Impacts of overhead transmission wires on birds at the Roberts Bank Superport in 1994-1995

by

Alan E. Burger and Alice L.E.V. Cassidy

Alan Burger Environmental Science and Ornithology
5012 Old West Saanich Road
Victoria, B.C.
V8X 3X1.
Phone (604) 479-2446.

Report to:

Roberts Bank Environmental Review Committee
(V. Niemela, Chair)
Environment Canada
224 West Esplanade
North Vancouver, B.C.
V7M 3H7,

British Columbia Hydro
Environmental Resources Office
6911 Southpoint Drive (E16)
Burnaby, B.C.
V3N 4X8

and

Vancouver Port Corporation
1900 Granville Square
200 Granville Street
Vancouver, B.C.
V6C 2P9

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ABSTRACT

1. We studied the effects of overhead wires and other hazards to birds at the Roberts Bank Superport from April 1994 through May 1995. Our focus was on mortality caused by collisions with the 60 kV overhead power line on the causeway.
2. Weekly censuses were made from Brunswick Point to the causeway and on both sides of the causeway out to 500 m from shore. An average of 17,411 birds were counted, with peak numbers from October through April. Sandpipers (61%), dabbling ducks (30%) and gulls (3%) were the most common birds. Monthly mean densities for each species are presented.
3. Observations of bird flights across the causeway were made year-round, and we recorded 5664 crossing events, involving 52,990 birds. The mean rate of crossing was 46,366 birds per day (16.9 million birds per year). Shorebirds (76%), ducks (12%) and gulls (8%) crossed most often.
4. Birds crossed all parts of the causeway, but many species showed preferences for certain areas (e.g. Shorebirds crossed most often in sectors 1-40 closest to the shore; Caspian Terns in sectors 60-70). Fewer birds crossed near or over the coalport terminal.
5. There were clear differences among bird types in the altitude and approach behaviour when crossing the power line. Many species (notably cormorants, herons, swans, shorebirds, gulls and Caspian Terns) crossed close to the upper wire (69% of all birds passed within 10 m). These species would have higher risk of collision. Overall, 95% of all birds flew over the wire, and 5% below, and <1% between the three wires.
6. About 53% of all birds crossing the causeway showed some deviation in flight when approaching the power line. Most (42% of events) gained height in a controlled manner. Severe or abrupt reactions were most common in shorebirds (38% of crossing events), particularly Western Sandpipers and similar peeps.
7. We witnessed only five collisions which resulted in one death (a newly fledged Caspian Tern). Near-collisions were quite common, especially among shorebirds in the late summer.

8. We conducted systematic carcass searches along the causeway at 7-day intervals year-round. These yielded 590 bird carcasses, of which 304 were considered to have been deposited during the study. Birds which had obvious injuries resulting from collisions included two Double-crested Cormorants (sample N = 4), one Great Blue Heron (N = 1), one American Coot (N = 1), 31 waterfowl (N = 149), 64 shorebirds (N = 90), 10 Caspian Terns (N = 10), one raptor (N = 2) and one owl (N = 1). A large proportion of the waterfowl carcasses appeared to be birds killed by raptors. It was impossible to accurately assign a cause of death to most carcasses.
9. The species distribution of carcasses reflected their flight paths. Carcasses of waterfowl tended to be clustered around poles, suggesting that many were raptor victims. Most carcasses were found within 10 m of the power line.
10. Scavenging of wire-killed carcasses was common (86% of all carcasses had been partly eaten), which indicates that many carcasses were eaten or removed before being counted. Raptors (principally Bald Eagles, Northern Harriers and Red-tailed Hawks) and other scavengers (crows and ravens) were present year-round and in all parts of the causeway.
11. To test our search efficiency and to estimate rates of disappearance of carcasses between searches, we conducted four series of tests (summer, fall, winter, spring) using 20 carcasses place randomly on the causeway. Search efficiency indices were 0.44 for Dunlin (44% of carcasses present would be found in a search), 0.19 for other small sandpipers, 0.71 for dark mid-sized birds (ducks etc.) and 0.83 for gulls. Carcass persistence was modelled with polynomial regressions. The mean persistence index (proportion of carcasses deposited between each 7-day search which remained) in summer and winter was 0.87 and 0.65 , respectively, for shorebirds, and 1.00 and 0.74, respectively, for all larger birds. These values were applied to models estimating total carcass deposition.
12. Monthly estimates of carcass deposition for each species (C_{tot}) were derived from carcass counts (C_f), search efficiency (e) and persistence (p) using the formula $C_{tot} = C_f/(e.p)$. This model gave an estimate of 710 carcasses deposited through the year, with Dunlin

(30%), Western Sandpipers (10%), American Wigeon (9%), Least Sandpiper (7%) and Mallard (5%) the most common species.

13. On average, the estimated carcass deposition was <2% of the mean census count during the period of occupancy of each species, and <1% of the maximum counts. Species with high rates of mortality from collisions, relative to local populations included Great-blue Herons (1-5.4% of local population killed), swans (1-2%), Black-bellied Plover (2-15%), Glaucous-winged Gulls (3-27%) and Caspian Terns (3-15%). The mortality of Caspian Terns is of particular concern because this is a rare bird in B.C., listed nationally as "vulnerable", and Roberts Bank supports the largest aggregations in the province. Although Dunlin and Western Sandpipers were the most abundant birds and contributed the most carcasses, these were estimated to be less than 2% of mean local populations.
14. A review of mitigation methods applicable to the Roberts Bank Superport was made. Burial of the power line would be the most effective, but also most expensive solution. Marking the uppermost conductor would certainly reduce collisions but would not be completely effective. Markers should ideally be mobile (e.g. streamers), rather than static, and yellow-green seems the most effective colour. Other options include: changing the configuration of the three wires from triangular to horizontal; the addition of a fourth, higher non-conducting wire to which numerous, cheap streamers could be attached; and growing rows of trees to provide a highly conspicuous barrier that forces the birds to cross safely above the power line.

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1. INTRODUCTION

We report the results of a study on the mortality of birds caused by overhead power transmission line, poles and stanchions at the Roberts Bank Superport south of Vancouver, British Columbia. The causeway and loading facilities of the superport were built on the Roberts Bank mudflats. This area is one of the most important feeding and staging areas for migratory birds in British Columbia and supports tens of thousands of birds, principally migratory shorebirds and waterfowl.

Concerns have been expressed by biologists and non-governmental organizations over the impact of the port development on these birds, ever since it was built. In particular, many people noticed that birds were being killed by collisions with the overhead power line leading across the causeway to the loading facility. There was also concern about collisions with the light towers, loading cranes and other structures within the loading terminal, which are floodlit year-round. Some of these issues were raised in earlier environmental studies of the Roberts Bank development (Beak Hinton 1977a, b, 1978, Gartner Lee 1992) and they were the focus of one short study (Roe and Williams 1984).

The present study was done to investigate these concerns year-round, and address shortcomings in previous studies. The principal objectives were as follows:

i. Determine the number and species of birds at risk.
To do this we conducted systematic, year-round censuses of all birds using the mudflats and nearshore shallows adjacent to the causeway.

ii. Determine the species, numbers and behaviour of birds regularly crossing the power line.
This was done through year-round visual observations on all sections of the causeway, and the use of radar to determine nocturnal activity patterns.

iii. Estimate the species, numbers, chronology and distribution of birds killed by collisions on the causeway and in the loading terminal.
This involved year-round carcass searches, examination of all carcasses to determine the causes of death and investigation into the factors affecting our carcass counts. We did experiments to measure our search efficiency and determine the rates of disappearance of carcasses, and applied these results to simple models to estimate overall carcass deposition rates.

iv. To determine the likely effects of the collision mortality on local and migrant populations.
An important question was whether the rates of mortality were having significant impacts on the populations of birds using the surrounding areas.

v. Suggest and test methods for mitigating the collisions.
We suggest several methods for reducing collisions. Testing of one or more of the techniques was postponed due to construction and re-positioning of part of the power line in 1995, and is not included in this report.

There were several shortcomings in the past studies, notably the lack of year-round monitoring of mortality, inadequate sampling during foggy days and at night, and inadequate methods for assessing the rates of collisions by shorebirds. Of particular concern was the lack of information on the effects of the overhead wires on Dunlin (*Calidris alpina*) that overwinter in large numbers near the causeway from December to March. The Roe and Williams (1984) study did not consider this period. The impacts of the wires, stanchions and lights on the high wintering populations of waterfowl, raptors and other migrants had also been inadequately studied.

Most of the birds affected by the superport are migrants and species composition and populations change dramatically through the year. Huge populations of birds pass through the area, sometimes staying for a few days only. For these reasons we conducted censuses, observations and

carcass searches at regular, frequent intervals throughout the year and in a full range of typical weather conditions.

2. GENERAL METHODS

2.1. Study area

The superport is situated off Tsawwassen, south of Vancouver. The coal loading terminal and container port development are at the end of a 4 km long causeway crossing the intertidal mudflats (Figure 1). The entire causeway is flanked by shallow water at high tide and most of it by mudflats at low tide. The shallow, placid sea is a favoured foraging area for a diverse and very large assemblage of waterbirds, while the exposed mudflats are equally important for migrant shorebirds (Butler and Campbell 1987, Butler and Cannings 1989, Butler 1992, Summers, Hayes and McKelvey 1994).

At high tide the water reaches close to the proximate (shoreward) end of the causeway, while at the lowest tides most of the causeway is flanked by extensive mudflats. During the study, most of the power line was flanked on the causeway by a paved road, a railbed and open ground largely covered by low shrubs, herbs and grass with no trees (some of the vegetated areas have since been paved or changed to railbed). In spring and early summer, plant growth was vigorous and covered most of the ground. The plants died back in late summer and in winter there were extensive areas of bare ground. The ground within the coal terminal was mostly devoid of vegetation, making it easier to find carcasses. Parts of the terminal were cleaned with hoses every few days, which might remove any carcasses deposited there, although workers told us they did not recall seeing dead birds.

2.2. Description of the power line and causeway sectors

The power line consisted of three live 60 kV wires with no ground wire, supported on wooden poles about 18 m tall. The wires were mounted in a triangular configuration (inset on Figure 1). The main line along the length of the causeway consisted of 75 poles, evenly spaced 60 m apart. These were labeled (pole 1 was nearest the mainland) and the ground between each pole treated as a **sector** for searching and observation

