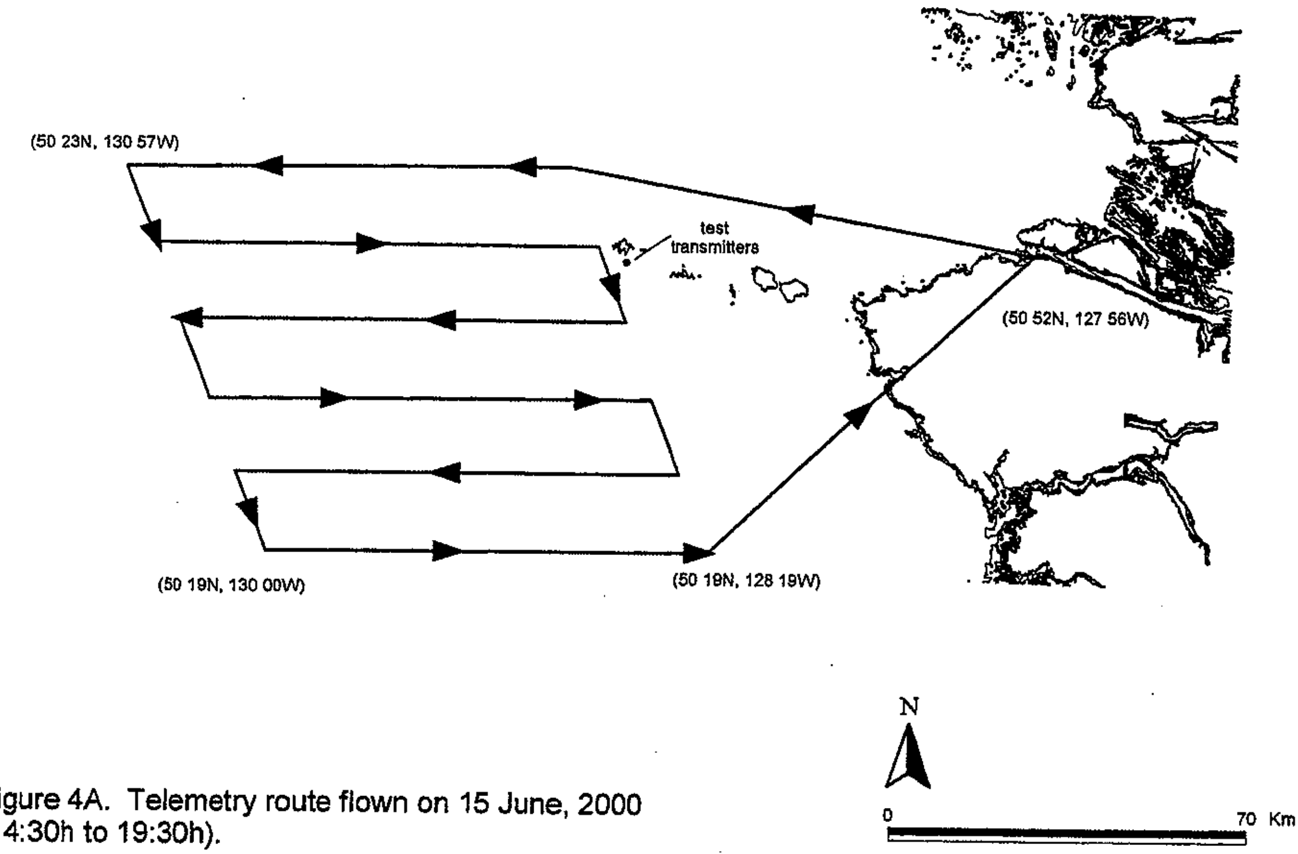


Figure 4A. Telemetry route flown on 15 June, 2000 (14:30h to 19:30h).

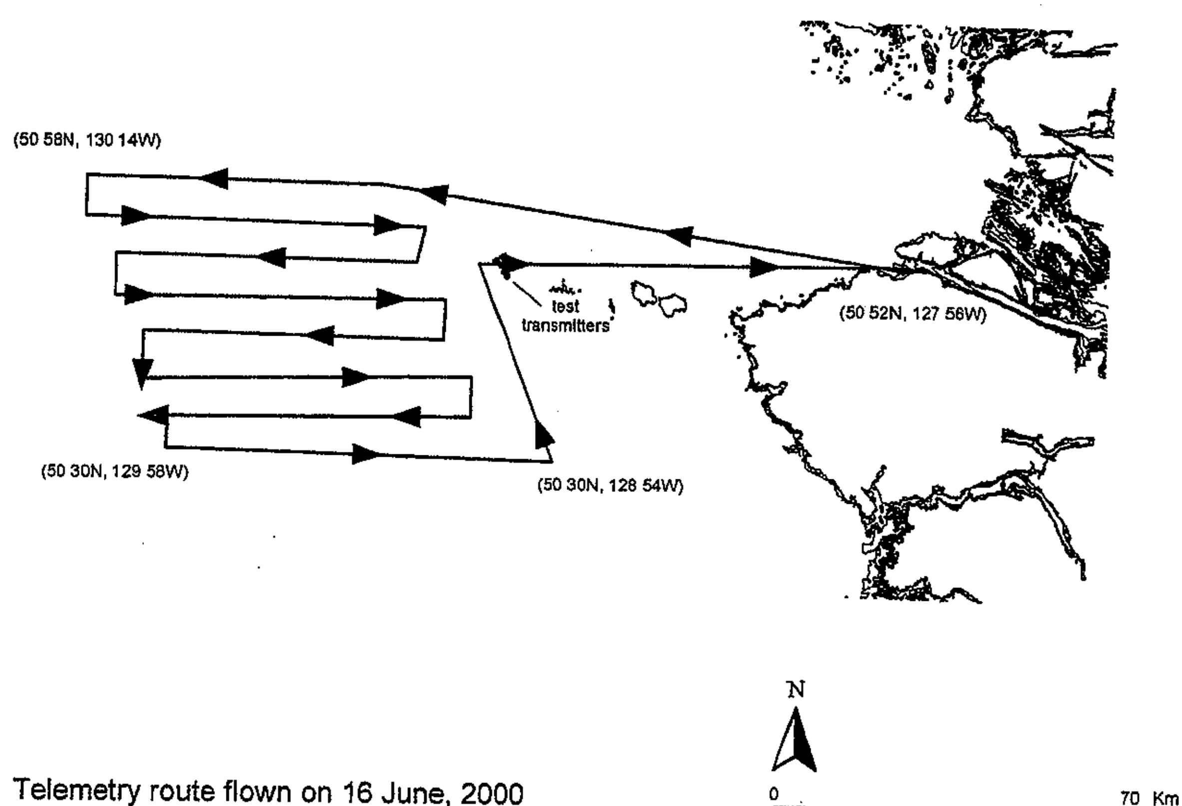


Figure 4B. Telemetry route flown on 16 June, 2000 (09:45h to 14:30h).

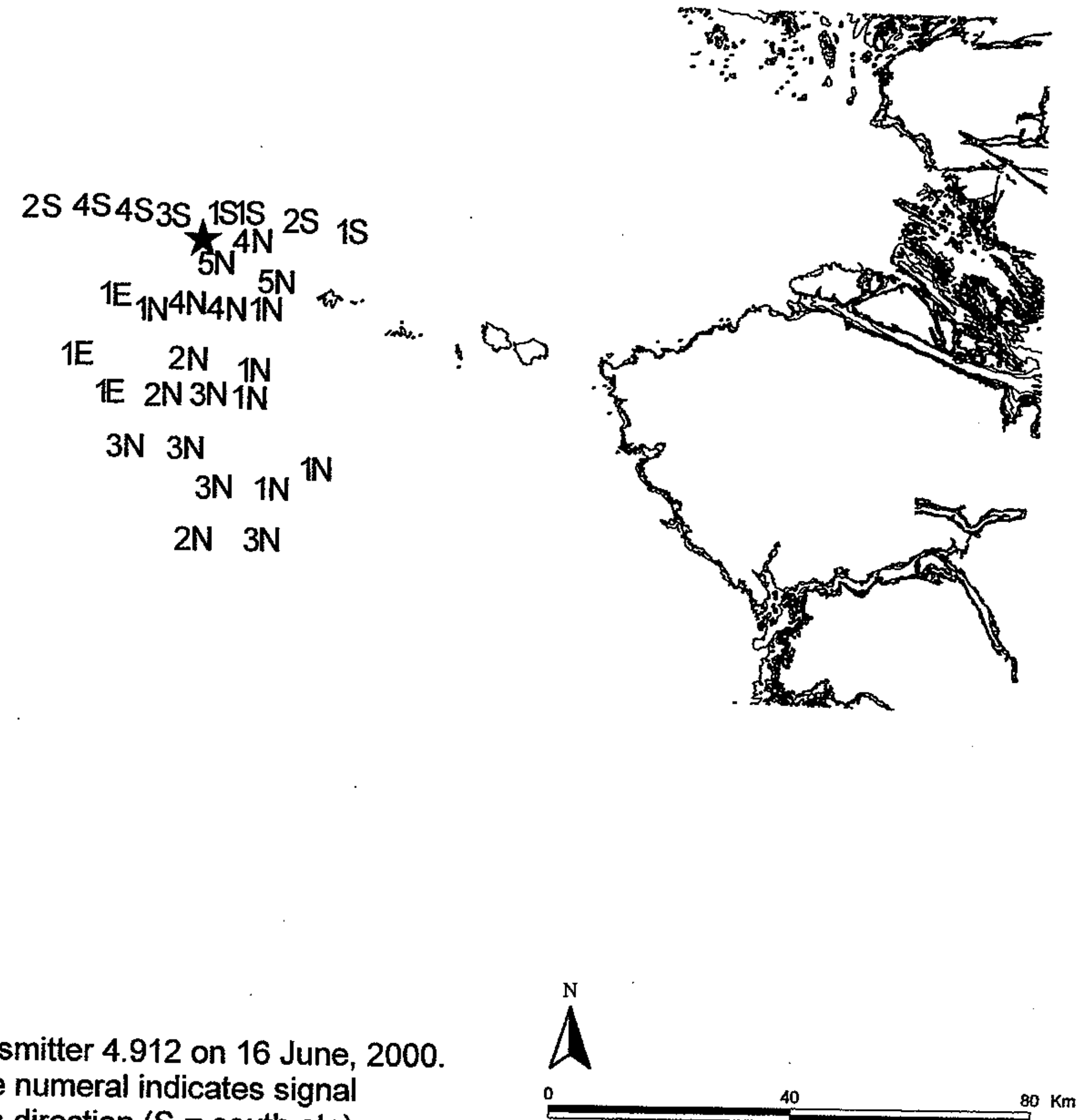


Figure 5. Example of data collected for transmitter 4.912 on 16 June, 2000. Inferred location is indicated by the star. The numeral indicates signal strength (1-5, max=5) and the letter indicates direction (S = south,etc).

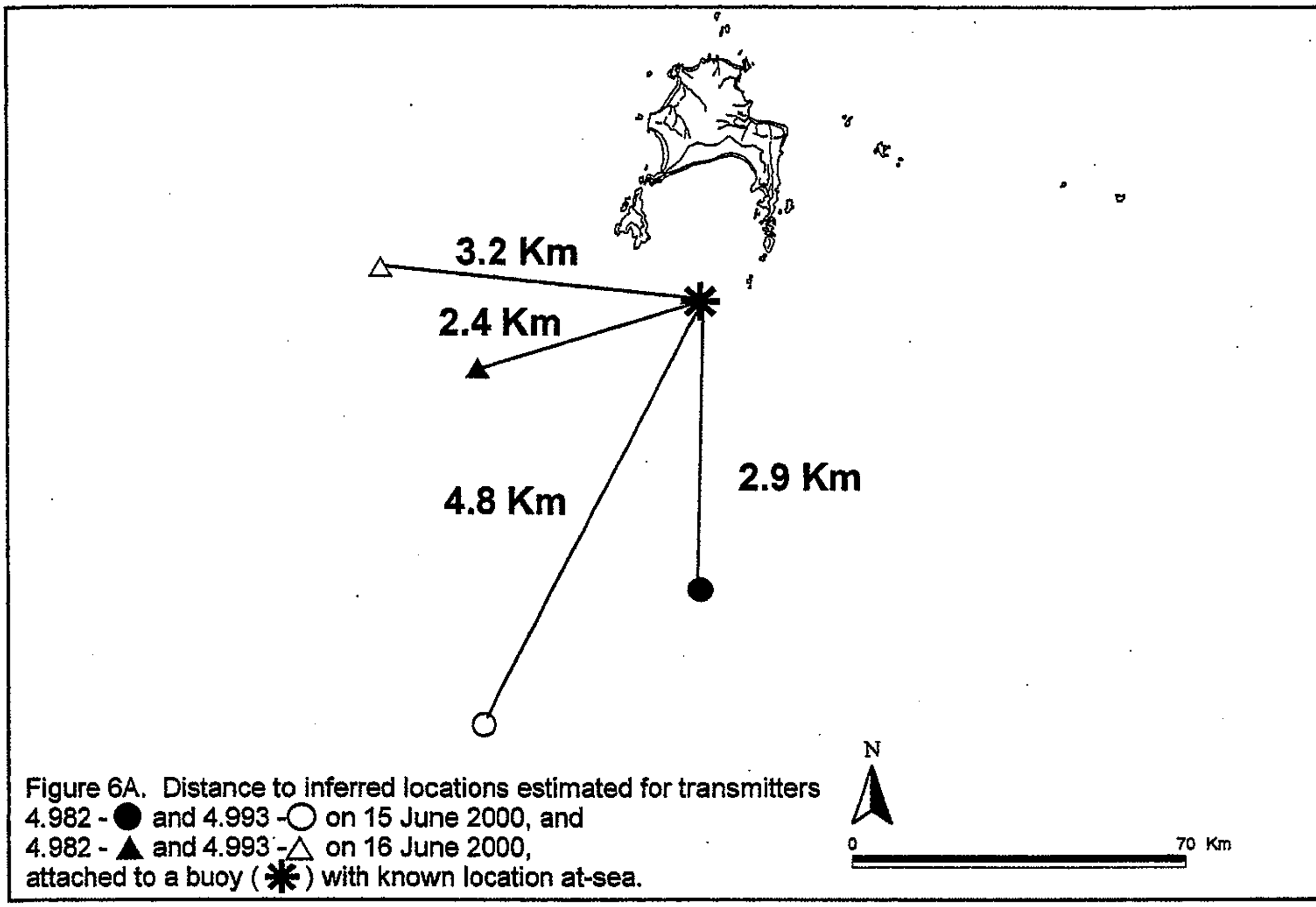


Figure 6A. Distance to inferred locations estimated for transmitters
4.982 - ● and 4.993 -○ on 15 June 2000, and
4.982 - ▲ and 4.993 -△ on 16 June 2000,
attached to a buoy (✱) with known location at-sea.

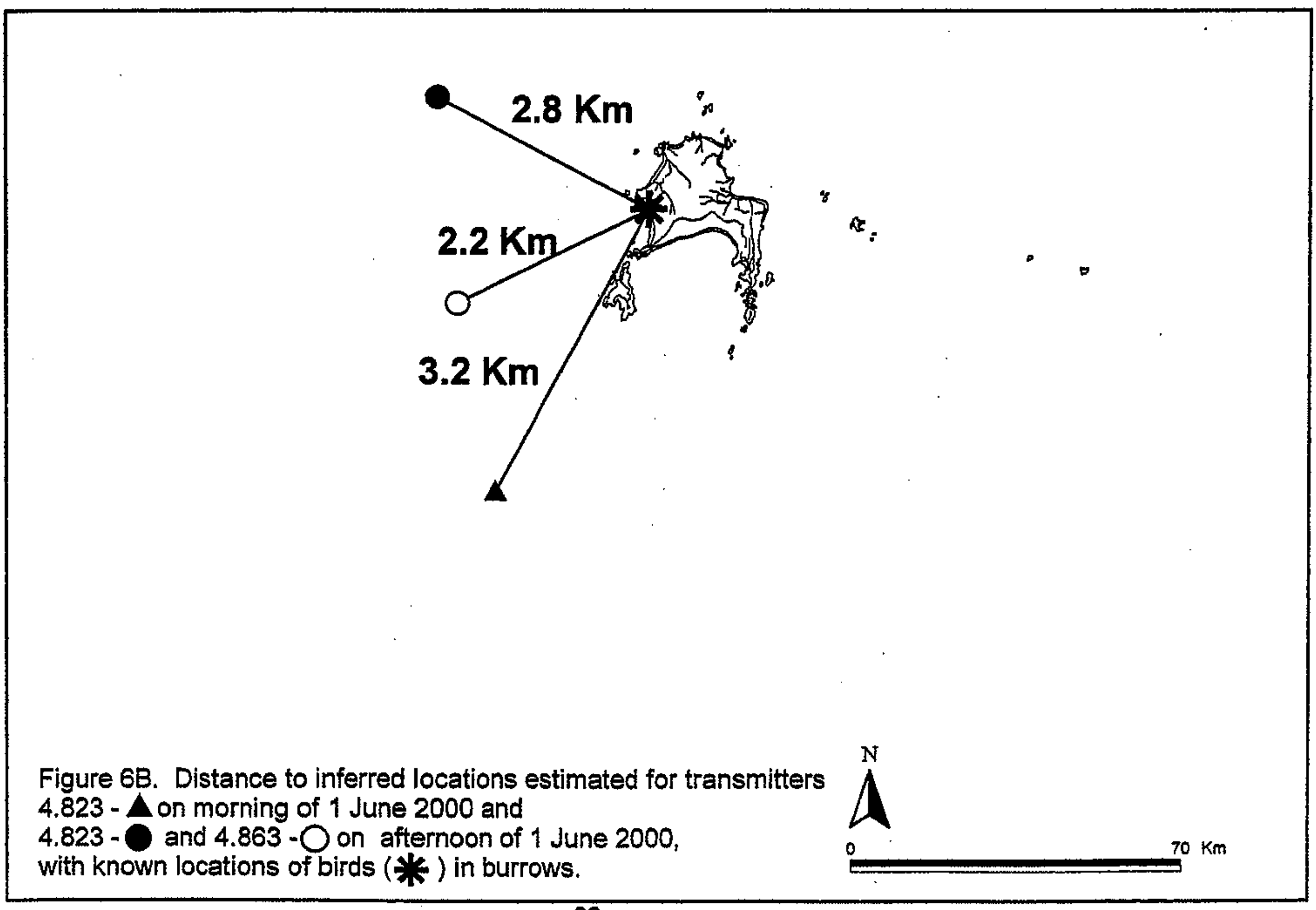


Figure 6B. Distance to inferred locations estimated for transmitters
4.823 - ▲ on morning of 1 June 2000 and
4.823 - ● and 4.863 -○ on afternoon of 1 June 2000,
with known locations of birds (✱) in burrows.

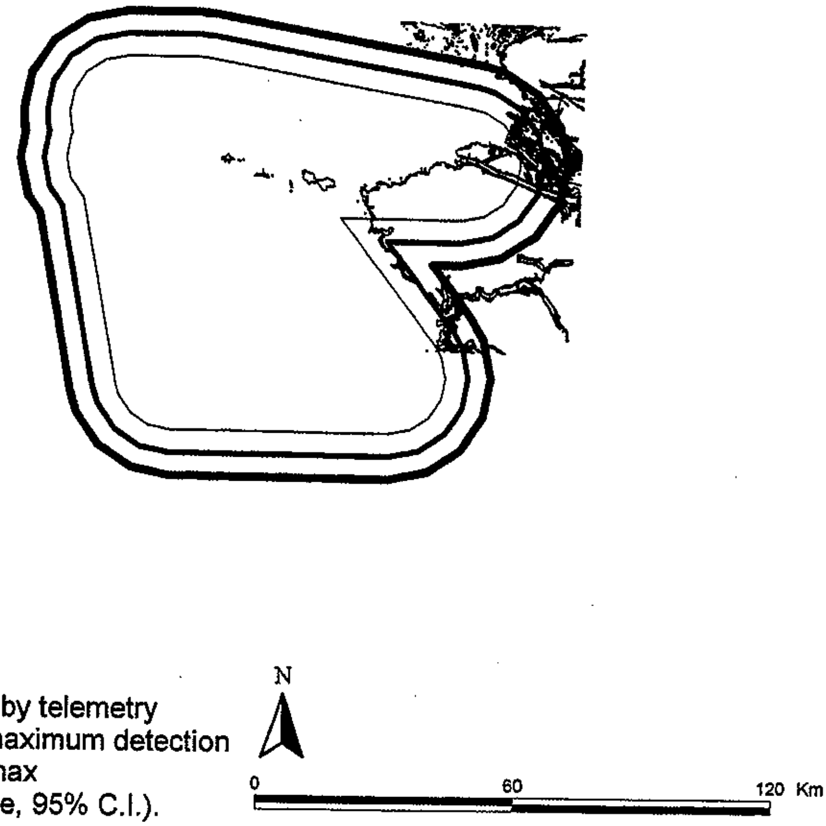


Figure 7A. Estimated area covered by telemetry on 31 May, 2000. (—— = average maximum detection distance, —— and ▬▬ = min and max average maximum detection distance, 95% C.I.).

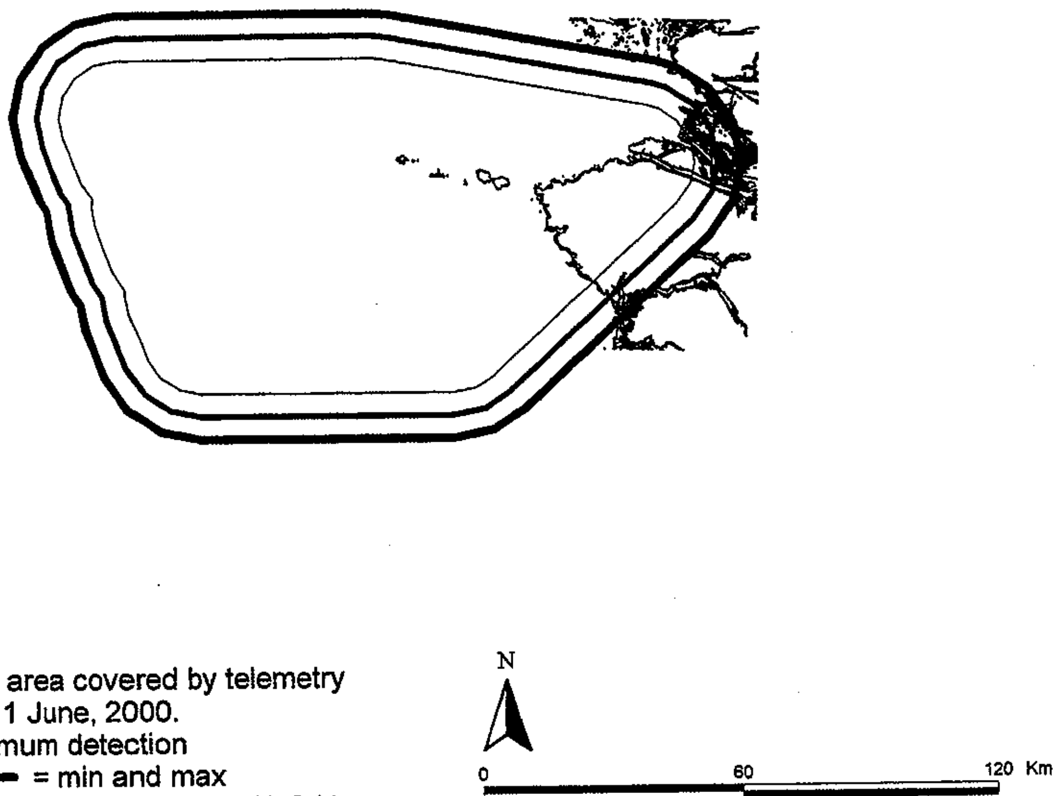


Figure 7B. Estimated area covered by telemetry during the morning of 1 June, 2000. (—— = average maximum detection distance, —— and ▬▬ = min and max average maximum detection distance, 95% C.I.).

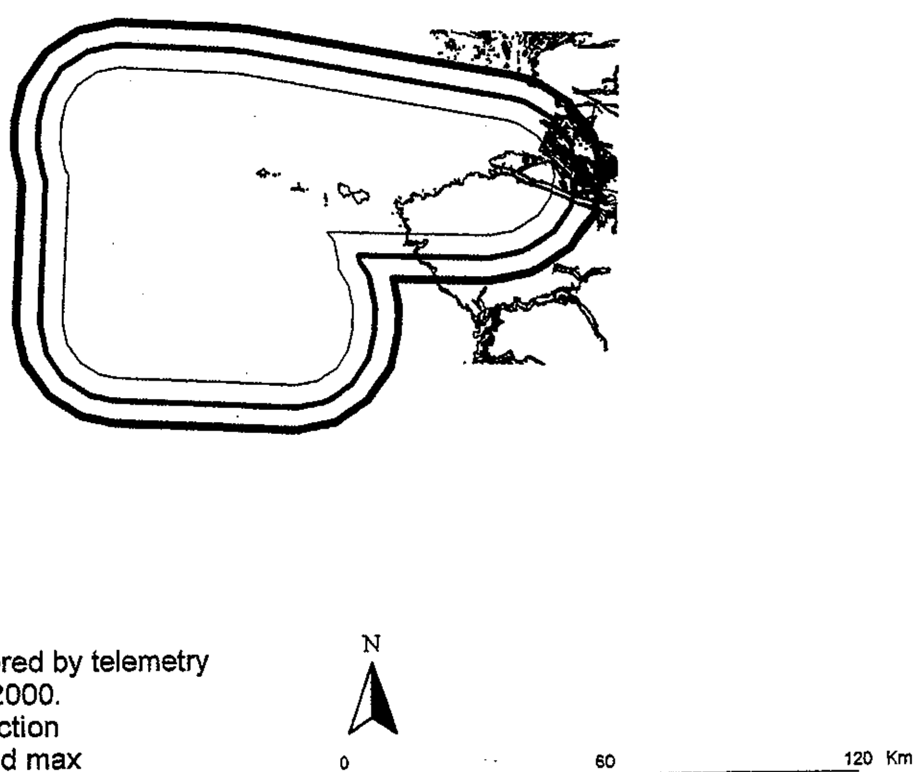


Figure 7C. Estimated area covered by telemetry during the afternoon of 1 June, 2000. (—— = average maximum detection distance, —— and ▬▬ = min and max average maximum detection distance, 95% C.I.).

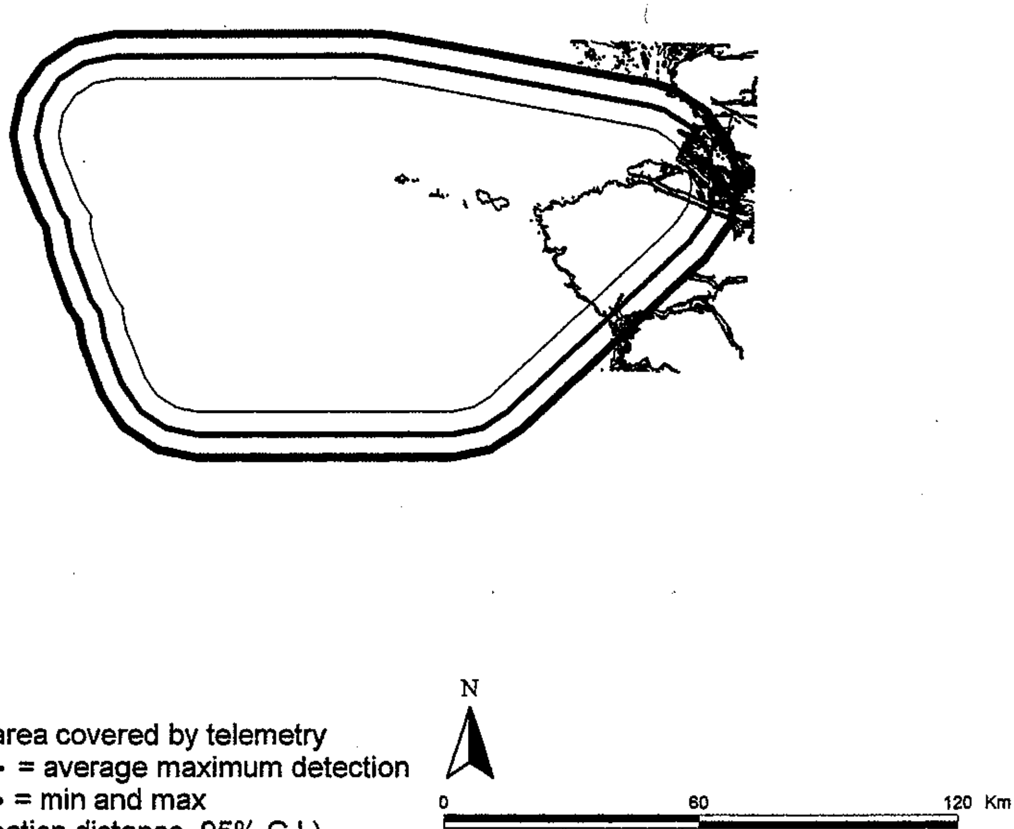


Figure 8A. Estimated area covered by telemetry on 15 June, 2000. (▬ = average maximum detection distance, — and ▬ = min and max average maximum detection distance, 95% C.I.)