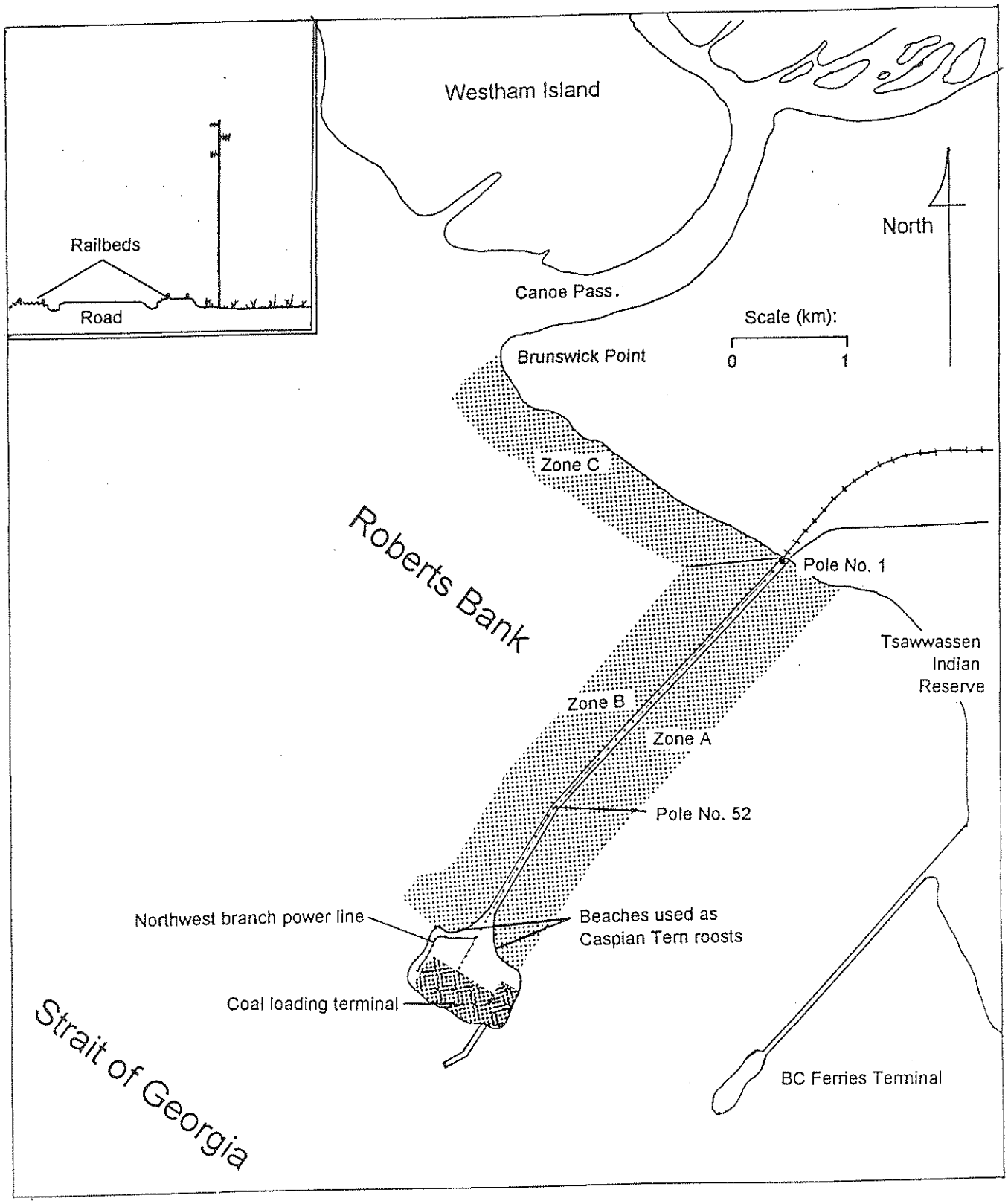

Figure 1. Schematic map of the Roberts Bank Superport, showing the three zones (A,B and C) used for censusing birds (light stippling), and the location of important features mentioned in the text. The inset shows the arrangement of the transmission wires on the pole, and the location of the road and railbeds along much of the causeway.

purposes. A branch transmission line led off from pole 68 and curved around towards the northwest to enter the coal terminal (Figure 1). [The power line beyond pole 50 was moved to the northwest during the summer of 1995 after our study was completed]. Our observations and searches focussed on sectors 1 through 70 (in the early weeks we focussed on 1-52), but carcass searches were also done in the 16 northwestern sectors, and in the coal terminal.

3. BIRDS AT RISK: CENSUS DATA.

3.1. Methods

We conducted 53 censuses of birds between 27 May 1994 and 11 May 1995, at an average of once every 6.6 days (range 2-15, mode 7 days). The census area was divided into three zones (Figure 1): zone A covered the south side of the causeway from the shoreline to the small bay where the loading terminal begins; zone B was the equivalent on the north side of the causeway; zone C extended off the dike between area B and the small bay just south of Brunswick Point. In all zones all birds within 500 m of the shoreline were counted and identified, with the aid of 7x35 binoculars, and a 15-45x spotting scope mounted on a tripod or vehicle window. Occasionally, with poor light or glare, some birds could not be identified to species level.

Forty-two counts were initiated one hour before high tide, and an additional 11 counts were made at low or mid-tide to get better estimates of shorebird numbers. On each census we recorded the starting time, duration, time and heights of low and high tides, percentage cloud cover, wind speed (Beaufort scale) and wind direction.

Numbers in very large flocks of waterfowl and shorebirds were estimated in one of three ways:

i. Counting birds individually up to 10 and then counting the number of such groups (with larger flocks, once 100 was reached this became the new unit of estimation);

ii. using the above technique to estimate the number of birds in the field of view of the spotting scope and then scanning the flock to count the number of "scope-views";

iii. estimating the number of birds in a "scope-view" by counting the number of birds across the vertical and horizontal axes, and then scanning across the flock as in ii.

3.2. Results

3.2.1. Bird counts per species

The annual mean count of each species is shown in Table 1, and the monthly means (2-5 counts per month, mode 3) in Figure 2.

Common Loons were present all year, with the largest numbers in September and October. Two Pacific Loons were seen on 20 December, one Red-throated Loon on 20 December and two on 31 December. Grebes were most common in September and October, with a maximum of 66 Horned Grebes on 17 September and 614 Western Grebes on 11 October. Double-crested Cormorants, a resident species which breeds on the pilings between Roberts Bank and the Tsawwassen ferry causeway, were common all year, with highest densities in July and October. Brandt's and Pelagic Cormorants were rare, with one and two birds seen, respectively. Great Blue Herons, resident breeders, were present all year, with the largest concentrations seen in spring through early fall (April through October).

Waterfowl (Family Anatidae) made up a large proportion of the birds counted, particularly over the winter from October through April. Trumpeter Swans were quite common in December and January, with a maximum of 151 on 24 January. They were often seen in late afternoon or evening, flying from farm fields to roost at Brunswick Point. Tundra Swans were less common. Geese were relatively uncommon around Roberts Bank, with the exception of Brant, which feed on eelgrass in the intertidal shallows. The huge flocks of Snow and Canada Geese, common in nearby fields, were not seen in the census area and the maximum counts were 121 and 500 respectively.

Dabbling ducks were the most abundant waterfowl, particularly Green-winged Teal, Mallard, Northern Pintail and American Wigeon. An average of 10,000 of these ducks were present between October and February.

Table 1. Mean numbers of birds per census through the year, and during the main period of occupancy of each species. Data from Brunswick Point through Roberts Bank.

Species	Species code	Year-round (N = 42 counts) Mean	SD	Maximum	During main occupancy period Period	Mean	No. counts
Red-throated Loon	RTLO	0.1	0.4	2	Dec	1.5	2
Pacific Loon	PALO	0.05	0.3	2	Dec	1.0	1
Common Loon	COLO	6.6	7.6	29	Aug-Apr	8.1	34
Horned Grebe	HOGR	7.3	12.7	64	Aug - Jan	9.3	33
Red-necked Grebe	RNGR	0.6	1.4	6	Oct-Nov	3.6	5
Western Grebe	WEGR	20.0	96.7	614	Sep-Oct	138.2	6
Double-crested Cormorant	DCCO	62.1	62.7	265	All year	62.1	42
Brandt's Cormorant	BRCO	0.02	0.2	1	Jan	0.5	2
Pelagic Cormorant	PECO	0.2	0.4	2	April	0.2	42
Great Blue Heron	GBHE	11.2	18.1	92	Apr-Oct	18.6	23
Tundra Swan	TUSW	11.1	33.4	151	Dec-Jan	77.3	6
Trumpeter Swan	TRUS	4.2	16.7	94	Dec-Jan	15.7	6
Snow Goose	SNGO	4.8	22.1	121	Oct-Nov	28.7	7
Brant	BRAN	88.9	324.1	1898	Mar-Apr	372.7	10
Canada Goose	CAGO	27.8	92.7	500	May-Aug	108.9	10
Green-winged Teal	GWTE	646.6	881.0	3436	Sep-Apr	891.1	30
Mallard	MALL	1045.8	1794.5	7499	Sep-Apr	1489.0	29
Northern Pintail	NOPI	1666.2	2496.9	9204	Sep-Apr	2754.5	29
Northern Shoveler	NOSL	2.0	6.0	31	Apr	5.0	4
Gadwall	GADW	4.6	20.2	115	Apr-Jun	24.0	7
Eurasian Wigeon	EUWI	0.8	2.0	11	Sep-Apr	3.0	29
American Wigeon	AMWI	1921.7	2428.3	10408	Sep-Apr	3137.5	29
Canvasback	CANV	0.9	2.8	12	Dec-Jan	6.0	6
Greater Scaup	GRSC	46.3	75.9	270	Oct-Apr	69.4	26
Unidentified Scaup	Scaup sp.	41.1	196.0	1270	Oct-Apr	64.0	26
Black Scoter	BLSC	28.3	51.9	295	Oct-Apr	44.0	26
Surf Scoter	SUSC	28.4	35.8	185	Oct-Apr	44.1	26
White-winged Scoter	WWSC	16.1	22.6	98	Oct-Apr	24.0	26
Unidentified Scoter	Scoter sp.	4.3	22.3	140	Oct-Apr	6.7	26
Common Goldeneye	COGO	3.6	4.8	18	Nov-Apr	7.7	20
Barrow's Goldeneye	BAGO	0.1	0.3	2	Nov-Apr	0.2	20
Bufflehead	BUFF	19.0	35.6	140	Nov-Apr	34.7	20
Common Merganser	COME	0.4	1.7	10	Oct	4.3	4
Red-breasted Merganser	RBME	2.7	6.0	24	Mar-May	10.1	10
Unidentified Duck	DUCK sp.	424.3	884.1	3100	Sep-Apr	387.4	29

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Species	Species code	Year-round (N = 42 counts) Mean	SD	Maximum	During main occupancy period Period	Mean	No. counts
Table 1, continued							
Bald Eagle	BAEA	2.6	3.1	13	Oct-Jul	3.1	34
Northern Harrier	NOHA	2.3	2.4	9	Oct-Jul	2.7	34
Red-tailed Hawk	RTHA	0.5	0.6	2	Oct-Jul	0.6	34
American Kestrel	AMKE	0.0	0.2	1	Oct-Jul	0.1	34
Merlin	MERL	0.1	0.4	2	Oct-Jul	0.2	34
Peregrine Falcon	PEFA	0.1	0.4	1	Oct-Jul	0.1	34
Gyrfalcon	GYRF	0.0	0.2	1	Oct-Jul	0.0	34
Black-bellied Plover	BBPL	63.8	94.1	427	All year	63.8	42
Semi-palmated Plover	SEPL	0.6	1.8	8	Aug & May	4.5	8
Killdeer	KILL	4.8	16.0	102	All year	4.8	42
American Avocet	AMAV	0.02	0.15	1	-	-	-
Lesser Yellowlegs	LEYE	0.1	0.6	4	-	-	-
Ruddy Turnstone	RUTU	0.02	0.15	1	-	-	-
Black Turnstone]	BLTU	0.1	0.6	3	-	-	-
Semi-palmated Sandpiper	SESA	1.4	9.1	60	Aug & May	15.0	8
Western Sandpiper	WESA	2924.4	16882.1	110705	Jul-Aug, Apr-May	13816.2	8
Least Sandpiper	LESA	0.5	3.4	22	Jul-Oct	1.8	12
Pectoral Sandpiper	PESA	0.7	3.2	18	Jul-Oct	2.4	12
Dunlin	DUNL	7632.3	8886.9	37000	Oct-Apr	11652.4	28
Long-billed Dowitcher	LBDO	0.2	1.2	8	Jun-Jul	1.6	5
Unidentified Dowitcher	DOWIT sp.	1.5	8.4	55	Jun-Jul	11.0	5
Whimbrel	WHIM	0.5	1.7	6	Jun-Jul	4.6	5
Unidentifed Peep	UN PEEP	11.7	43.9	240	Jul-Oct	38.5	13
Unidentified shorebird	OTHER4	1.2	4.3	25	Aug-Jan	2.6	20
Bonaparte's Gull	BOGU	0.3	1.4	9	Sep-Oct	2.4	5
Mew Gull	MEGU	50.7	89.6	352	Sep-May	66.2	31
Ring-billed Gull	RBGU	152.2	294.5	1227	Jun-Sep	452.6	14
California Gull	CAGU	50.1	119.0	513	Jul-Oct	155.3	13
Glaucous-winged Gull	GWGU	39.0	63.4	410	All year	39.0	41
Unidentified Gull	GULL SP.	270.5	898.8	4890	Jun-Sep	805.4	14
Caspian Tern	CATE	28.4	78.8	419	May-Sep	79.5	15
Short-eared Owl	SEOW	0.1	0.8	5	All year	0.1	42
Common Raven	CORA	0.3	0.7	3	All year	0.3	42
Total all birds		17411	20657	123715	Oct-Apr	24906	27