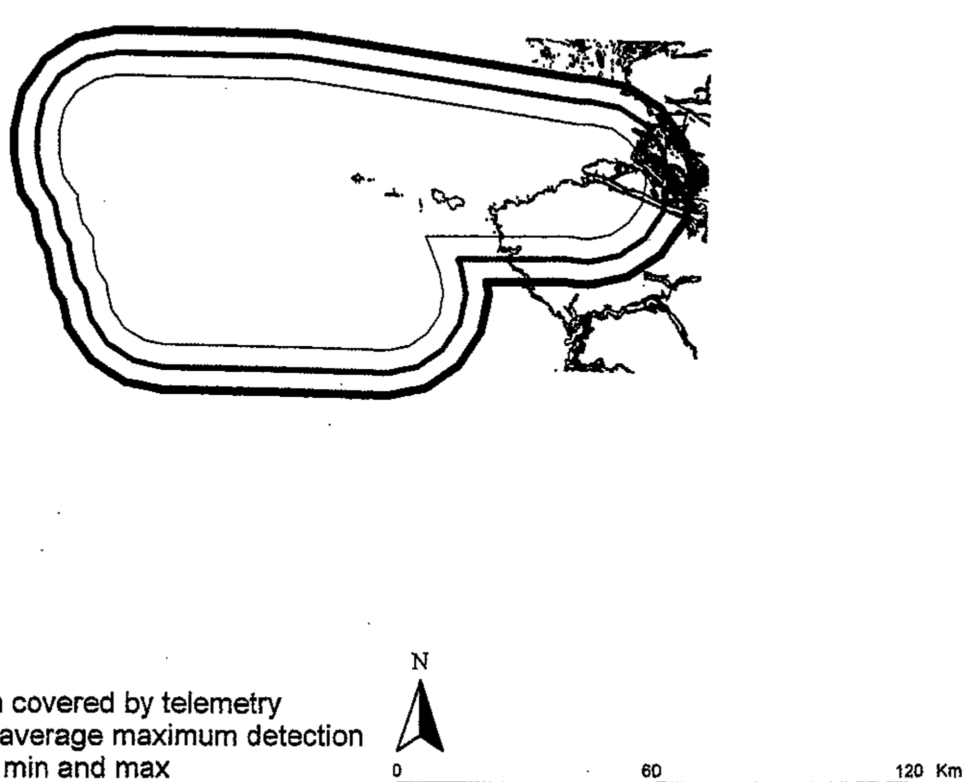


Figure 8B. Estimated area covered by telemetry on 16 June, 2000. (▬ = average maximum detection distance, — and ▬ = min and max average maximum detection distance, 95% C.I.)

Figure 9. Number of aerial detections for each transmitter (all survey dates) versus the maximum horizontal detection distance for each transmitter determined in South Bay on 22 May 2000.

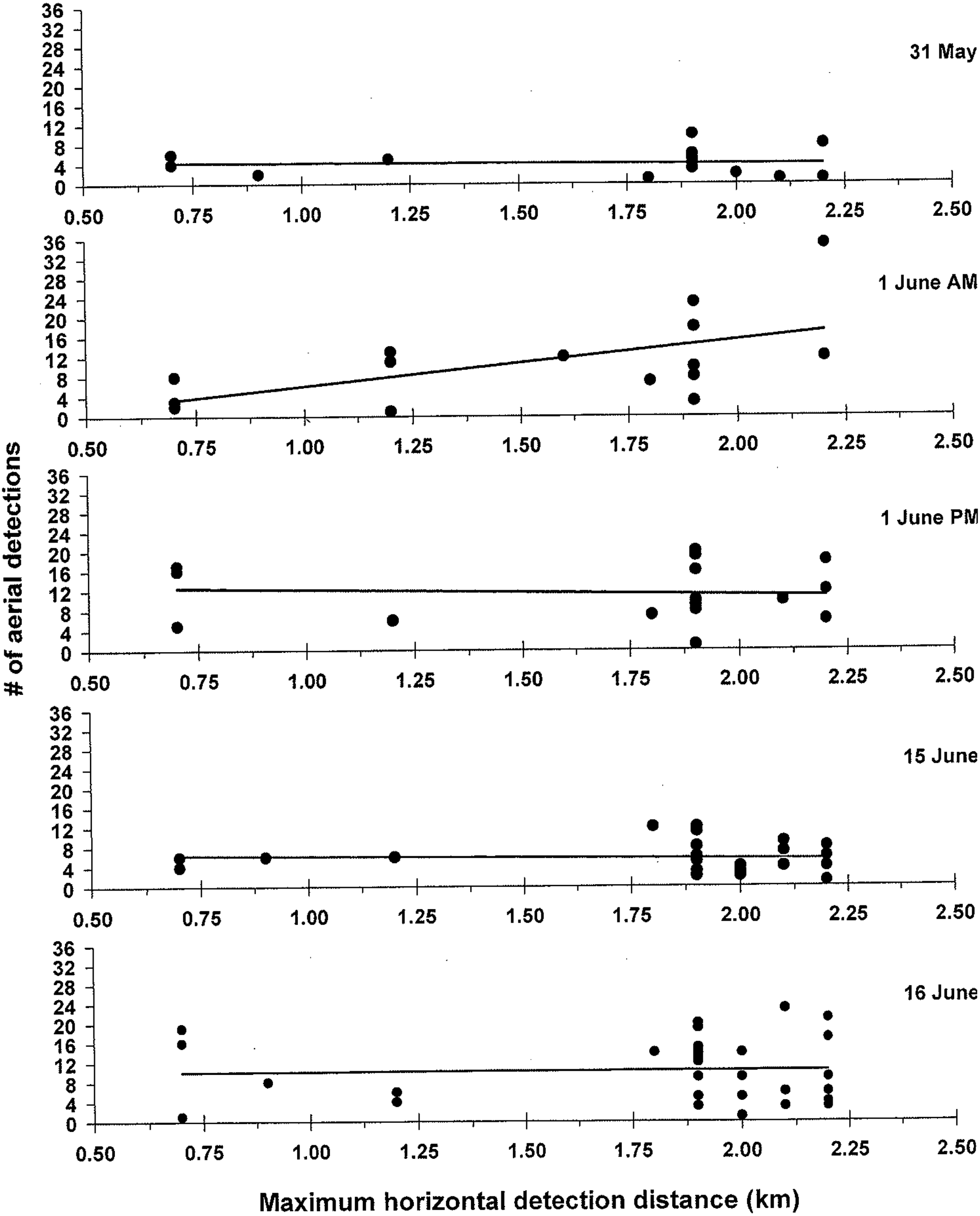


Figure 10A. Frequency histogram showing the number of transmitters versus detections per transmitter on the morning of 1 June, 2000. Strong radios had maximum horizontal detection distances >1.5 km, weak radios were <1.5 km

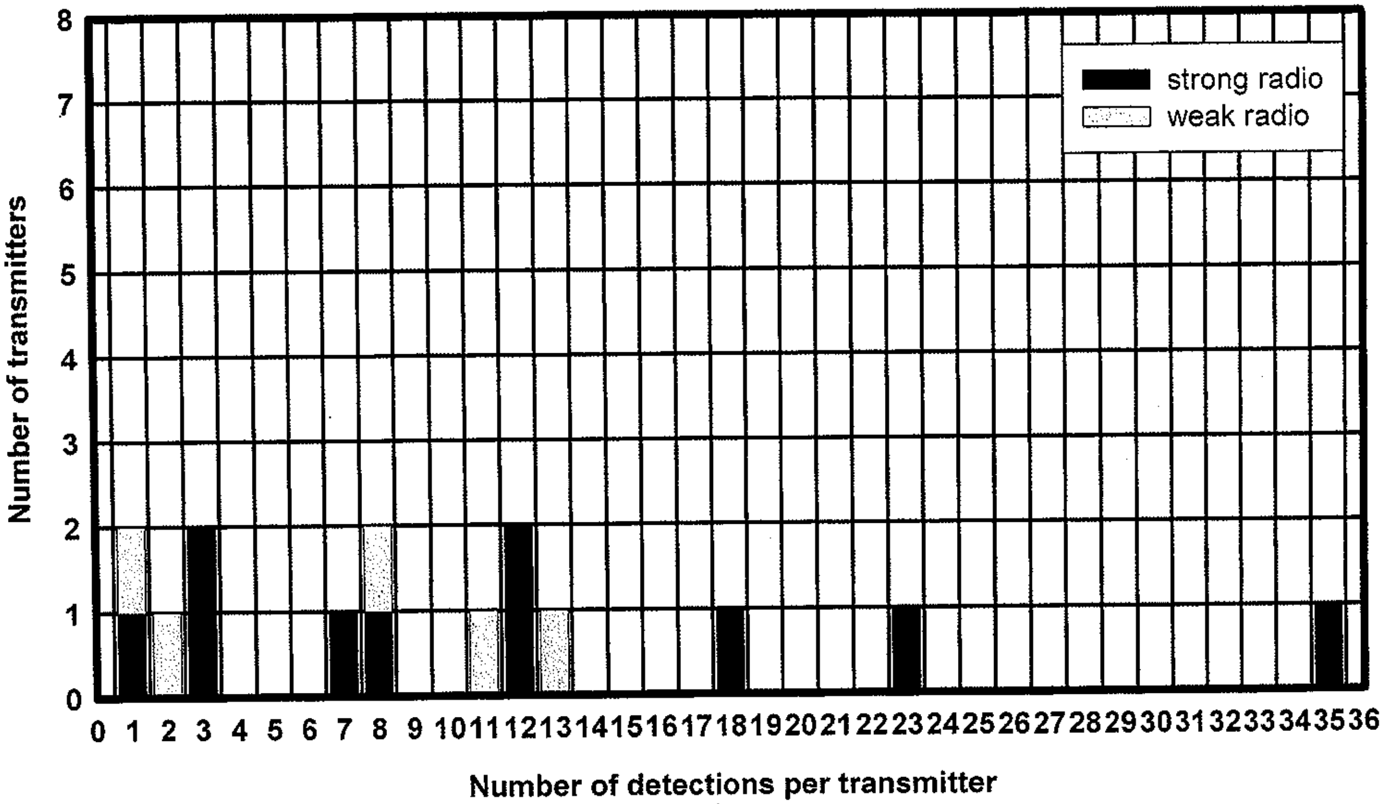
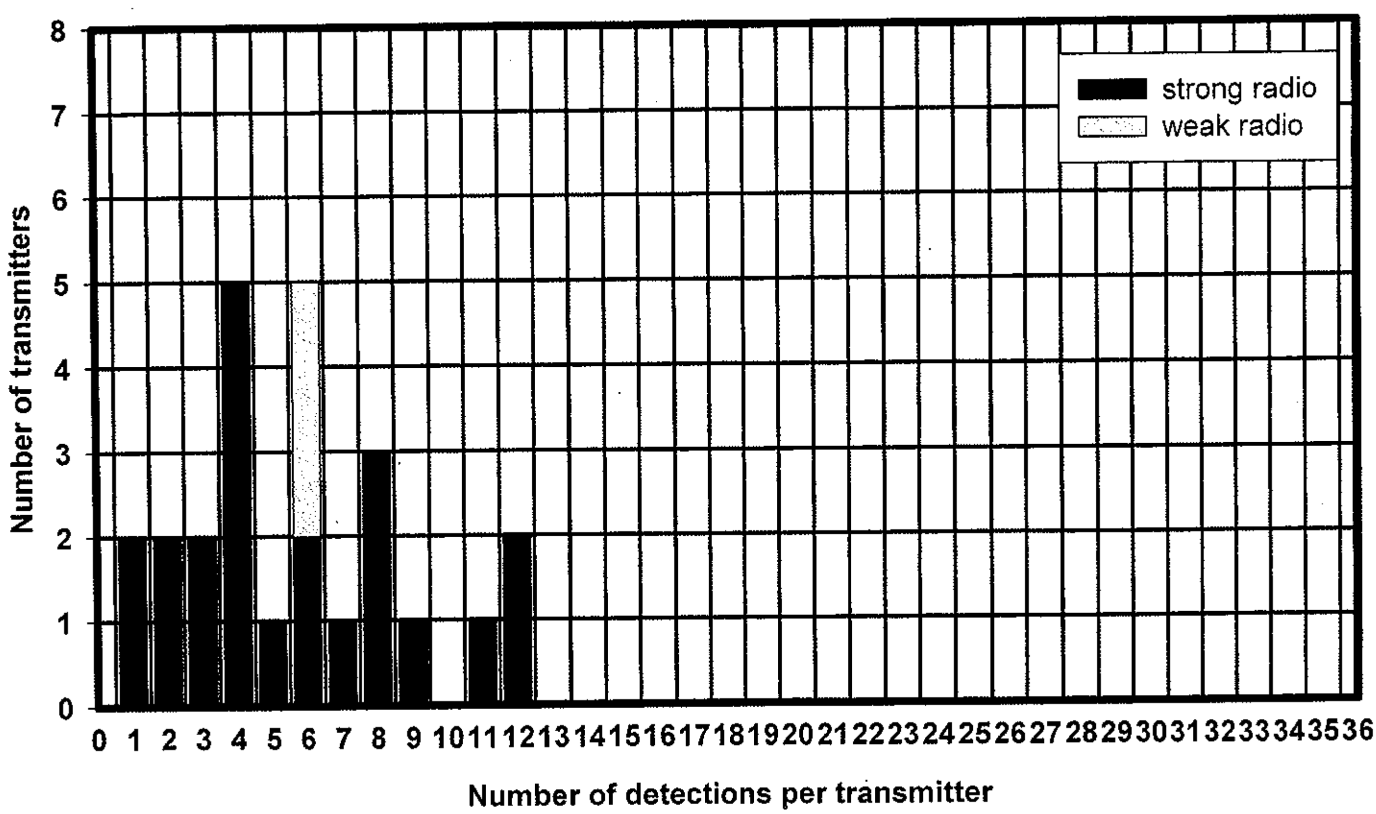