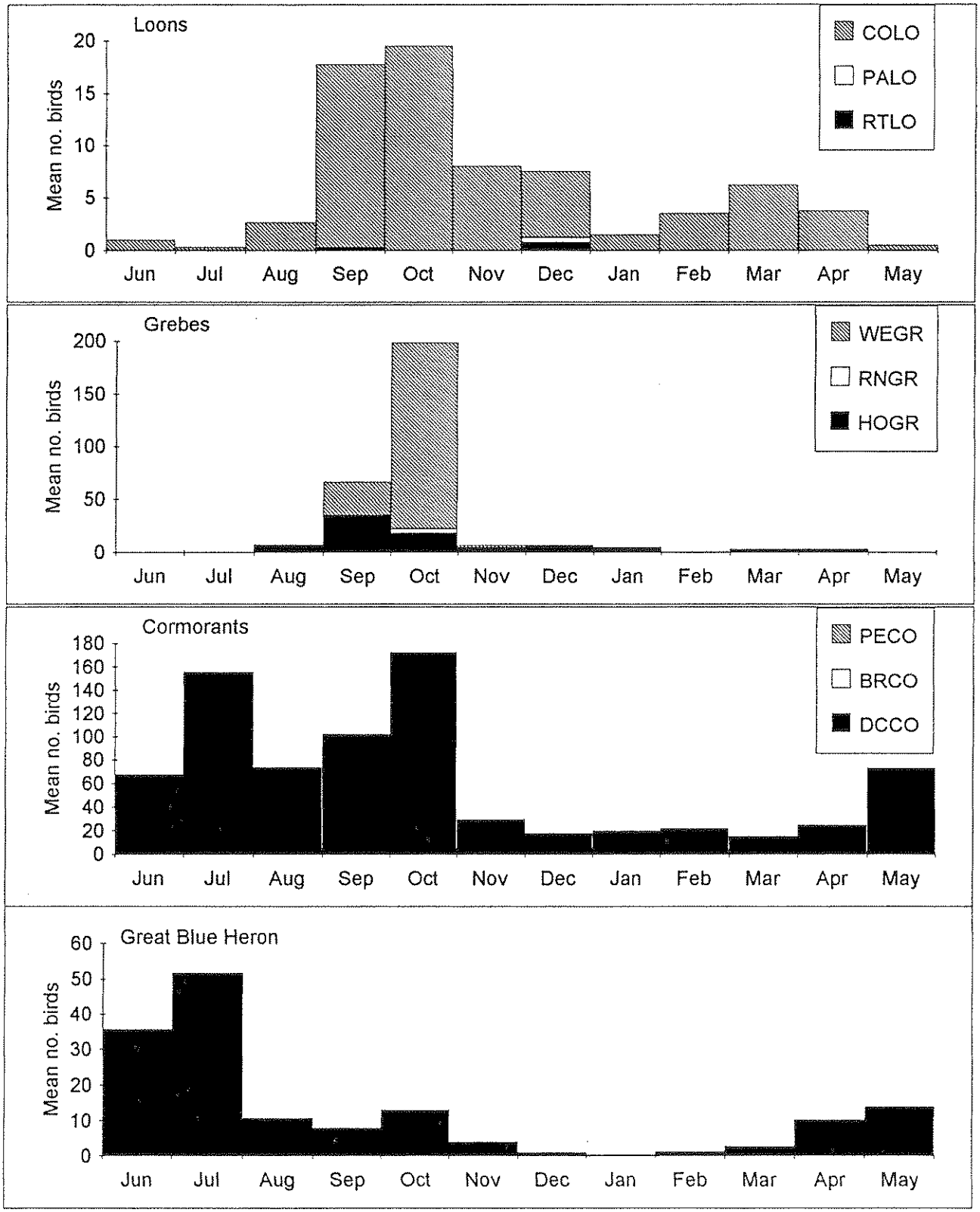
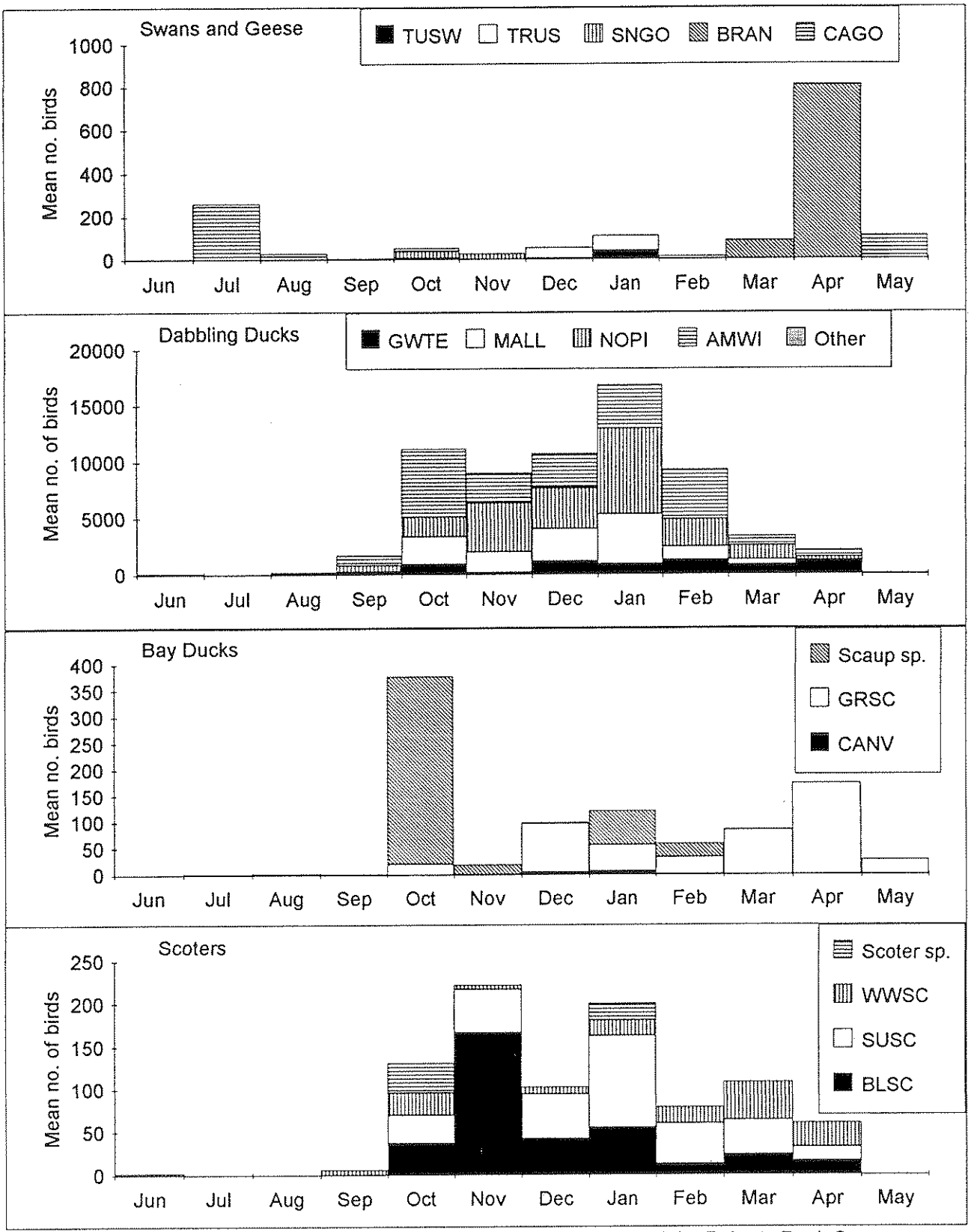


Figure 2. Monthly mean counts of birds off Brunswick Point and the Roberts Bank Causeway in 1994-1995. See Table 1 for species codes. Continued on following pages.



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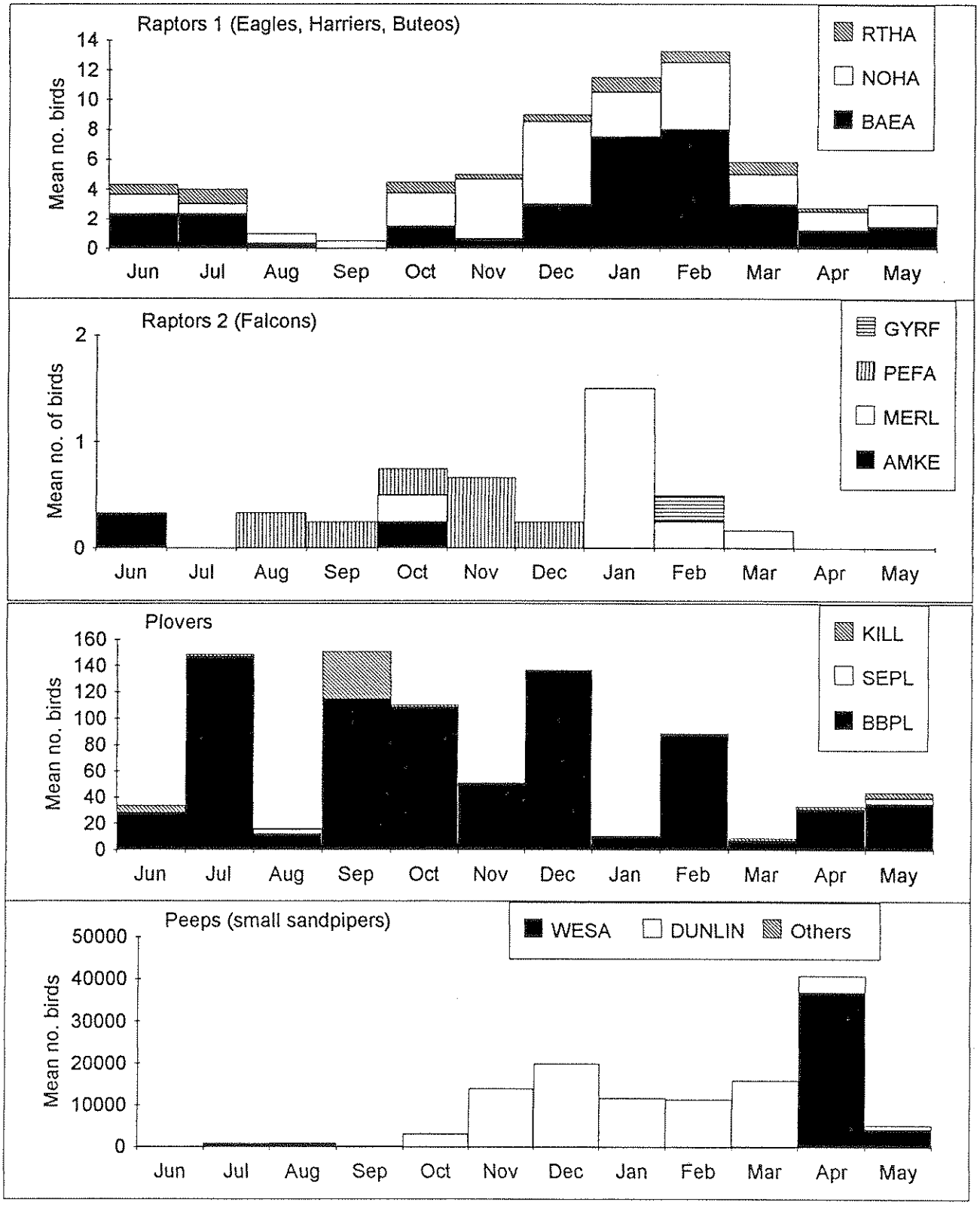

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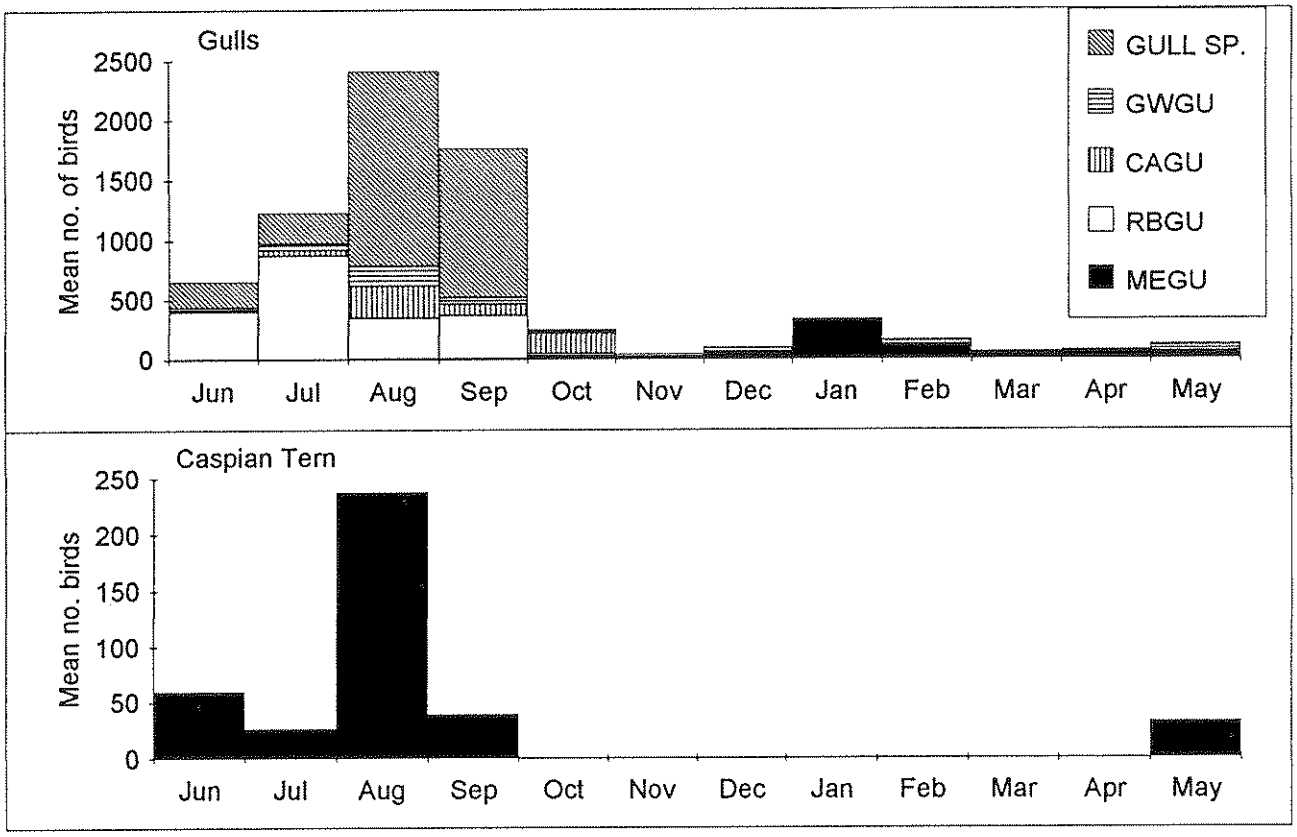


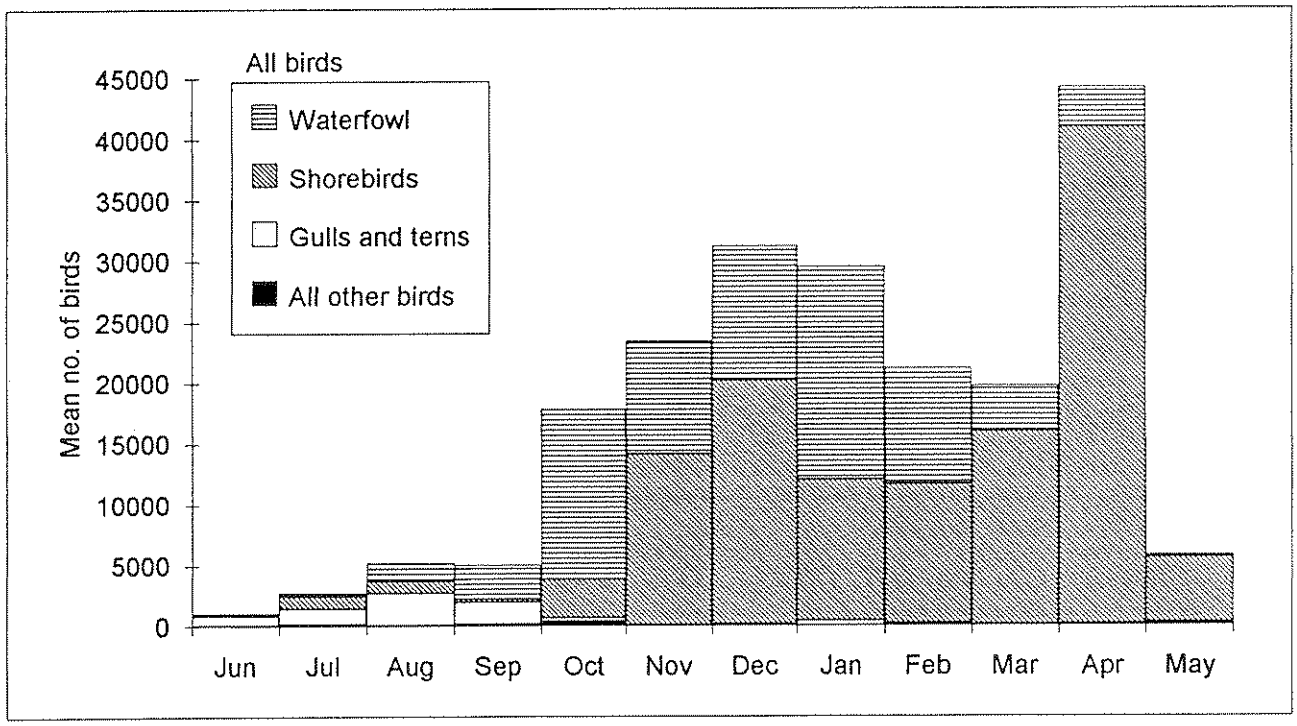


Figure 2, continued. Monthly mean counts of birds off Brunswick Point and the Roberts Bank Causeway in 1994-1995. See Table 1 for species codes.

Diving ducks were far less common, and were predominantly Greater Scaup, and the three species of scoters. The presence of high numbers of Black Scoters in November 1994 was unusual for this area (Butler and Campbell 1987). Our censuses underestimated the numbers of diving ducks within the general Roberts Bank area, because they were often in the deeper water more than 500 m from shore.

The census area included an important foraging area for several raptor species. Bald Eagles, Northern Harriers and Red-tailed Hawks were present all year, but in much larger numbers from October through March. Four species of falcons were recorded.

Roberts Bank is immensely important as a staging and wintering area for huge populations of shorebirds (Families Charadriidae and Scolopacidae). Common species included Black-bellied Plover, Western Sandpiper and Dunlin. The latter two species were the most abundant birds seen, with maximum counts of 110,000 and 37,000 birds, respectively. Western Sandpipers and other similar small sandpipers (Peeps) passed through the area in two migratory pulses. The southward, post-breeding pulse occurred in July and August, and the northward spring migration April. Fewer Western Sandpipers were seen in our counts in the late summer migration than in spring, but in most years these numbers are similar in this area and in Boundary Bay (reference and check). This suggests that we missed the peak days of their summer movements, or the large flocks were foraging elsewhere on our census days. Dunlin overwinter in this area (it is one of the main wintering grounds of the species) and we consistently had counts of 10,000 birds from November through March.

Several species of gulls frequent the area. Mew and Glaucous-winged gulls were seen all year, in variable numbers, but the largest aggregations of gulls were the migrant Ring-billed and California gulls in June through September. Most of the unidentified gulls seen at this time were these two similar species.

Roberts Bank supports the highest concentrations of Caspian Terns in British Columbia (Campbell et al. 1990). They appeared in May and

remained until September with peak densities in August (maximum count of 420 on 13 August). The presence of large numbers of family groups, including newly fledged juveniles, suggests that the species was breeding nearby, but no known breeding colonies were reported in 1994. These terns concentrated at day-roosts on two small beaches on either side of the superport causeway, near the loading terminal (Figure 1). They frequently flew across the causeway from one beach to another, exposing themselves to the risk of collisions with the wires.

Notable sightings of unexpected birds included one American Avocet (27 May 1994), six Whimbrel (26 June), an Emperor Goose (13 December) and a Prairie Falcon (23 February 1995).

Overall, there was a very strong seasonal pattern to bird numbers. By far the highest mean monthly counts, ranging from 15,000 to 45,000 birds, occurred in fall through early spring (October through April), dominated by migratory and overwintering shorebirds and waterfowl (Figure 2).

3.2.2 Species of special concern

We paid particular attention in our analysis to species for which the Roberts Bank area was of national or global significance, and to species which were rare, threatened or endangered.

The area is particularly important for Dunlin and Western Sandpipers. The Fraser Delta, including Roberts Bank, is one of the primary wintering grounds of Dunlin, and therefore of global significance (Butler and Campbell 1987, Butler 1992). The intertidal mudflats are its principal foraging and roosting sites, but they also forage in agricultural land. Large numbers regularly cross the causeway during the winter, including at night and in foggy conditions, and there is concern that the power line poses a significant source of mortality to the wintering population. The mudflats of the Fraser Delta are also of global significance as a migratory staging ground for Western Sandpipers. Individual Western Sandpipers remain in the area for only 2-

3 days, but the total numbers passing through might reach 500,000 in spring and 1.2 million in autumn (Butler and Campbell 1987).

Several of the species at Roberts Bank are on the national and provincial lists of endangered, vulnerable and threatened species. Birds listed nationally by COSEWIC (Council on the Status of Endangered Wildlife in Canada; Munro 1993) as **endangered** include the Anatum race of Peregrine Falcon (probably seldom found at Roberts Bank), while those listed as **vulnerable** include the Trumpeter Swan, Caspian Tern, Cooper's Hawk (not seen during our censuses but present in the area), Peale's race of Peregrine Falcon (the race seen most often in our area), and the Common Barn Owl. Species listed on the provisional British Columbia provincial **Red List** include Western Grebe, Pelagic Cormorant, Brandt's Cormorant, Peregrine Falcon and Prairie Falcon, and species on the Blue List include Double-crested Cormorant, Great Blue Heron, Green-backed Heron (seen near the ferry terminal), Trumpeter Swan, Surf Scoter, Swainson's Hawk (present but not recorded in censuses), Caspian Tern and Red-necked Phalarope.

Roberts Bank is of special importance to Caspian Terns. This species is listed as Vulnerable by COSEWIC (at risk because of low or declining numbers, occurrence at the fringe of its range or in restricted areas) one notch down from Endangered; Munro 1993). There is only one published breeding record for British Columbia: sightings of a single brood at Roberts Bank in 1984 (Campbell et al. 1990). This tern is increasing in numbers at colonies in Washington (probably the source of the juveniles seen in this study) and is being reported in increasing numbers in southern B.C. Roberts Bank consistently had the largest aggregations in B.C. (Campbell et al. 1990). Our highest count here (419 birds on 13 August) was far higher than the maximum given by Campbell et al. (1990). Caspian Terns are spectacular birds, popular with naturalists and perceived as rare and vulnerable. Their behaviour at Roberts Bank put them at frequent risk of collisions with the wires (see below). If the causeway power line proves to be a major cause of mortality to the core of the B.C. population, there will be public pressure for immediate mitigation.

4. FLIGHT BEHAVIOUR OF BIRDS CROSSING THE CAUSEWAY.

4.1 Background

We systematically observed birds crossing the causeway in order to determine the species and numbers of birds exposed to potential collisions. We also made detailed notes on their altitude and flight behaviour as they approached and crossed the wires in order to determine which species were most likely to collide with the wires, and to assist in developing mitigation techniques.

4.2. Methods

During preliminary surveys in May and June 1994 we developed a protocol that was followed from July 1994 through May 1995. Each observation block covered one hour and 10 sectors (600 m). The observer sat at one end of the 10 sectors, rather than in the middle, to avoid having to turn around to look for birds. Binoculars were used for species identification. Data were recorded on standardized sheets (Appendix 1). Weather and tide conditions were recorded every 15 minutes. Each bird or flock that approached the power line was treated as a separate record, and the following data recorded (see Appendix 1):

- **time** (usually to the nearest 10 min);
- **sector number;**
- **species code** (see Table 1);
- **age and sex** (when readily discernable);
- **flock size;**
- **approach** (before crossing) **and departure** (after crossing wires)
- **behaviour** within 10-20 m of the power line, coded as N (no reaction to the cable), C (climb or gain altitude); D (descend or lose altitude); M (maintain height after crossing); T (turn back); S (spiral climb) and X (collide with wires). These behaviours were also linked with qualifiers: G (gradual), A (abrupt) and F (flare, meaning poorly controlled flight, flailing of wings) to indicate increasing severity of the approach or departure responses. For example, GC represented a controlled gradual climb, AC an abrupt, urgent climb within 5 m of the wires, and SF a spiral climb which ended in a flare.

- **crossing height** (estimated in metres above the upper cable (+) , between the cables (B) or below the lowest cable (-);
- **flight direction** (going northerly or southerly across the causeway).

Other notes were also made, e.g. interactions among birds and other factors likely to influence their behaviour. Horizontal and vertical distances were estimated using the pole length (18 m) and the distance between the upper and lower wires (2.5 m) as references.

We completed 195 observation periods, in all months from July 1994 through April 1995, totalling 192 hours (1923 sector-hours), with a mean of 27.5 hours per sector (range 16-53 h). More observations were done in July, August and October through February to cover the periods when there were large numbers of migrating and overwintering birds. On days when we did dawn to dusk watches, we switched sectors randomly every hour to cover as much of the causeway as possible.