Figure 10B. Frequency histogram showing the number of transmitters versus detections per transmitter on 15 June, 2000. Strong radios had maximum horizontal detection distances >1.5 km, weak radios were <1.5 km



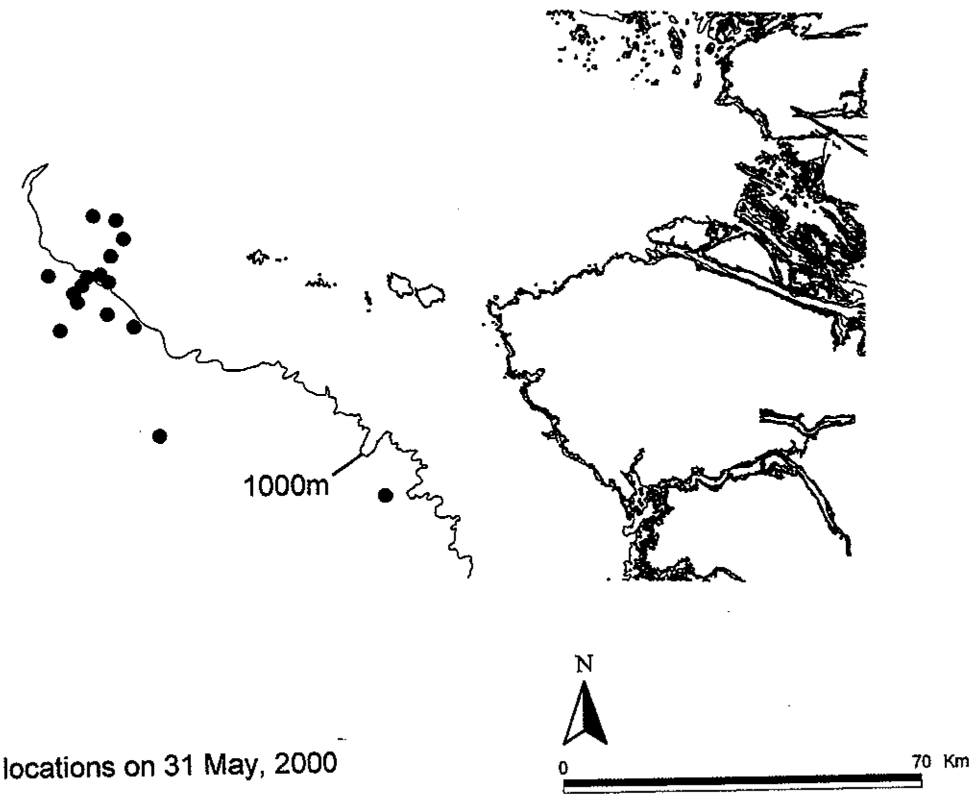


Figure 11A. Transmitter locations on 31 May, 2000 (14:00h to 17:15h).

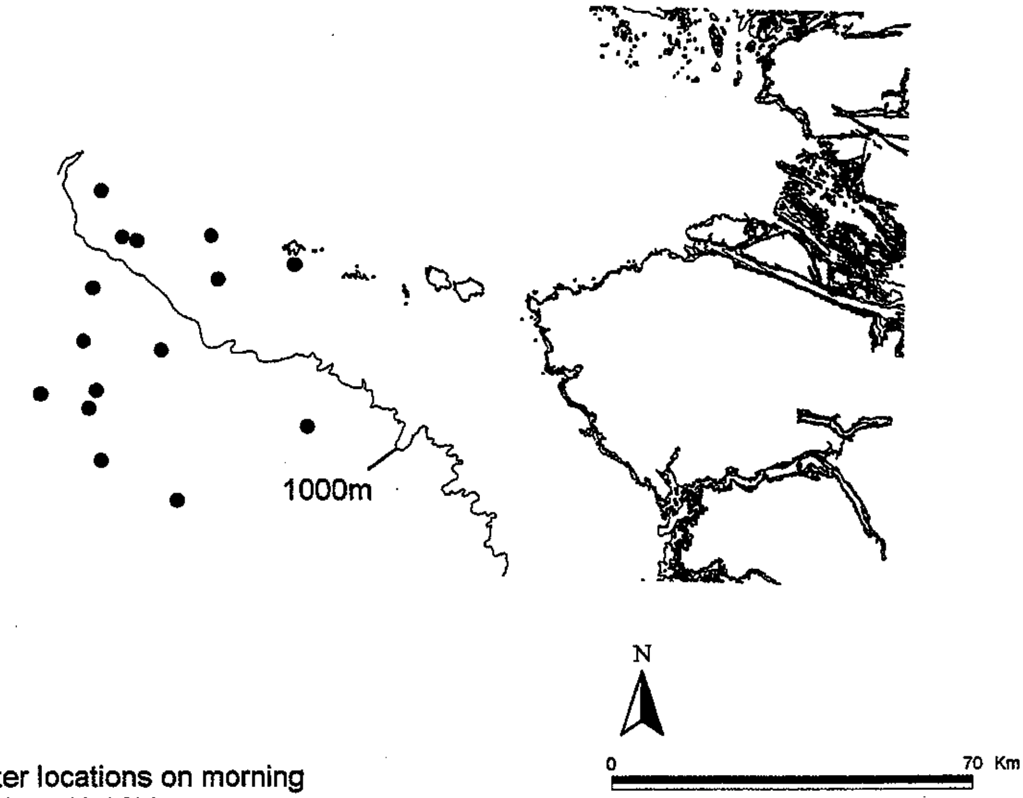


Figure 11B. Transmitter locations on morning of 1 June, 2000 (09:00h to 13:30h).

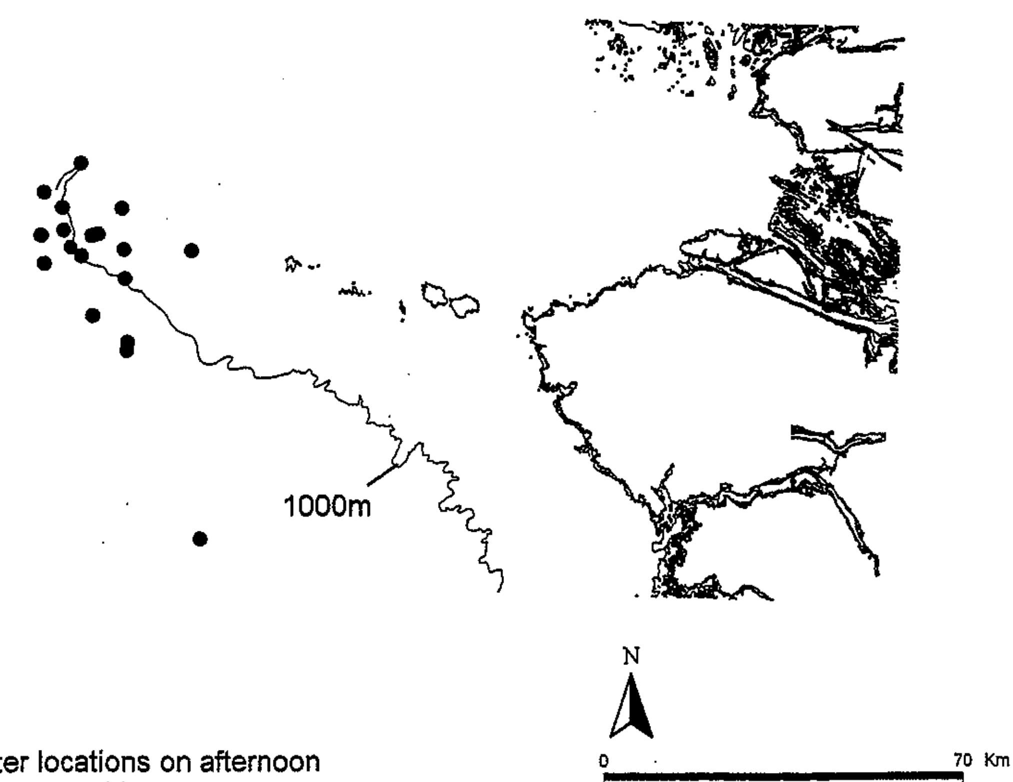


Figure 11C. Transmitter locations on afternoon of 1 June, 2000 (15:00h to 19:00h).

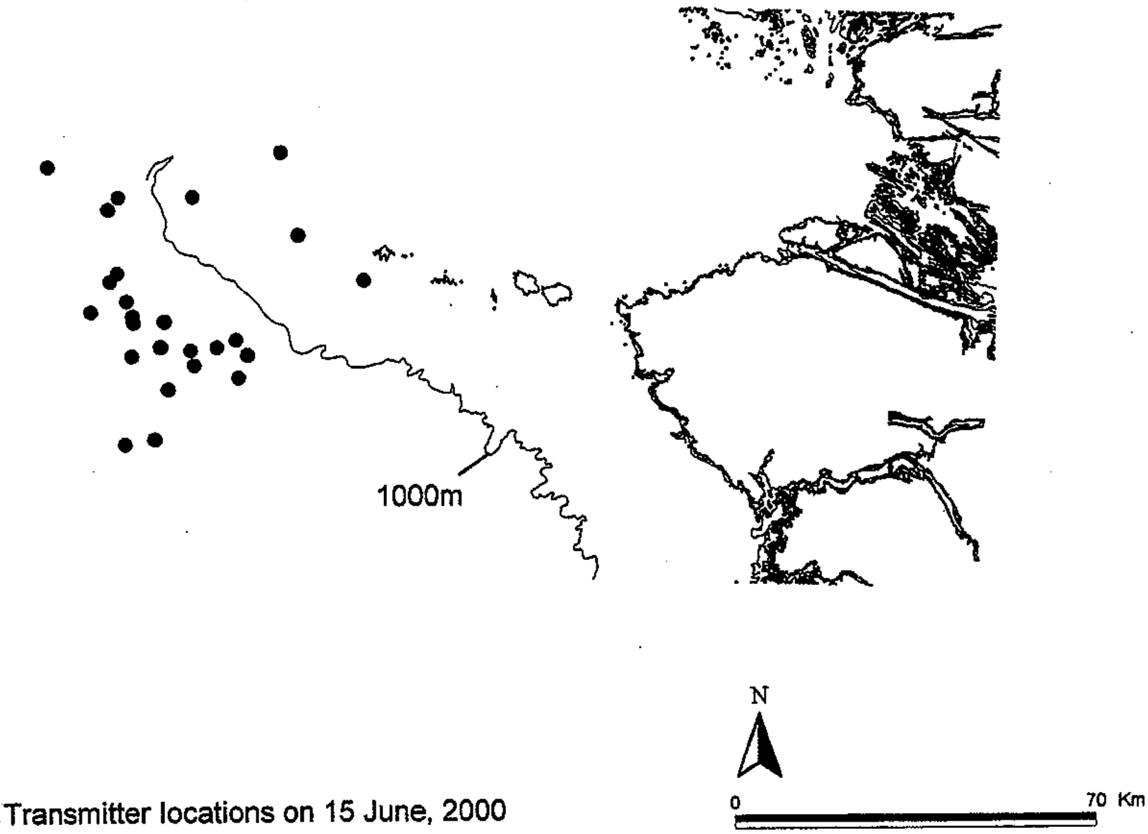


Figure 12A. Transmitter locations on 15 June, 2000 (14:30h to 19:30h).

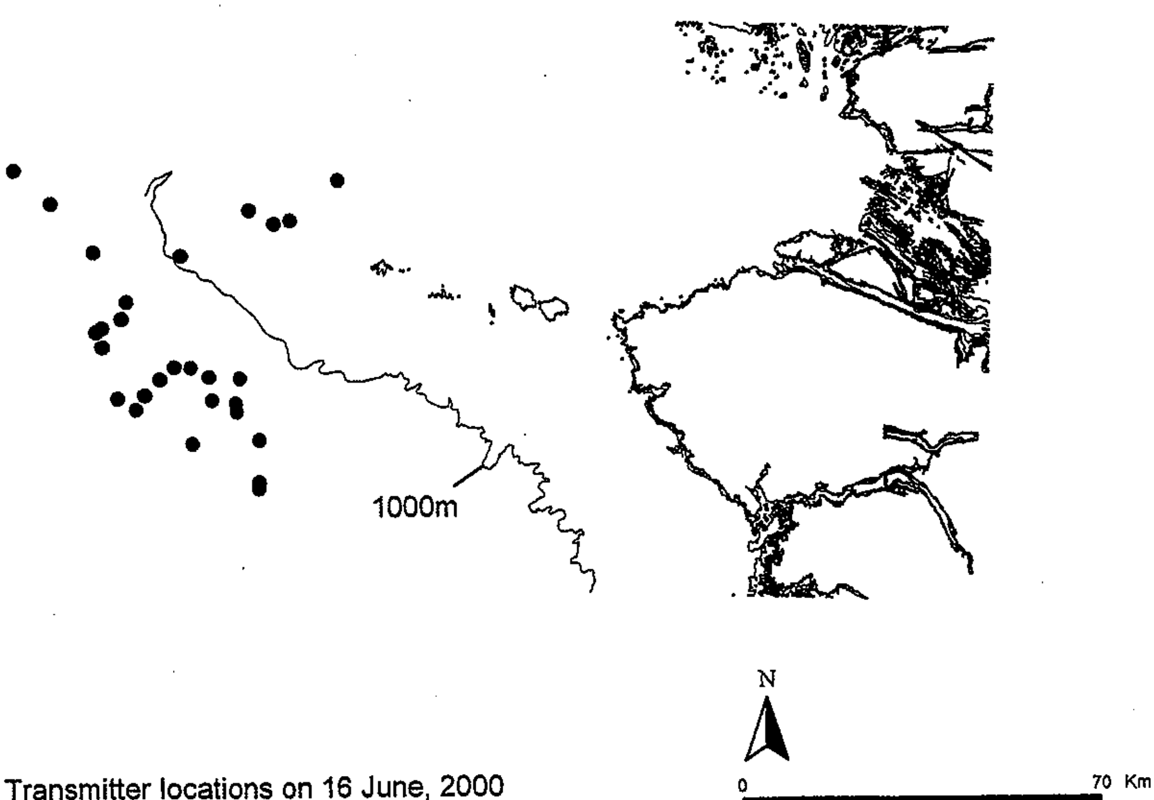


Figure 12B. Transmitter locations on 16 June, 2000 (09:45h to 14:30h).