Since tides had a major effect on bird activities, we spread our observations over all phases of the tide cycle (with 55, 43, 56 and 41 periods at falling, low, rising and high tides respectively) and with all possible substrate types adjacent to the observation site (Table 2). Observations were made along the entire causeway (sectors 1-70), but more were made in the first 21 sectors (Figure 3) where we did the radar tracking and where most of the shorebirds crossed. The rate of crossing activity was calculated as birds per hour of observation for each sector.

Table 2. Distribution of observation effort of birds flying over the power lines per month and per tide phase The substrate adjacent to the site of observation is also shown.

Tide	Substrate adjacent	Code	Month										Total
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
Low	Mud	LM	9	11	0	2	2	5	7	5	0	0	41
Low	Mud and water	LW	0	0	0	0	2	0	0	0	0	0	2
Rising	Mud	RM	2	3	2	0	1	3	2	5	1	3	22
Rising	Mud and water	RMW	7	3	0	2	1	2	0	3	3	1	22
Rising	Water	RW	0	4	1	2	1	2	0	1	0	1	12
High	Water	HW	10	17	1	3	2	1	4	2	1	0	41
Falling	Mud	FM	1	1	0	0	2	5	1	8	1	2	21
Falling	Mud and water	FMW	1	3	0	5	2	3	2	4	1	1	22
Falling	Water	FW	2	1	0	1	1	4	3	0	0	0	12
Total			32	43	4	15	14	25	19	28	7	8	195

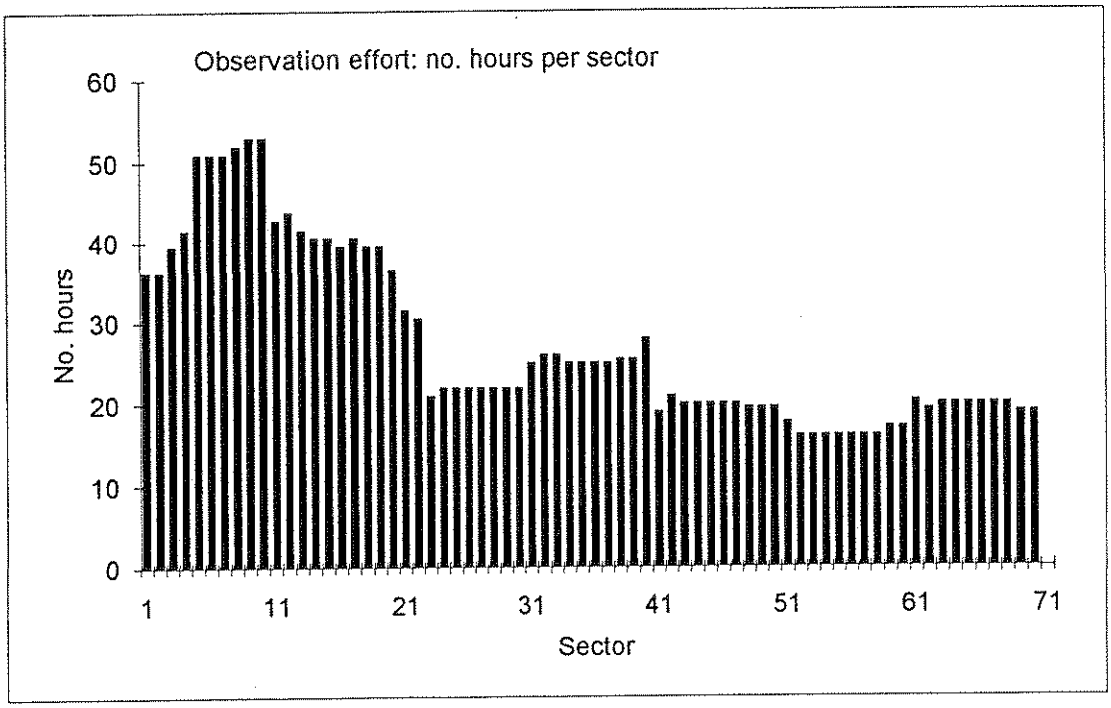


Figure 3. Distribution of effort in observing birds crossing the power lines at Roberts Bank causeway, between July 1994 and April 1995.

4.3. Results

4.3.1. Total number of crossings

Our database included 5664 records of crossing events, totalling 52,990 birds (mean flock size was 9.4 birds per crossing event). Given that we watched 10 sectors per observation hour and had 192 observation hours, the total number of birds crossing the entire causeway (70 sectors) was estimated to be 46,366 crossings per day or 16.924 million crossings per year.

Ninety-six percent of the birds crossing belonged to three groups: ducks (12%), shorebirds (76%) and gulls (8%). The proportions of crossings by the more common species are discussed later, in comparison with census counts and carcass deposition rates (Tables 9 and 10).

4.3.2. Spatial distribution of crossing events

We compared species composition and frequencies of crossing events along the length of the causeway (70 sectors) to identify where the highest risks of collision occurred and to help focus where mitigation was most necessary.

Most species crossed at all parts of the causeway, but some showed clear preferences for selected areas (Figure 4). This was usually related to their foraging habits. Great Blue Herons foraged in water of variable depths along the entire length of the causeway and crossed along its entire length. Similarly gulls and most raptors, being generalist predators and scavengers, foraged and crossed along the entire causeway length. Swans were concentrated at the proximate end (closest to shore) and geese showed no apparent preferences, but the relatively small sample of both these groups was primarily birds travelling to or from more distant foraging sites. Birds that foraged in the water by diving (loons, cormorants and diving ducks) crossed more often at the distal end (farthest from shore), whereas those that foraged along the edge of the tideline in shallow water (dabbling ducks) tended to be concentrated in the middle sections of the causeway. Shorebird crossings were concentrated in the first 40 sectors, and larger shorebirds (mostly Black-bellied Plovers) and small sandpipers (mostly Western Sandpipers)

in the first 20 sectors. Dunlin were more evenly spread across the first 40 sectors. Crossings by Caspian Terns were tightly concentrated in sectors 60-70 between their two roosts on the small bays on either side of the causeway, but a few crossed elsewhere. The terns foraged by plunge diving for near-surface fish, and tended to forage in deeper water than most gulls, off the distal end of the causeway.

Overall, we recorded high frequencies of birds crossing along the entire length of the causeway. Although fewer birds crossed at the distal end, beyond sector 50 (Figure 4), this was still a critical area, because Caspian Terns were most concentrated there.

We did not conduct systematic flight observations over the loading terminal or northwestern power line, but our informal observations while searching for carcasses there, and while making flight observation in nearby sectors, indicated that few birds were crossing there and most of them were gulls. The marked decline in crossing events in the distal end of the main causeway supports this impression (Figure 4).

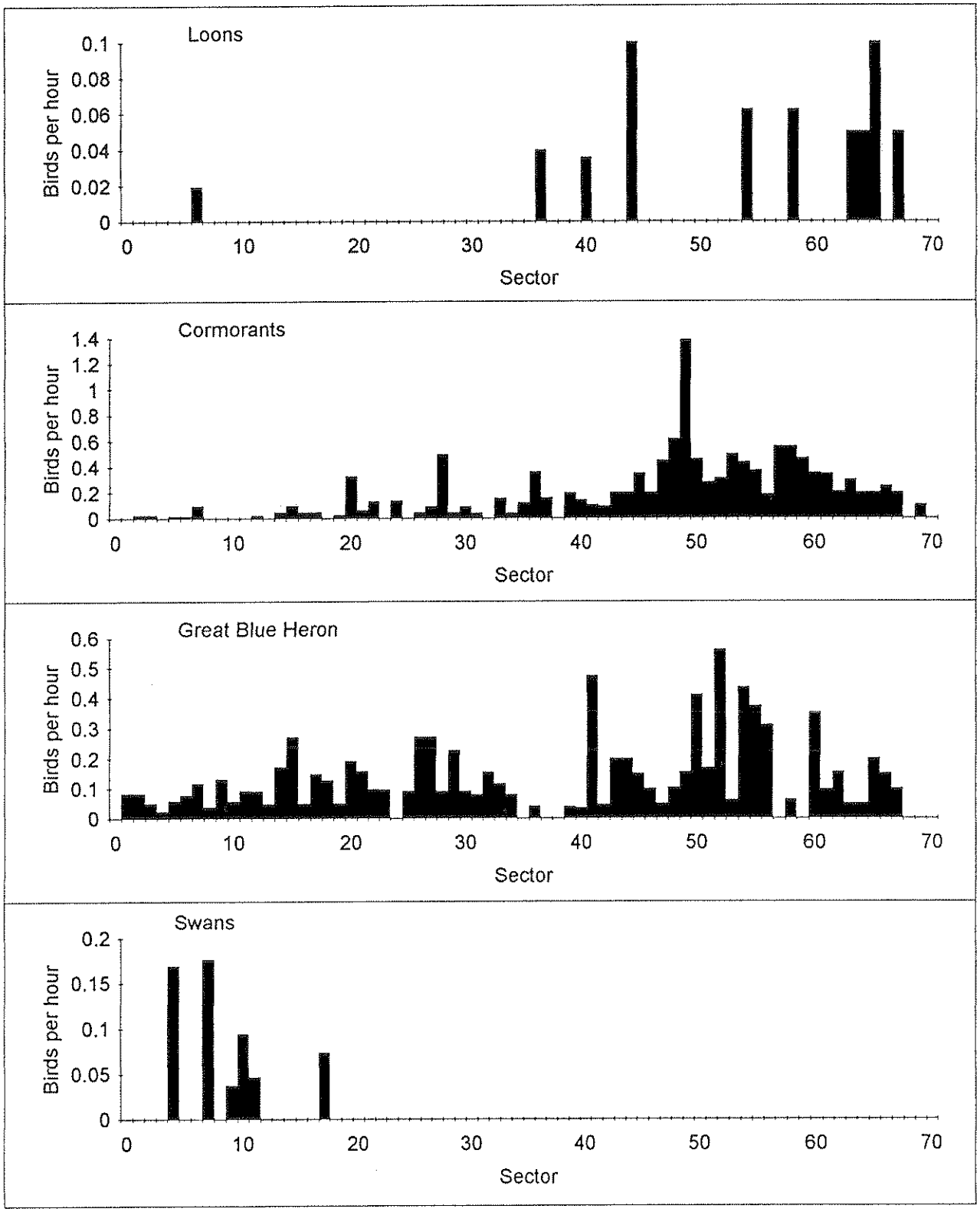


Figure 4. Distribution of birds crossing the power line on the Roberts Bank causeway between July 1994 and April 1995. Sector 1 is nearest the mainland. Continued on following pages.

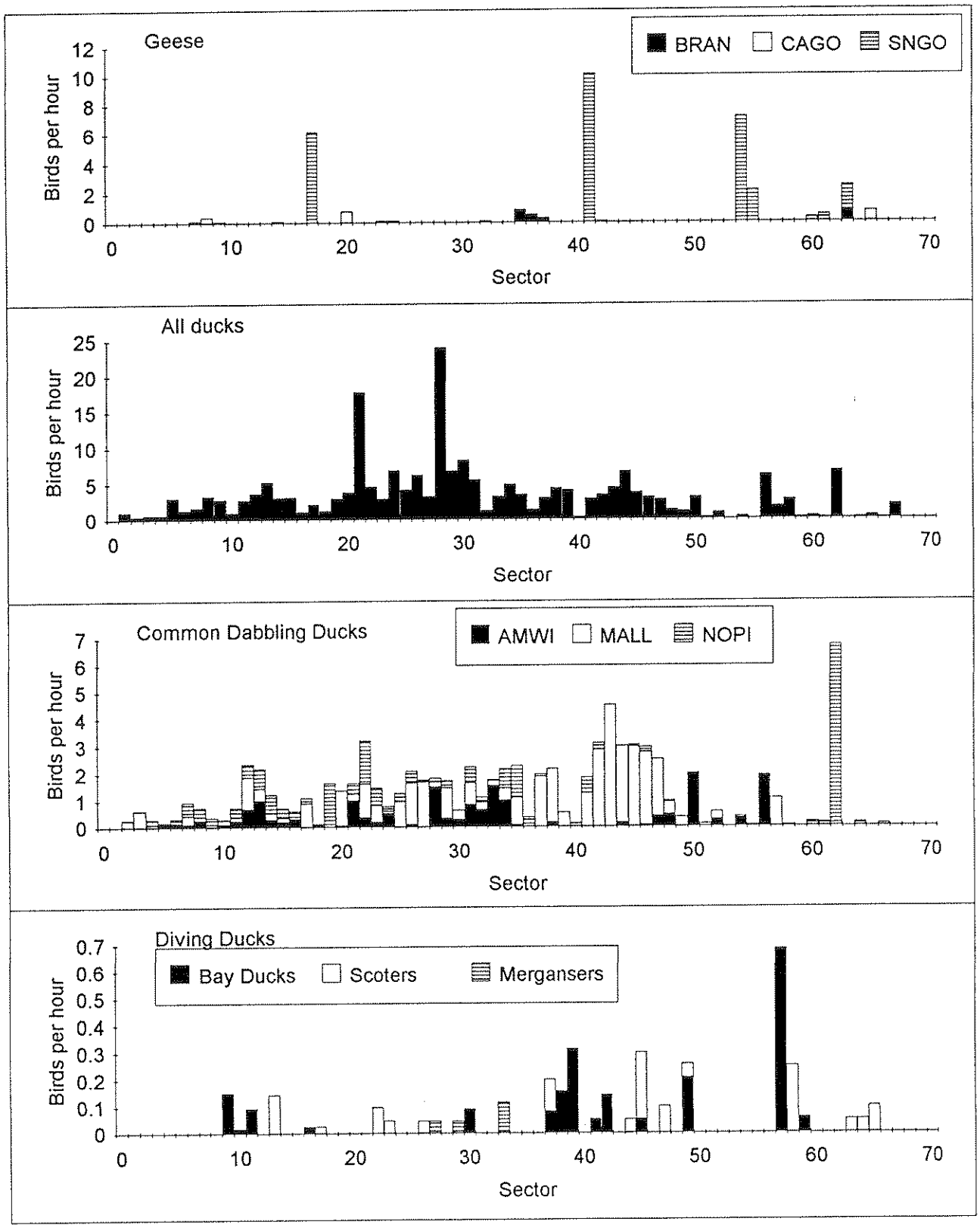


Figure 4 (continued). Distribution of birds crossing the power line on the Roberts Bank causeway between July 1994 and April 1995. Sector 1 is nearest the mainland. Continued on following pages.

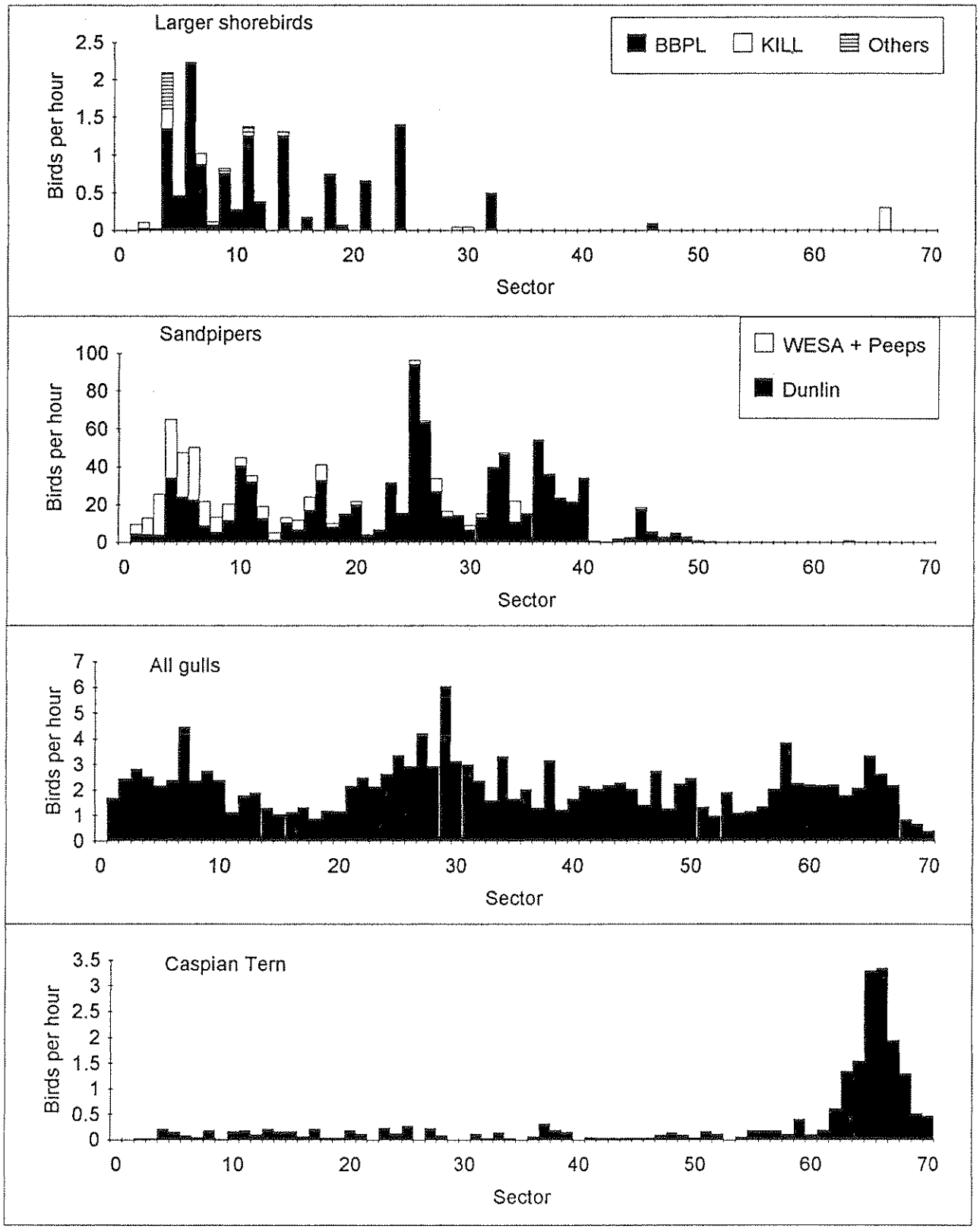
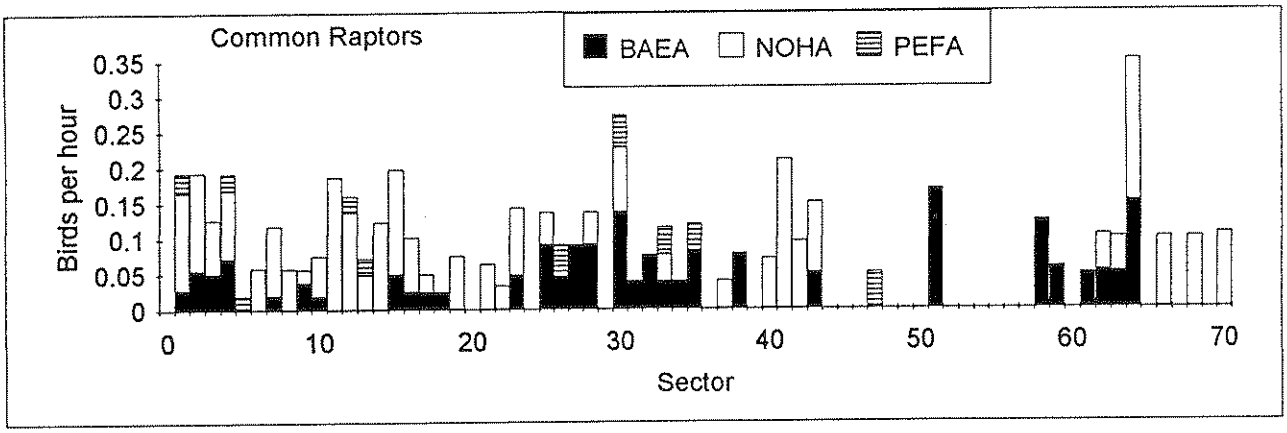


Figure 4 (continued). Distribution of birds crossing the power line on the Roberts Bank causeway between July 1994 and April 1995. Sector 1 is nearest the mainland. Continued on following page.



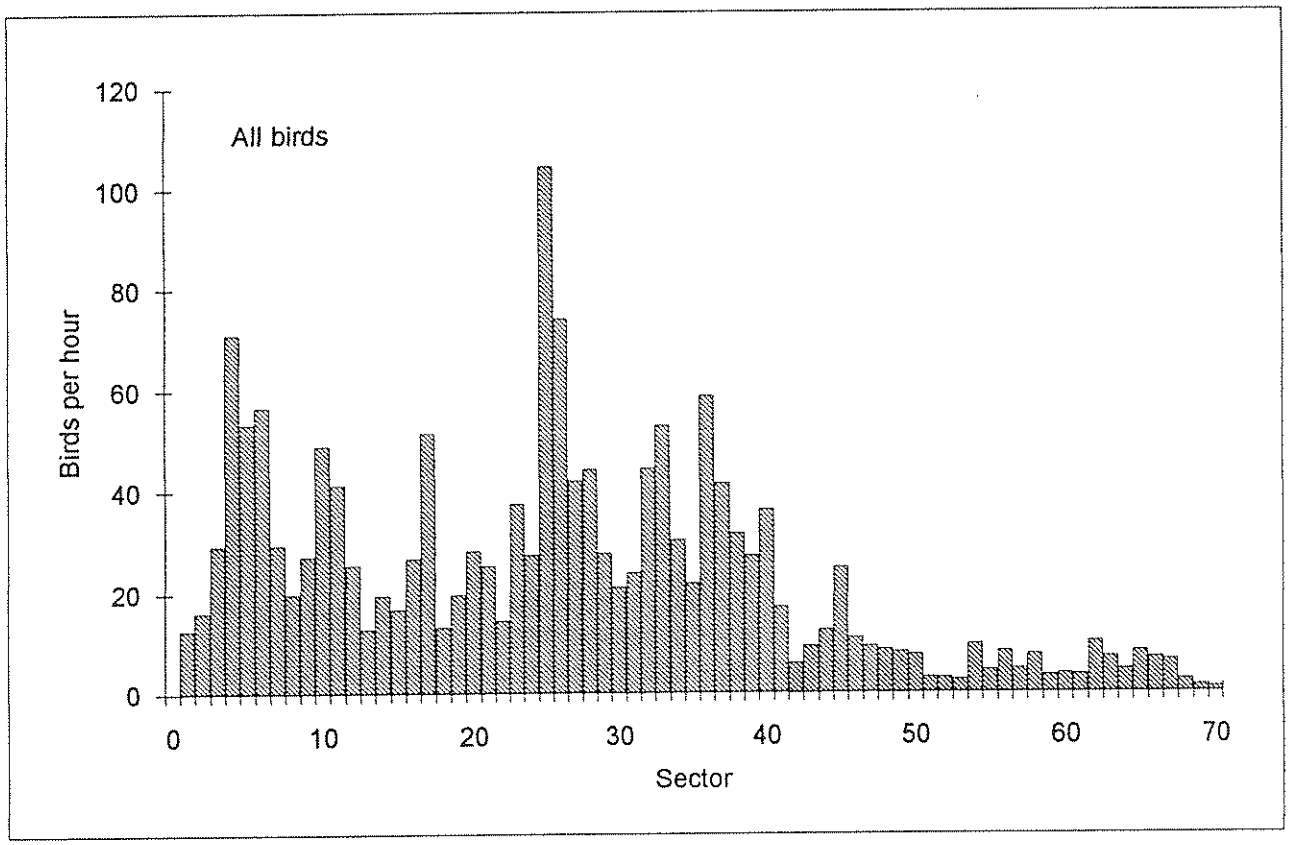


Figure 4 (continued). Distribution of birds crossing the power line on the Roberts Bank causeway between July 1994 and April 1995. Sector 1 is nearest the mainland.

4.3.3. Altitude of birds crossing.

It is important to know the height at which birds of each species cross the wires, to determine which types approach more closely to the wires and which wires (upper or lower) pose the greatest risk. Overall we found little difference among similar species, and so have lumped most species into family or sub-family groups (Figure 5).

Several patterns emerge. Overall, all species showed a very strong preference for crossing above the wires, even though that often meant gaining altitude to avoid them. The only exception was the Northern Harrier, which usually hunted on the wing a few metres above the ground and frequently flew below the wires. Overall 95% of the birds (N = 40,504) crossed above the wires. Many species (notably Double-crested Cormorants, Great Blue Herons, Trumpeter Swans, all shorebirds and gulls, and Caspian Terns) crossed close to the upper wire (69% of all birds sampled went over the top within 10 m or less of the upper wire). Many of these birds, particularly gulls and Caspian Terns, crossed within less than a metre or two of the upper wire, gaining just enough height to clear it. Loons, geese and ducks tended to fly high and very seldom approached within 5 m or less of the upper wire. Virtually no birds flew between the three strands of wire.