Figure 13A. Frequency histogram showing the number of transmitters versus distance from Triangle Island to inferred location on the morning of 1 June, 2000.

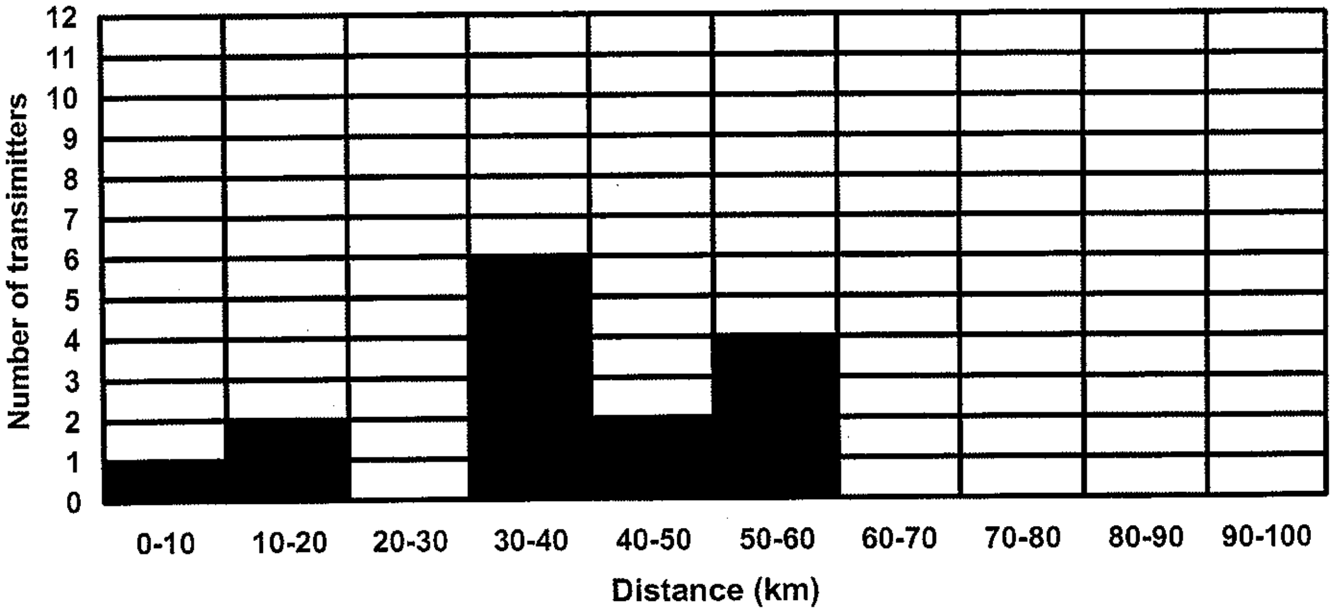
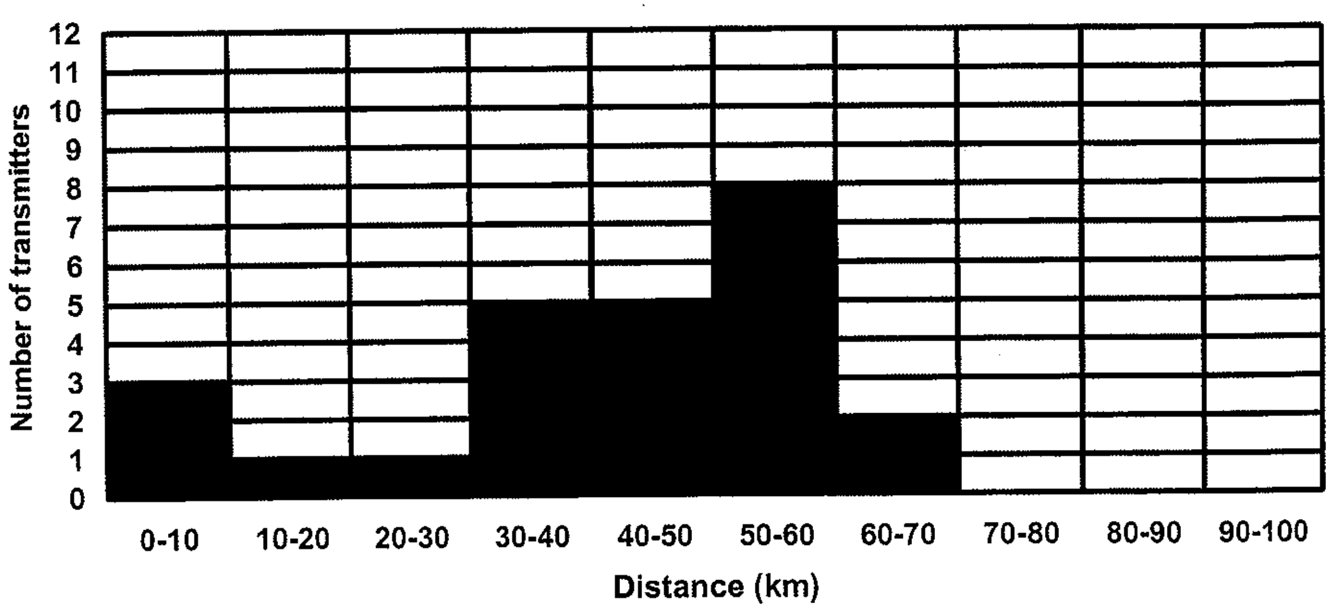


Figure 13B. Frequency histogram showing the number of transmitters versus distance from Triangle Island to inferred location on 15 June, 2000.



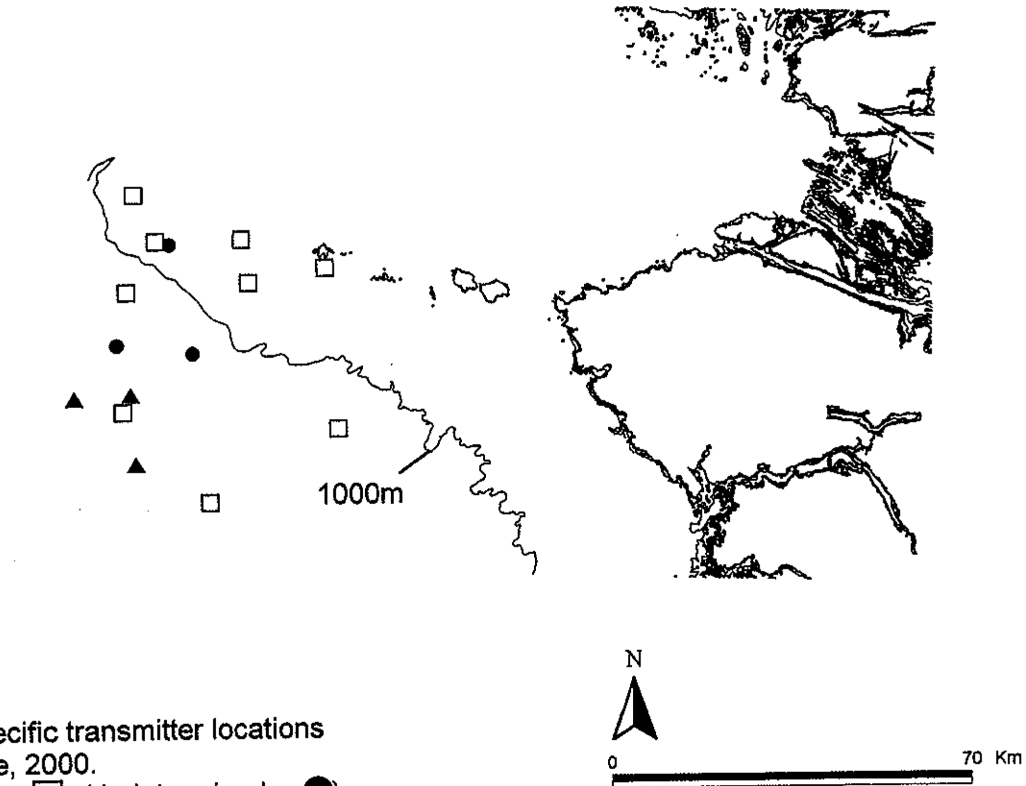


Figure 14A. Sex specific transmitter locations on morning of 1 June, 2000.
(Female = ▲ , Male = □ , Undetermined = ●)

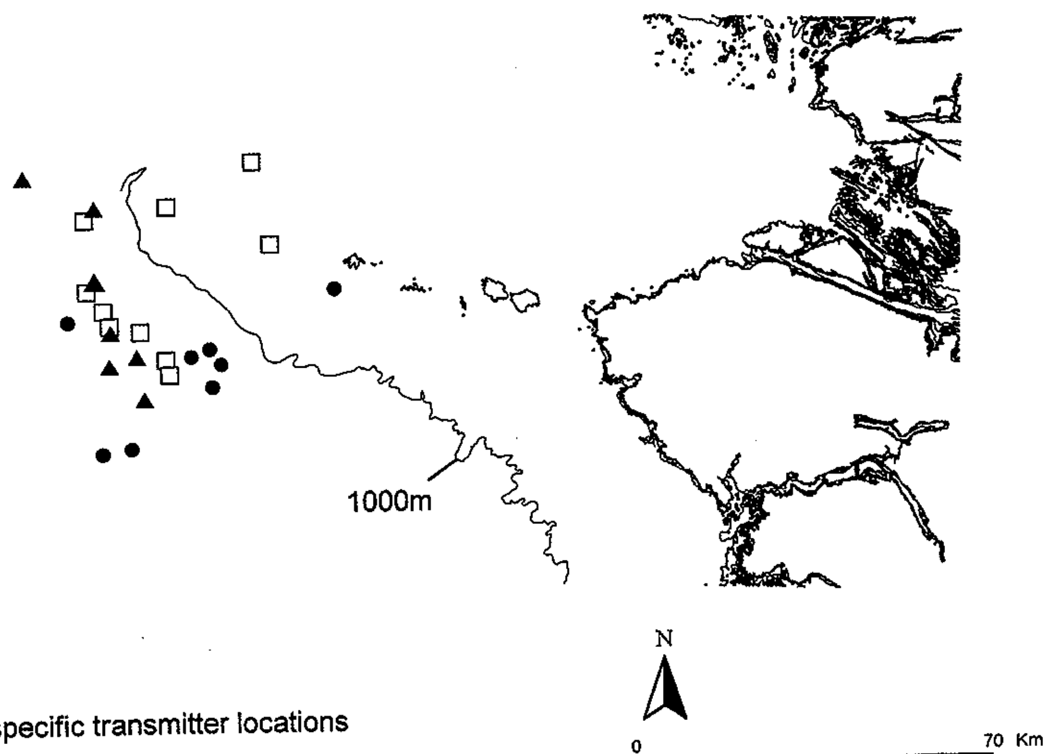


Figure 14B. Sex specific transmitter locations on 15 June, 2000.
(Female = ▲ , Male = □ , Undetermined = ●)

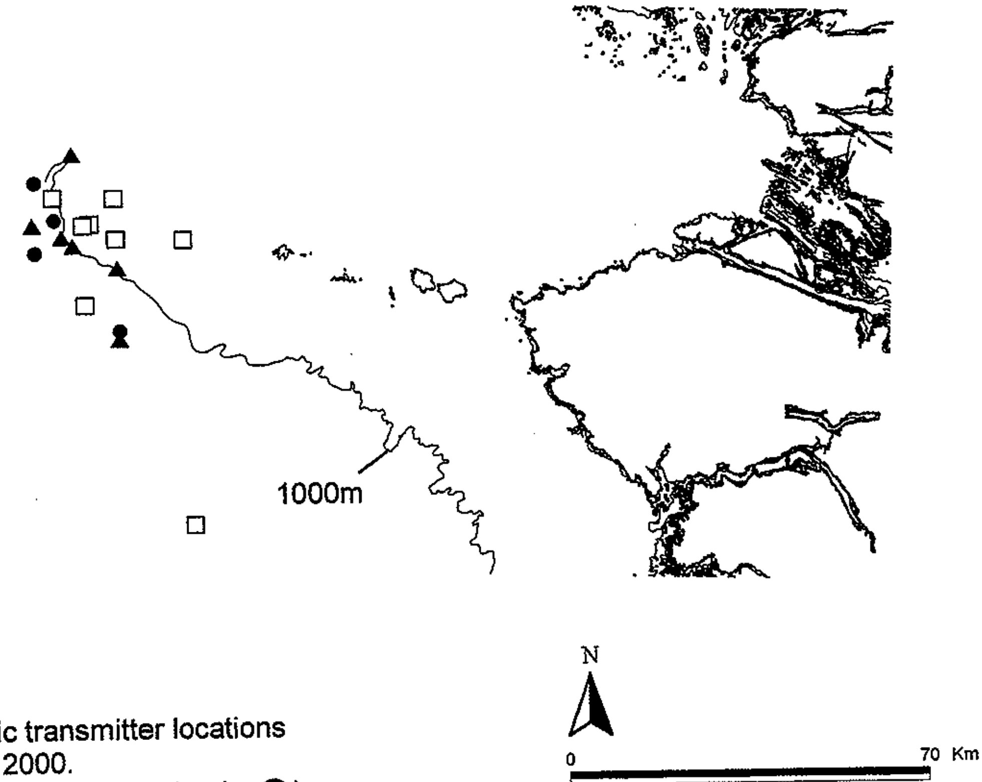


Figure 15A. Sex specific transmitter locations on afternoon of 1 June, 2000.
(Female = ▲ , Male = □ , Undetermined = ●)