These results indicate that most of the birds crossing the causeway were at risk of collision. The highest risk of collision was with the upper of the three wires, and mitigation should include making this strand far more visible.

4.3.4. Reactions of birds approaching the power line.

Fifty-three percent of all birds crossing the causeway showed some deviation in flight behaviour as they approached the power line (Table 3, Figure 6). In most cases (42% of all crossing events) the reaction was mild and consisted of the bird or flock gradually gaining height to cross (39% of all crossing events), gradually spiralling higher (3%), or rarely, descending (0.1%) or gradually turning back (0.4%). Abrupt (sharp changes within 5 m of the wire) or severe reactions (flaring) were, however, seen among all the bird groups, and were particularly

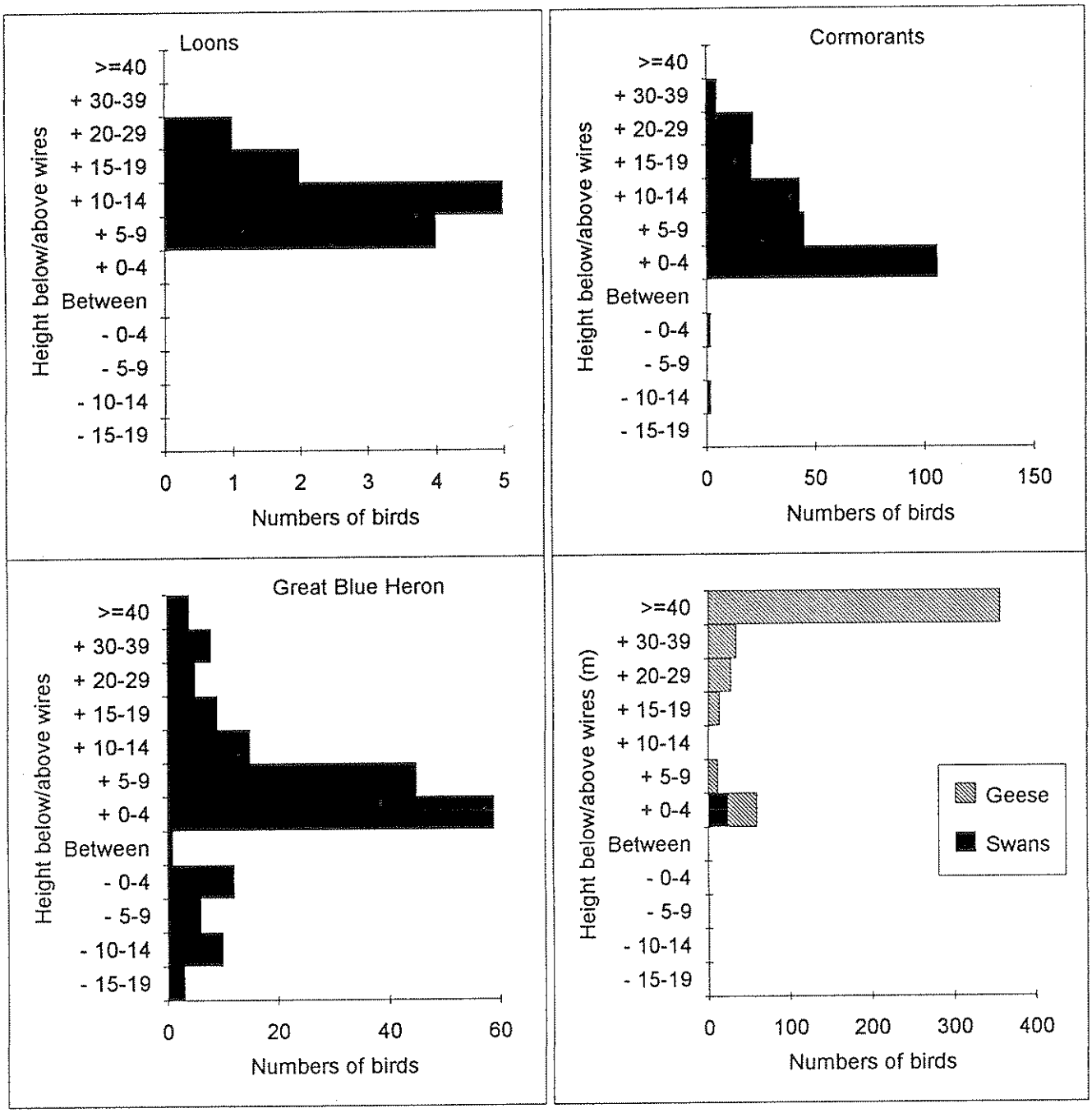


Figure 5. Frequency distribution of the altitude of birds crossing the powerlines at Roberts Bank. Altitude is measured in metres above the upper wire, below the lower wire, or between the wires.

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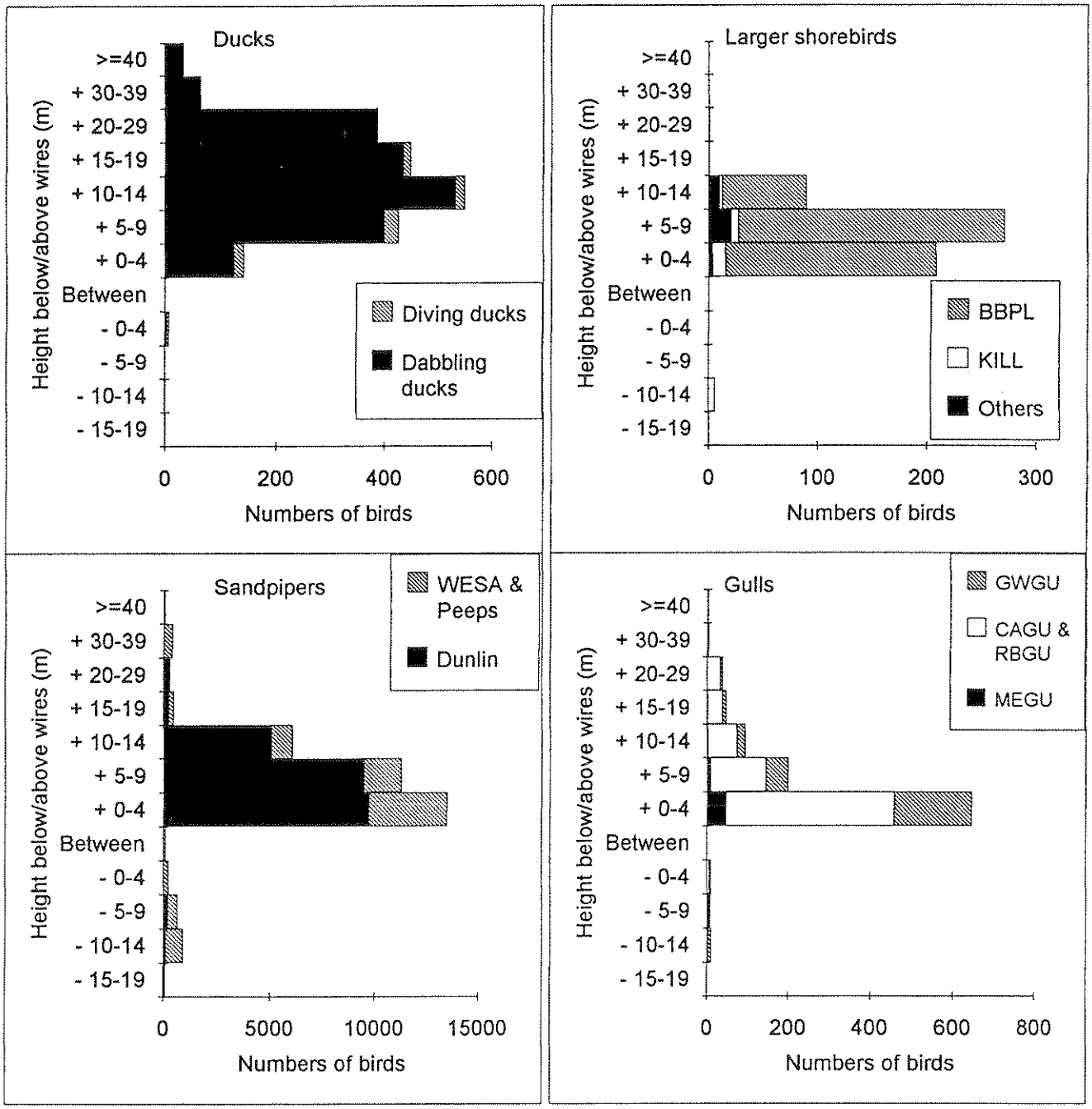

Figure 5 (continued). Frequency distribution of the altitude of birds crossing the powerlines at Roberts Bank. Altitude is measured in metres above the upper wire, below the lower wire, or between the wires.

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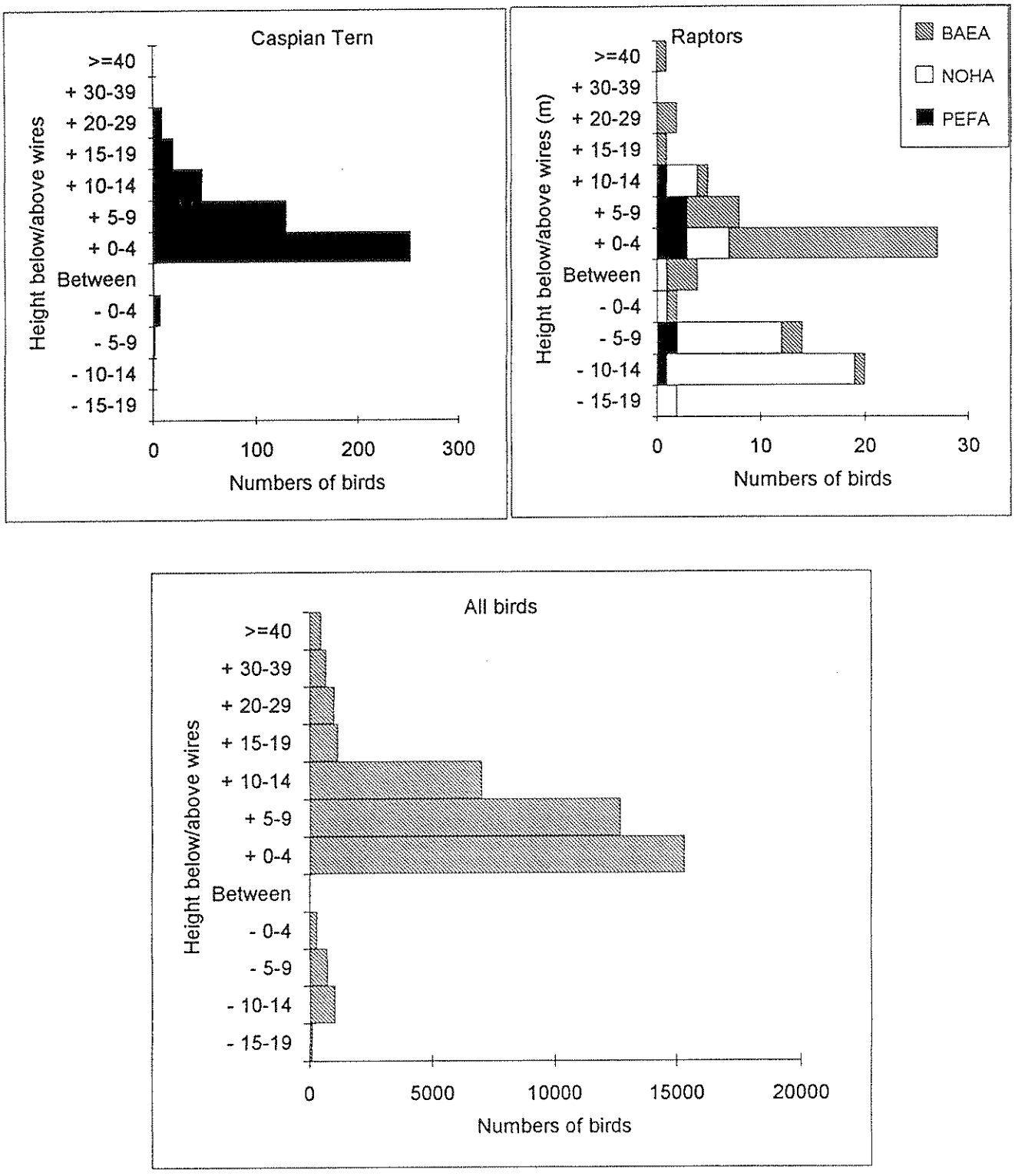

Figure 5 (continued). Frequency distribution of the altitude of birds crossing the powerlines at Roberts Bank. Altitude is measured in metres above the upper wire, below the lower wire, or between the wires.