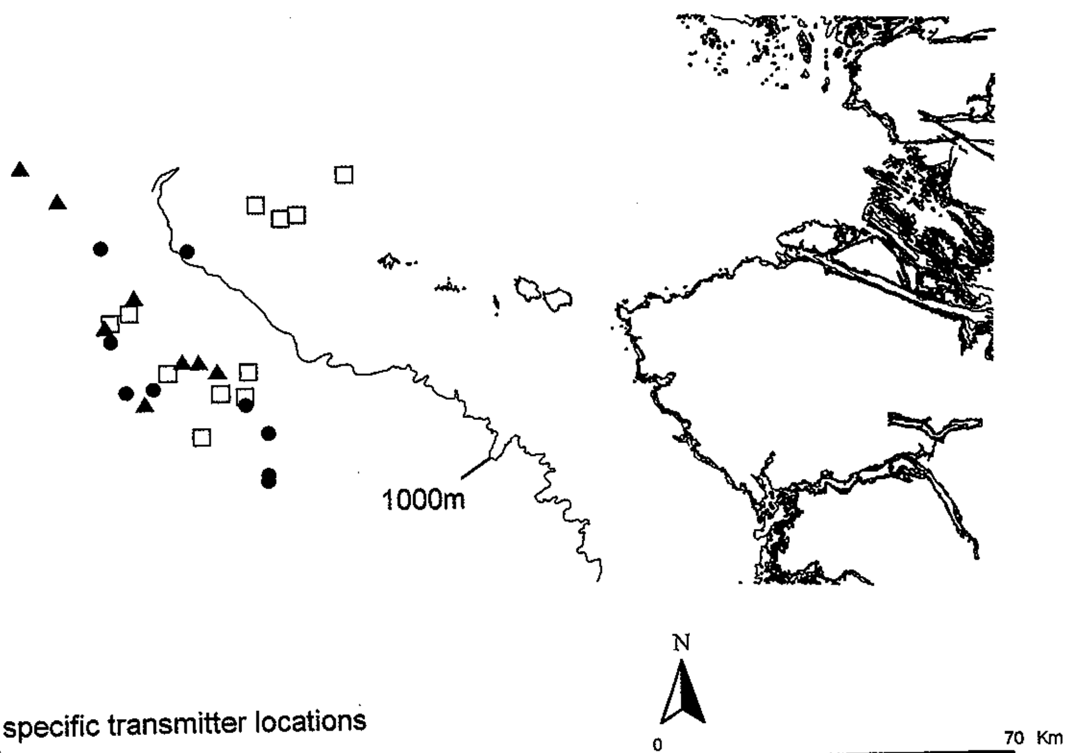


Figure 15B. Sex specific transmitter locations on 16 June, 2000.
(Female = ▲ , Male = □, Undetermined = ●)

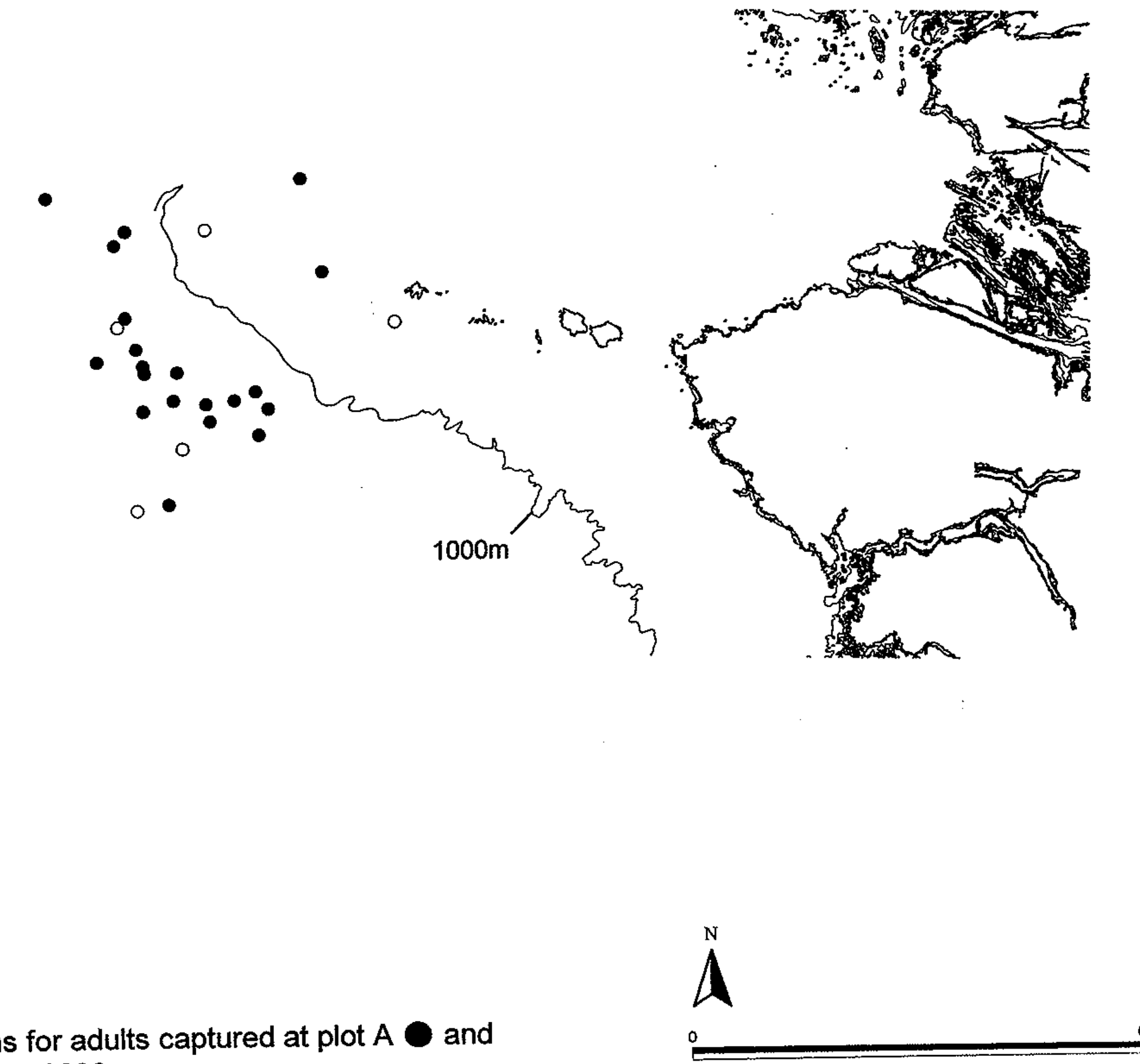


Figure 16. Transmitter locations for adults captured at plot A ● and captured at plot B ○ for 15 June, 2000.

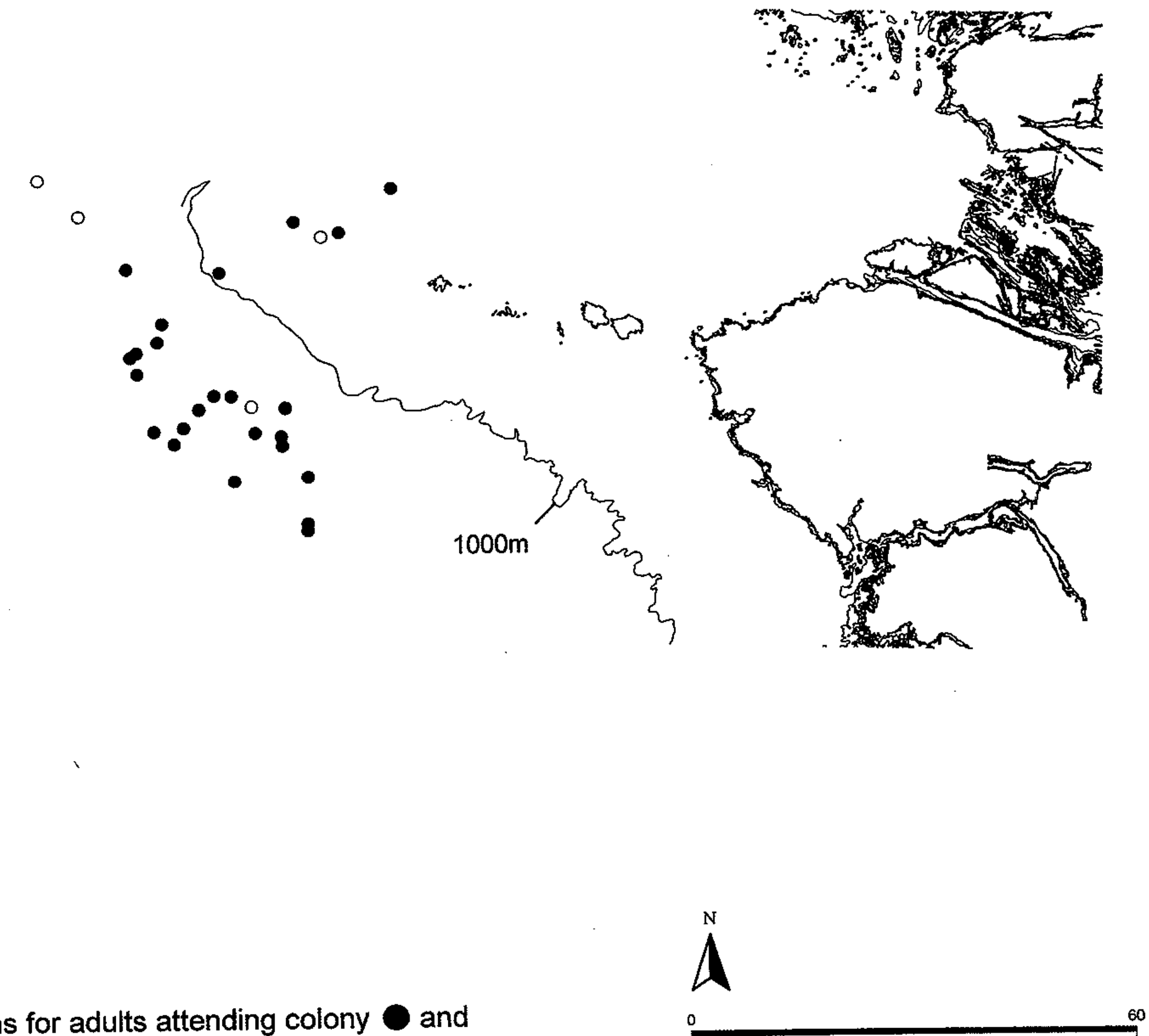


Figure 17. Transmitter locations for adults attending colony ● and not attending colony ○ for 16 June, 2000.

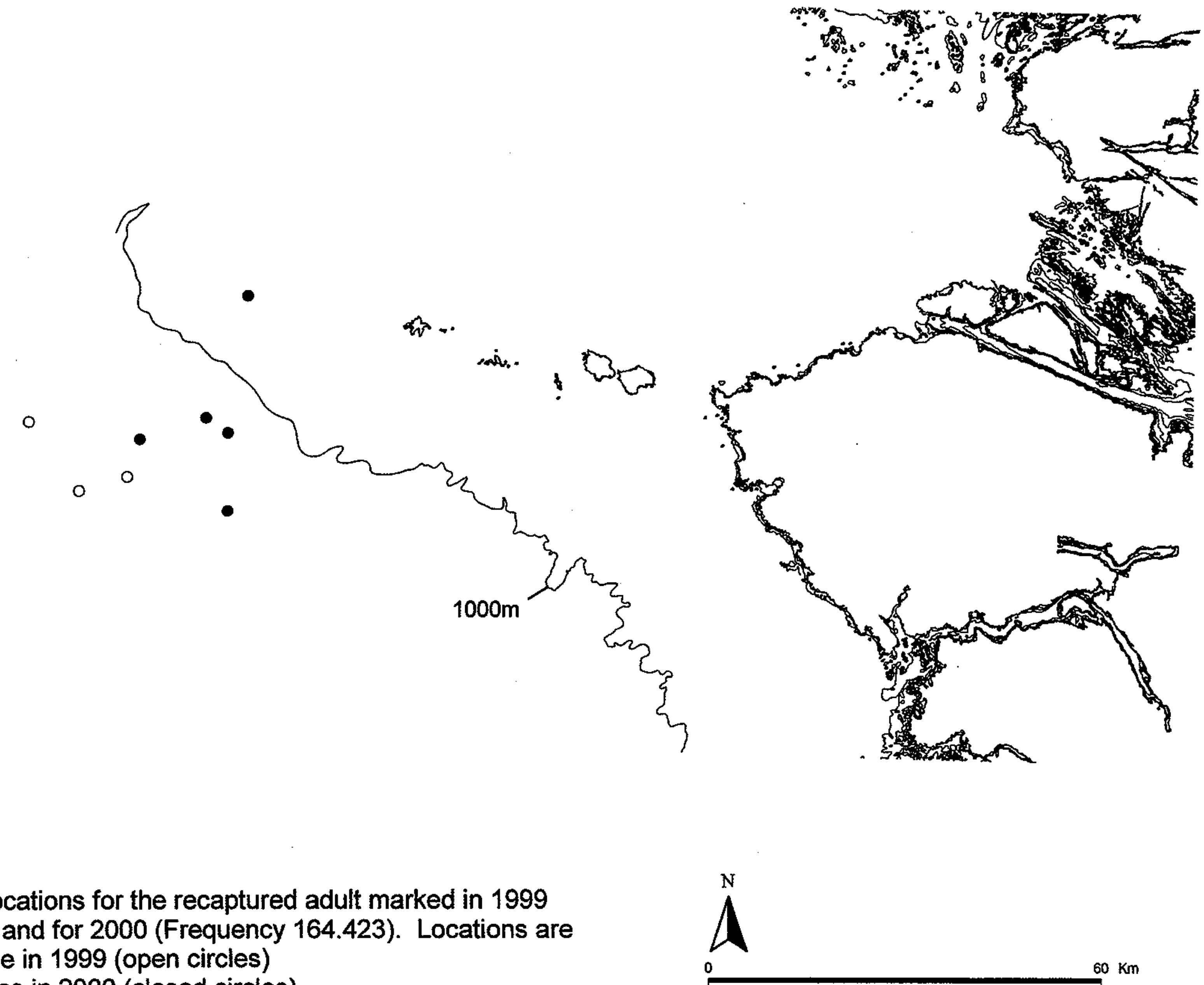


Figure 18. Inferred locations for the recaptured adult marked in 1999 (Frequency 164.124) and for 2000 (Frequency 164.423). Locations are for 10, 23 and 24 June in 1999 (open circles) and for all survey dates in 2000 (closed circles).

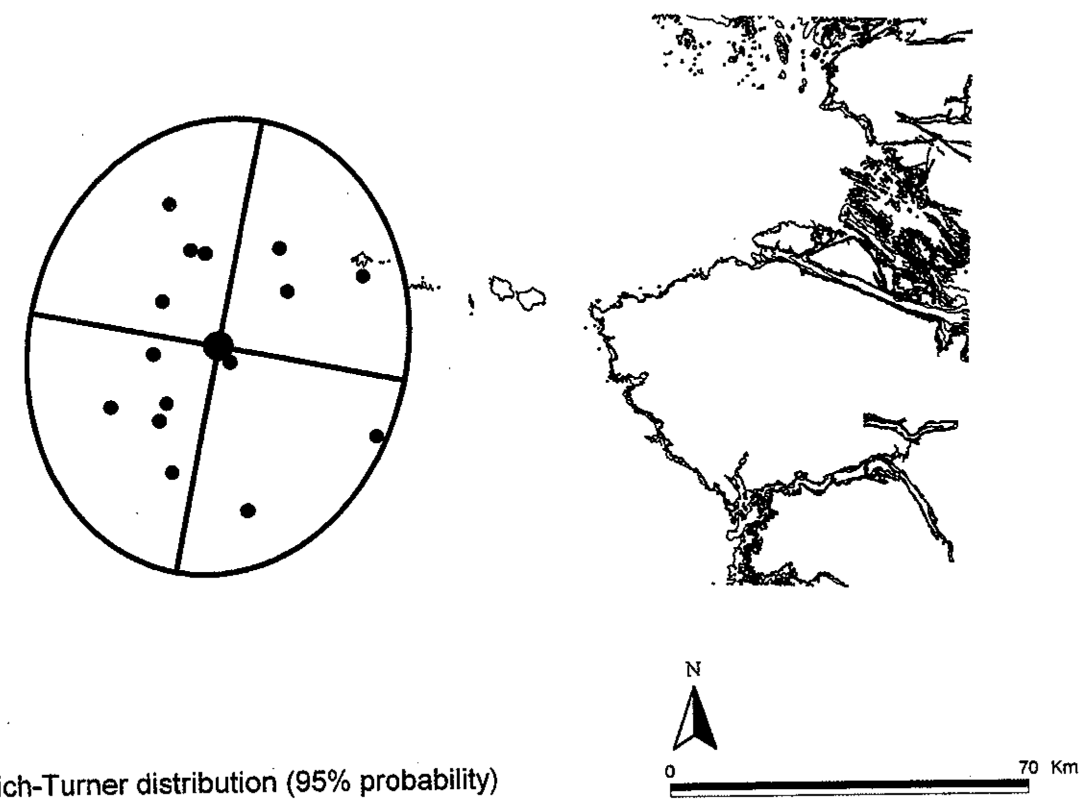


Figure 19A. Jenrich-Turner distribution (95% probability) estimated for the morning of 1 June, 2000.

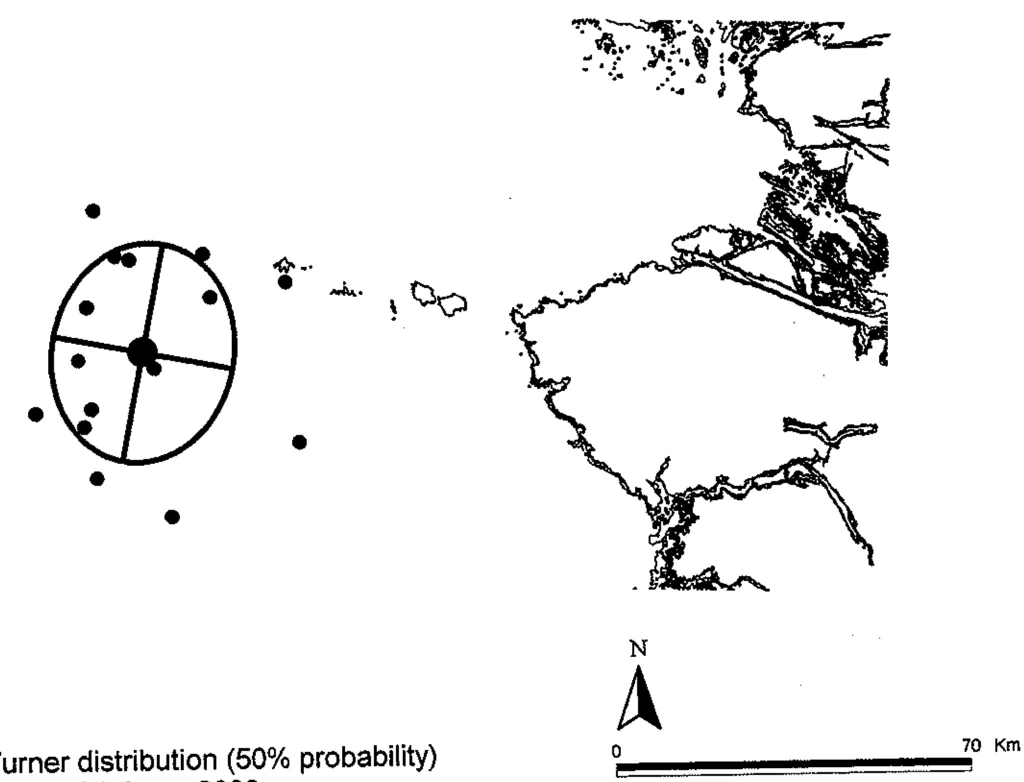


Figure 19B. Jenrich-Turner distribution (50% probability) estimated for the morning of 1 June, 2000.

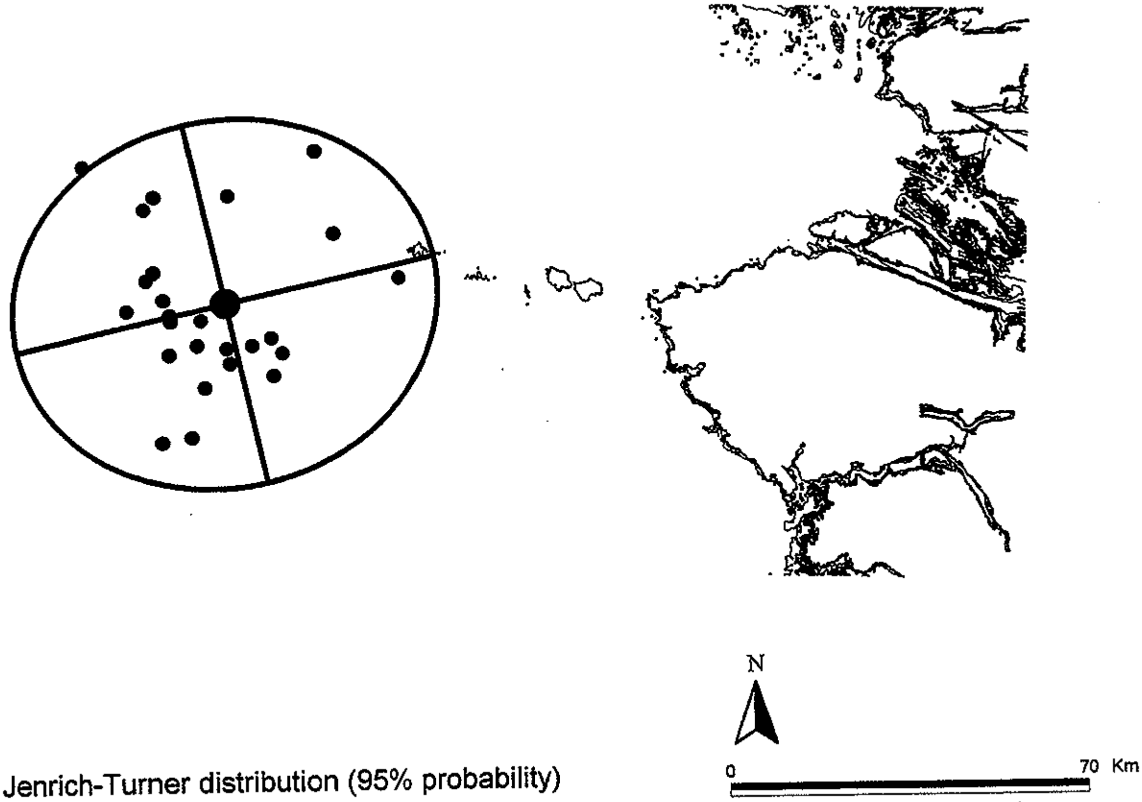


Figure 20A. Jenrich-Turner distribution (95% probability) estimated for 15 June, 2000.

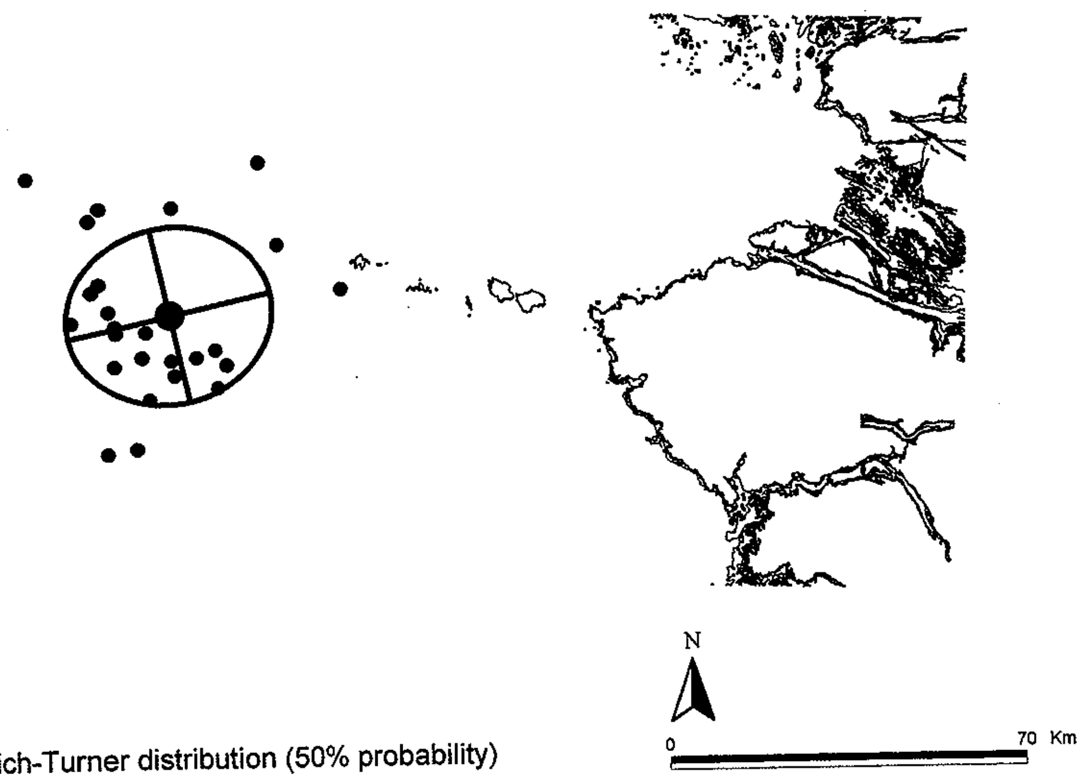


Figure 20B. Jenrich-Turner distribution (50% probability) estimated for 15 June, 2000.

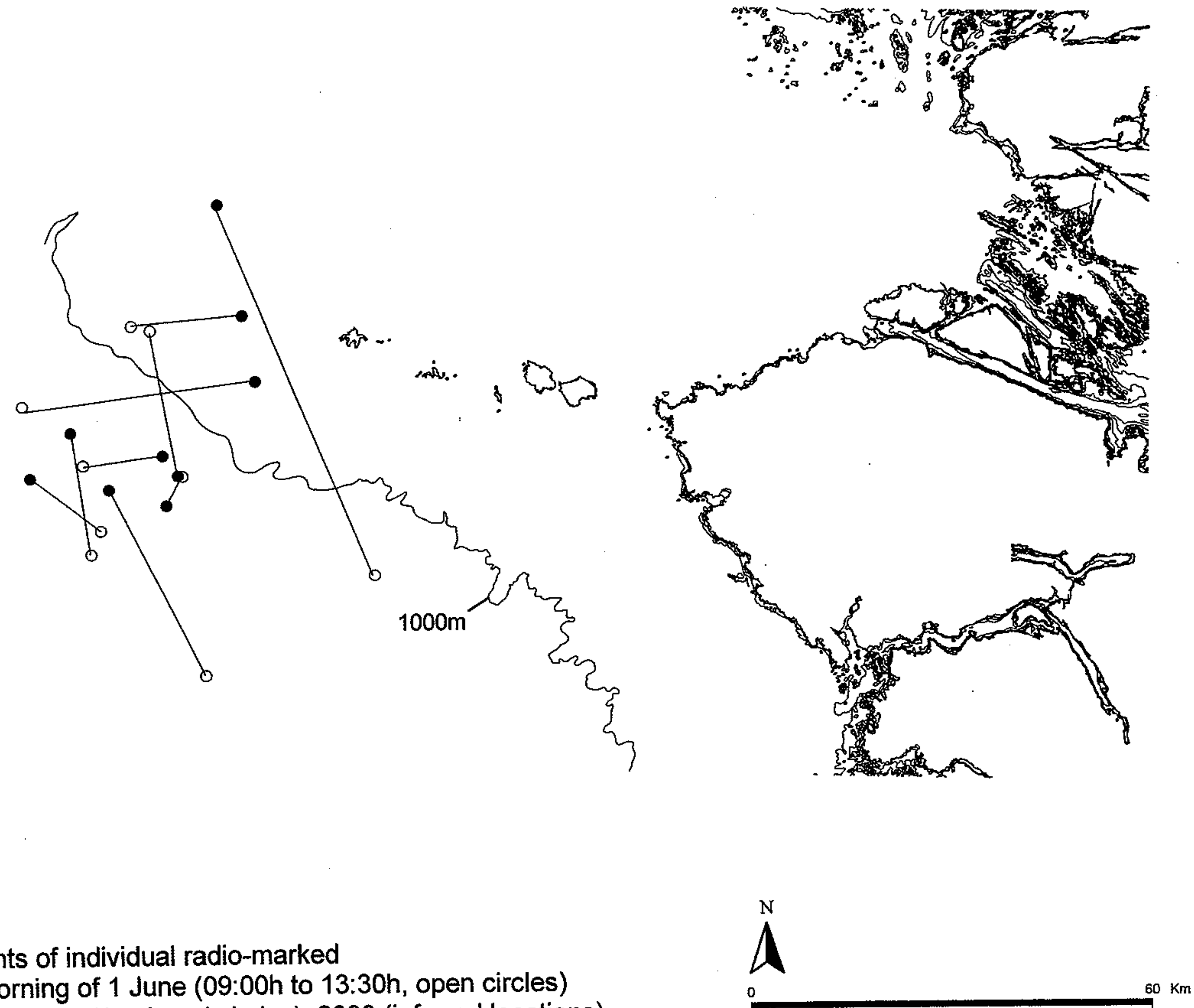


Figure 21. Movements of individual radio-marked birds between the morning of 1 June (09:00h to 13:30h, open circles) and 15 June (14:30h to 19:30h, closed circles), 2000 (inferred locations).

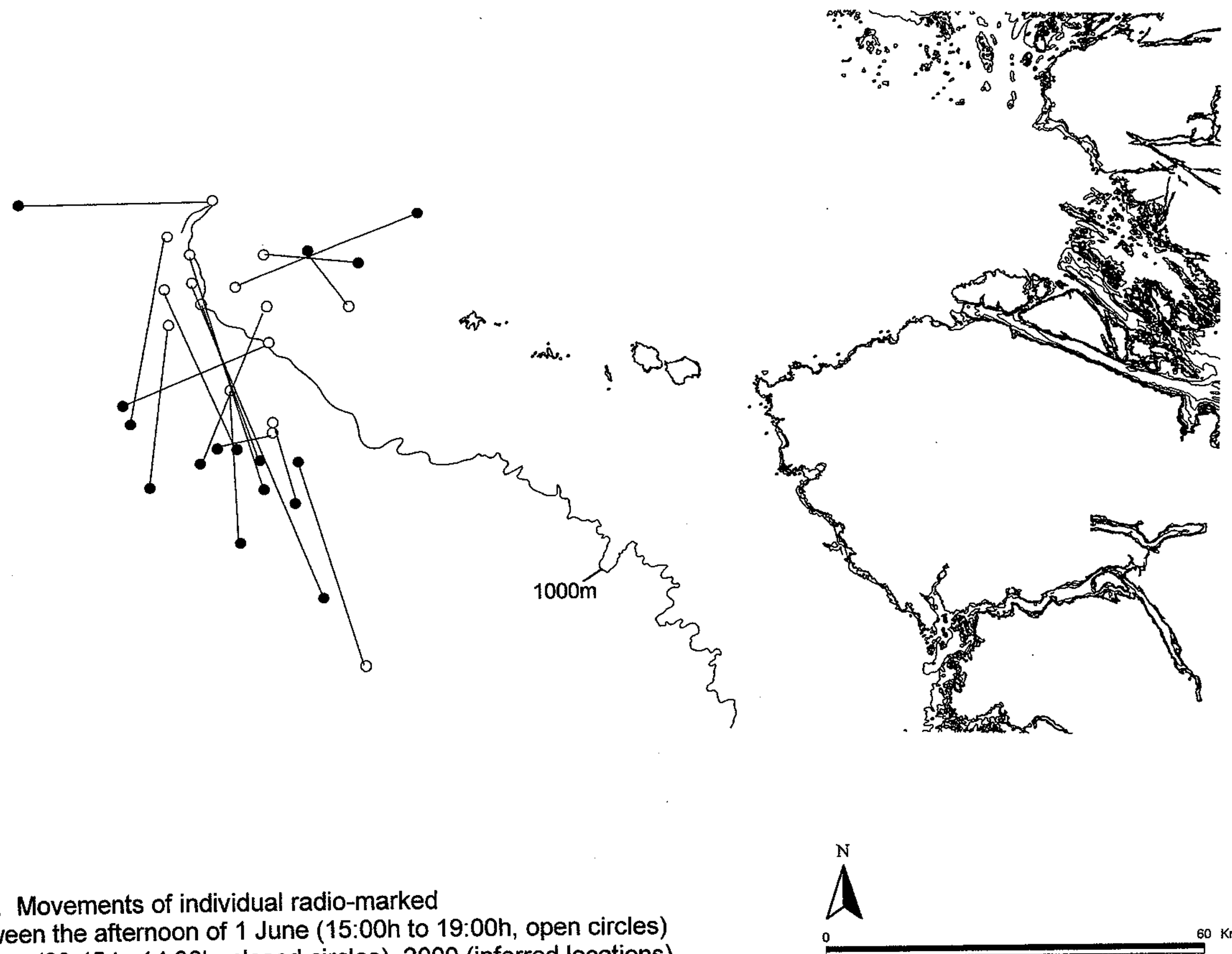


Figure 22. Movements of individual radio-marked birds between the afternoon of 1 June (15:00h to 19:00h, open circles) and 16 June (09:45 to 14:30h, closed circles), 2000 (inferred locations).

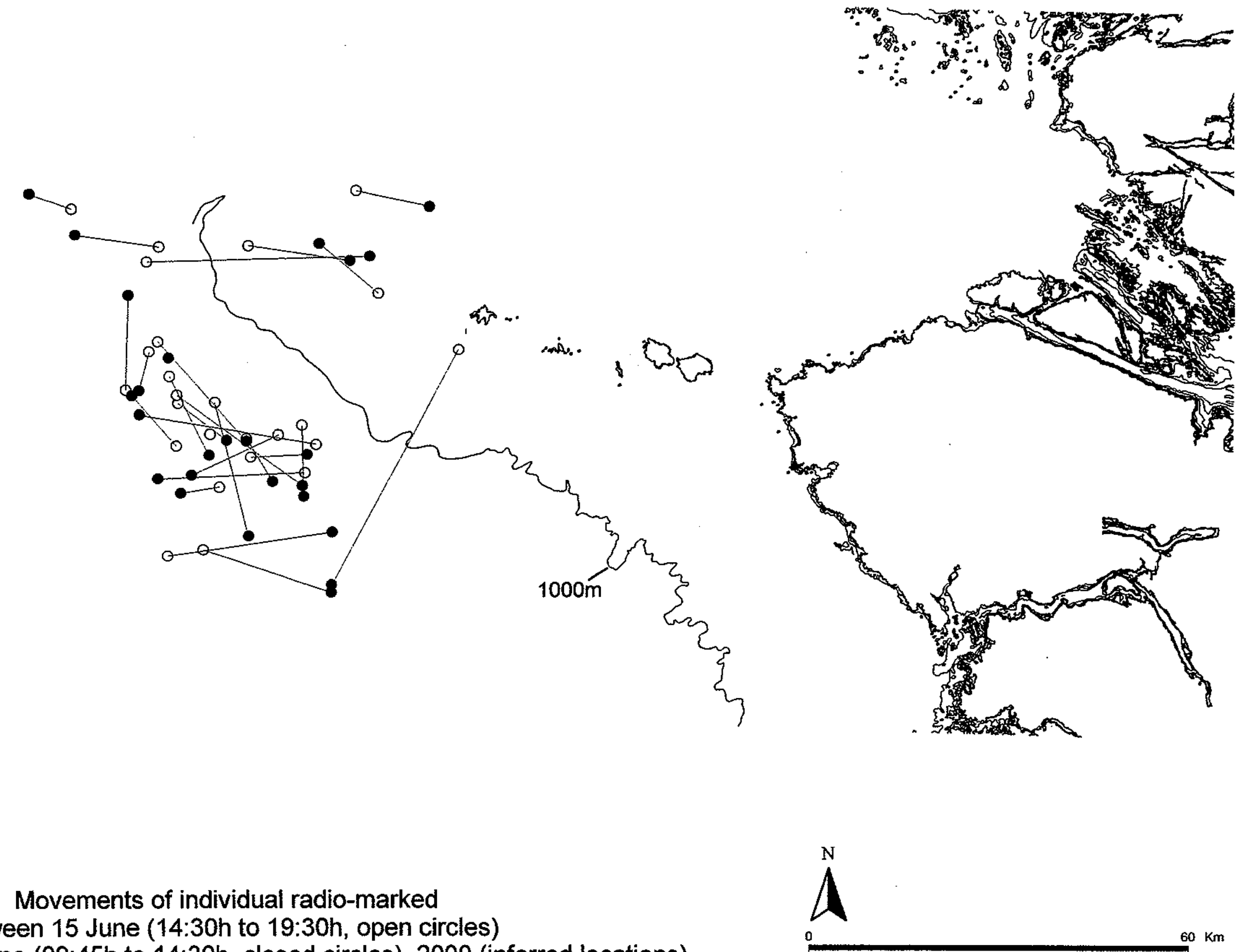


Figure 23. Movements of individual radio-marked
birds between 15 June (14:30h to 19:30h, open circles)
and 16 June (09:45h to 14:30h, closed circles), 2000 (inferred locations).

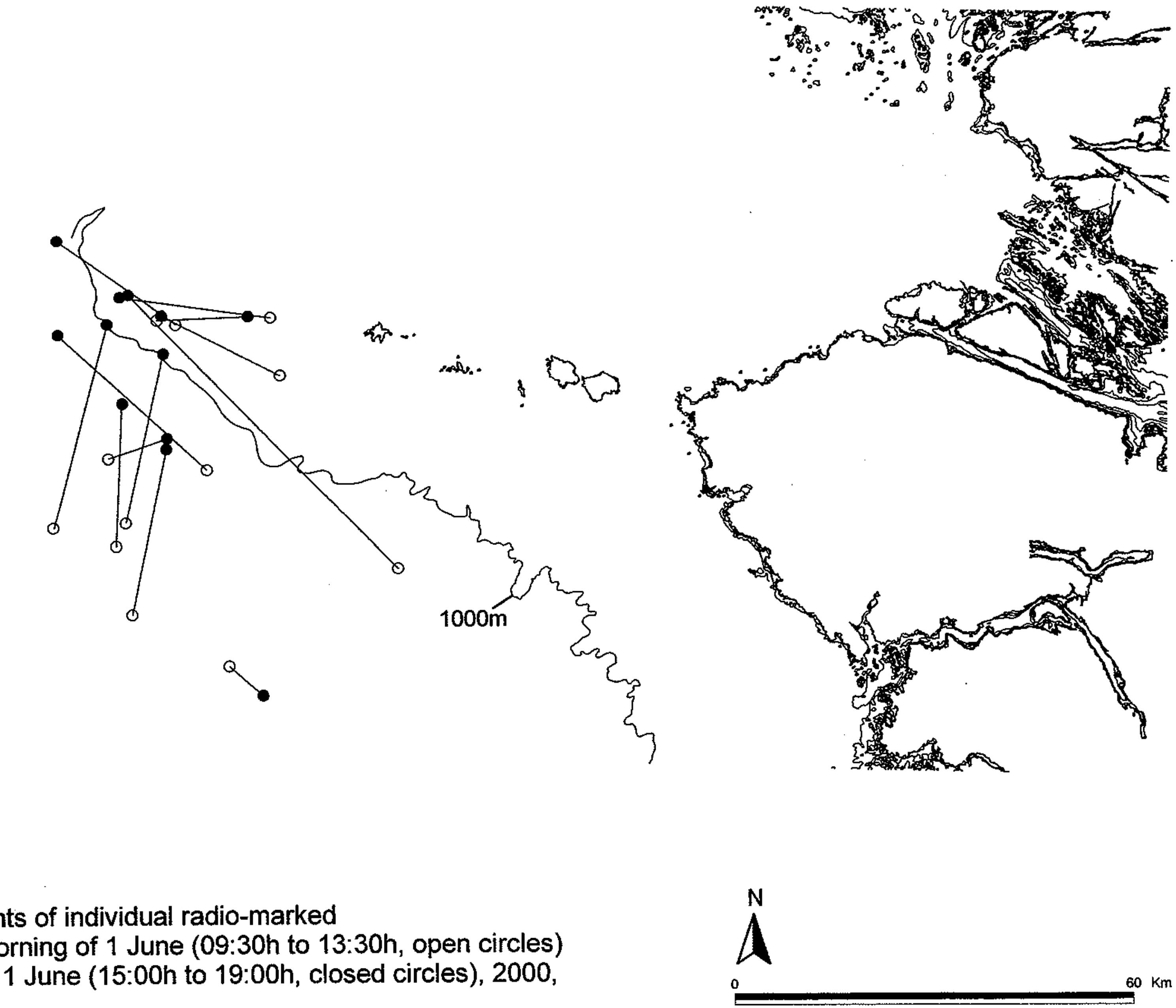


Figure 24. Movements of individual radio-marked birds between the morning of 1 June (09:30h to 13:30h, open circles) and the afternoon of 1 June (15:00h to 19:00h, closed circles), 2000, (inferred locations).