Table 3. Percentage breakdown of the reactions by various birds when approaching the overhead power wires on the Roberts Bank causeway.

Severity of reaction	Reaction of bird	Loons	Cormorants	Great Blue Heron	Swans & Geese	Dabbling ducks	Diving ducks	All ducks	Larger shorebirds	Dunlin	Small sandpipers	All gulls	Caspian Tern	All raptors	Total % all birds	Total no. crossings all birds
Severe	Flare and descend	0	0	0	0	0	0	0	0	0	2	0	1	0	0	14
	Flare and climb	0	1	0	0	1	0	1	0	7	7	2	5	1	3	107
	Flare and maintain height	0	1	0	0	0	0	0	0	1	2	0	0	2	1	24
	Flare and spiral climb	0	0	0	0	0	0	0	0	0	5	0	0	1	1	26
	Flare and turn back	0	0	0	4	0	0	0	0	3	2	0	1	3	1	29
Subtotal severe reactions		**0**	**2**	**0**	**4**	**2**	**0**	**2**	**0**	**11**	**18**	**2**	**6**	**8**	**5**	**[200]**
Abrupt	Abrupt climb	0	5	4	0	2	0	2	7	15	23	9	13	2	9	367
	Abrupt spiral climb	0	0	0	0	0	0	0	0	0	5	0	0	1	1	28
	Abrupt descent	0	0	0	0	0	0	0	0	1	2	0	0	0	0	12
	Abrupt turn back	0	0	1	0	0	0	0	0	0	2	0	0	0	0	16
Subtotal abrupt reactions		**0**	**5**	**5**	**0**	**2**	**0**	**2**	**7**	**16**	**31**	**10**	**14**	**3**	**11**	**[423]**
Mild	Gradual climb	17	48	38	28	36	42	36	37	61	26	37	49	6	39	1530
	Gradual spiral climb	0	5	4	4	3	6	3	7	1	1	3	2	1	3	105
	Gradual descend	0	1	1	0	0	0	0	0	0	0	0	0	1	0	5
	Turn back	0	1	0	4	0	0	0	2	1	0	0	0	0	0	17
Subtotal mild reactions		**17**	**54**	**42**	**36**	**40**	**48**	**39**	**46**	**63**	**28**	**41**	**52**	**8**	**42**	**[1657]**
None	No obvious reaction	83	40	53	60	55	52	57	48	11	22	47	28	81	43	1691
Subtotal no reactions		**83**	**40**	**53**	**60**	**55**	**52**	**57**	**48**	**11**	**22**	**47**	**28**	**81**	**43**	**[1691]**
Total no. of crossings		12	174	168	25	420	33	502	46	314	455	1340	394	88		3971

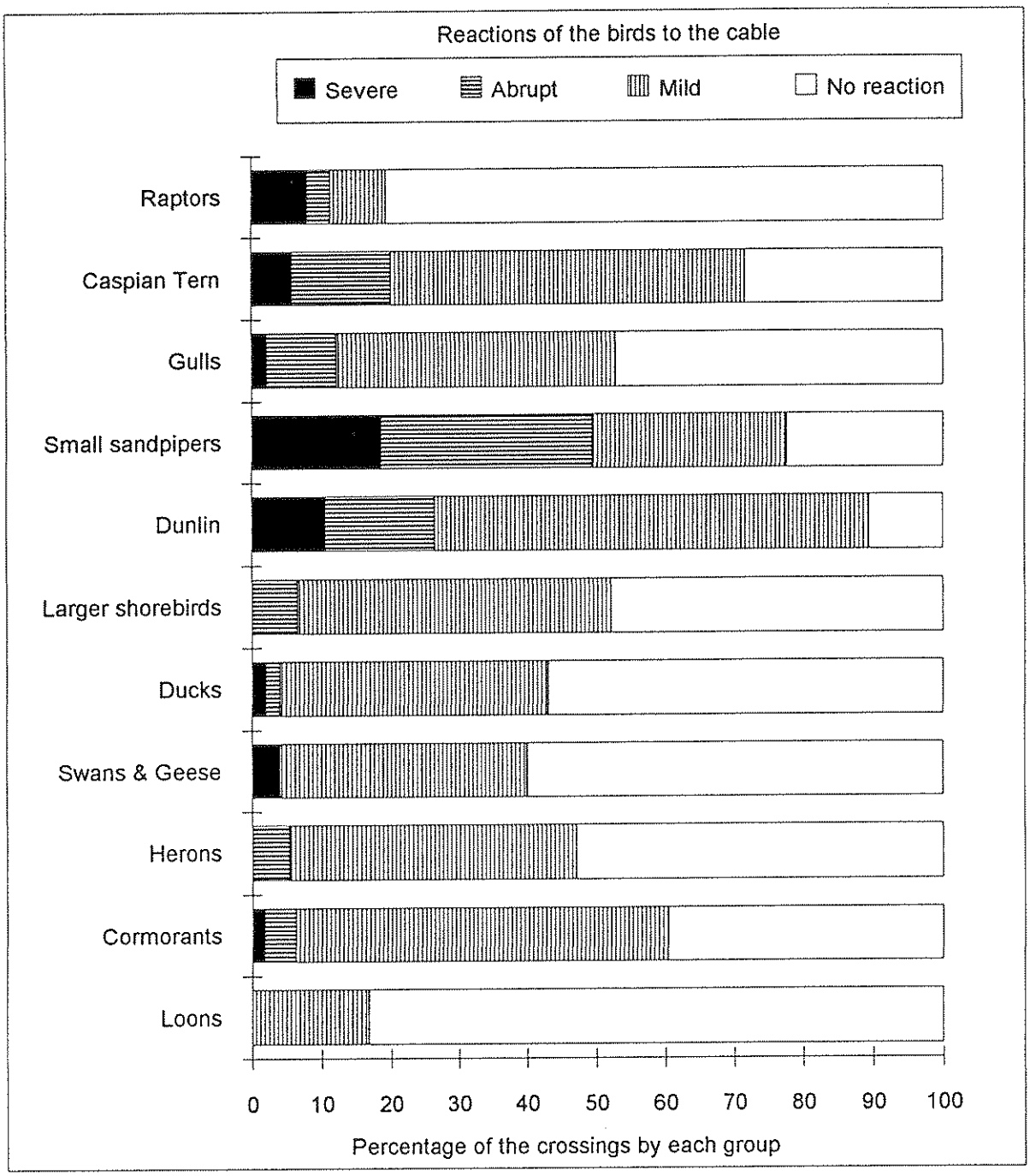

Figure 6. Percentage breakdown of the severity of reactions when approaching the overhead power wires on the causeway. See Table 3 for details.

common among shorebirds. In this group severe and abrupt reactions were reported from 14% and 24%, respectively, of all crossing events (N = 815), with small sandpipers (Western Sandpipers and similar peeps) showing the highest proportions of such reactions (Table 3).

Species and groups which tend to cross within 5 or 10 m of the wire (Figure 5) were, as expected, more prone to severe or abrupt reactions when approaching the wire (Table 3, Figure 6). Although Caspian Terns and gulls had similar crossing altitudes, severe or abrupt reactions were more common in the tern crossings (20%) than those by gulls (12%; Table 3, Figure 6).

4.3.5. Collisions observed.

We witnessed remarkably few collisions. In 192 hours, watching 5664 crossing events involving 52,990 birds, we saw only five collisions. This would amount to 1597 collisions per year if our daylight sample is representative. On 10 August 1994 at 10:27 one of us (ALEVC) saw a flock of nine Western Sandpipers approached the wire flying into a strong headwind (Beaufort scale 3; 12-18 km h^{-1}) under partly cloudy, bright skies. Within a few metres of the wires the flock flared, some spiraled up and two passed between the wires, one appeared to collide but continued flying. Later that morning (10:57) under the same conditions, one of a flock of six Western Sandpipers appeared to touch the wire as the flock flared and passed between the wires. On 30 August 1994 at 20:00 at sector 64, under clear skies and very little wind (Beaufort scale 1; 2-6 km h^{-1}), AEB saw an adult Glaucous-winged Gull hit the upper wire with its wing, flutter, then continue flying. On 31 August 1994, under similar weather conditions, AEB saw two collisions involving juvenile Caspian Terns (time 19:25, sector 64; and 19:29, sector 67). In each instance the juvenile was flying behind two adults, presumably its parents, making continuous loud begging calls. The adults flew just above the upper wire, but the following juvenile, probably watching the parents, hit it. In the first instance the juvenile hit with its wing, fluttered briefly, and continued flying. In the second, the bird hit the wire with its forehead, dropped, hit a lower wire and fell to the ground, dead. The forehead skull was crushed.

We also witnessed many near-collisions involving shorebirds. Typically a flock would approach the power line, gain altitude to cross and then when 1-5 m from the line, appear to become confused. The flock would split, with some birds flying above the wires, some below, some turning back, and some fluttering and stalling in front of the wires. Because peeps like Western Sandpipers are small, it is likely that we missed seeing some collisions that occurred during our watches, particularly in low light conditions, and thus underestimated the rates of collisions during observation periods. On two occasions we found fresh carcasses under the wire in searches made immediately after a watch.

5. DAILY PATTERNS OF FLIGHT ACTIVITY: RADAR STUDIES

5.1. Background

We used radar to determine the 24-hour patterns of flight activities over the causeway. This was necessary to determine whether our daylight observations were typical of the entire 24-hour day, and to determine whether many birds were crossing the causeway at night, when they might be more vulnerable to collisions. The radar could not be used to determine flight altitude, flock size of small birds or behaviour of birds crossing the wires.

5.2. Methods

Flying birds were tracked with a high-frequency surveillance radar (Furuno FR810D, 9410 MHz, 10 KW, with a 2.0 m antenna) mounted on a truck with the antenna 3.2 m above ground level. The antenna was tilted slightly upwards to scan a 25^{o} vertical segment above the horizon, and an aluminum screen was mounted along its lower edge to reduce ground clutter (Cooper et al. 1991). Both the rain and sea scatter suppressors were turned off and the gain was set at full strength to give maximum sensitivity to the signals. Previous tests showed that small birds could readily be detected but those flying near the ground were less visible. At least two or three successive "hits" (target images on the screen) were needed to identify flying birds, and often birds flying low did not produce that many. The images produced by flocks of birds could usually be separated from those of single birds.

5.3. Results

5.3.1. Comparing visual and radar detections

On three days, for a total of 14 daylight hours, we conducted simultaneous visual and radar surveillance of the same sectors. Many more crossing events were recorded visually than with radar, and overall 41% of the 295 crossings seen by observers were also seen on the radar. The proportion detected on radar was lowest with shorebirds (29%; N = 93 crossing events), intermediate with raptors (38%; N = 8) and gulls (41%: N = 168), and highest in the higher-flying ducks (80%; N = 25). The birds that were missed by the radar were those that approached in low-level flight and made a brief ascent and descent to cross the wires. Overall, 33% of birds that climbed to cross the wires were detected on radar, compared with 52% of those flying higher and showing no change in altitude. This difference was particularly striking among shorebirds (21% vs. 64%, respectively). This meant that the radar could not be used to determine absolute numbers of birds crossing the wires, because a large proportion of the approaching birds flew low and then climbed to cross. The radar was, however, useful in monitoring relative rates of crossing to compare daylight with night.

5.3.2. Flight activity over 24-hour periods.

A pilot radar study overnight on 19-20 January 1995 showed high levels of flight activity among birds crossing the wires and flying over the mudflats (Figure 7). Flight activity was higher at high tide than at low tide. Subsequently, two 24-hour continuous surveillance periods were undertaken on 3-4 and 8-9 February (Figures 8 and 9). On both occasions the frequency of flight activity at night was similar to that during daylight, and tides had a stronger influence on flight frequencies than time of day. The most frequent flights occurred with rising tides close to high tide, when the rising water caused flocks of shorebirds and dabbling ducks to move further up the shore. They usually flew parallel to the causeway, but shorebirds often crossed the causeway at this time (e.g. peak of activity at sunset on 3 February).

The radar observations confirmed that the rates of crossing measured by visual observations in daytime could reasonably be extrapolated to cover

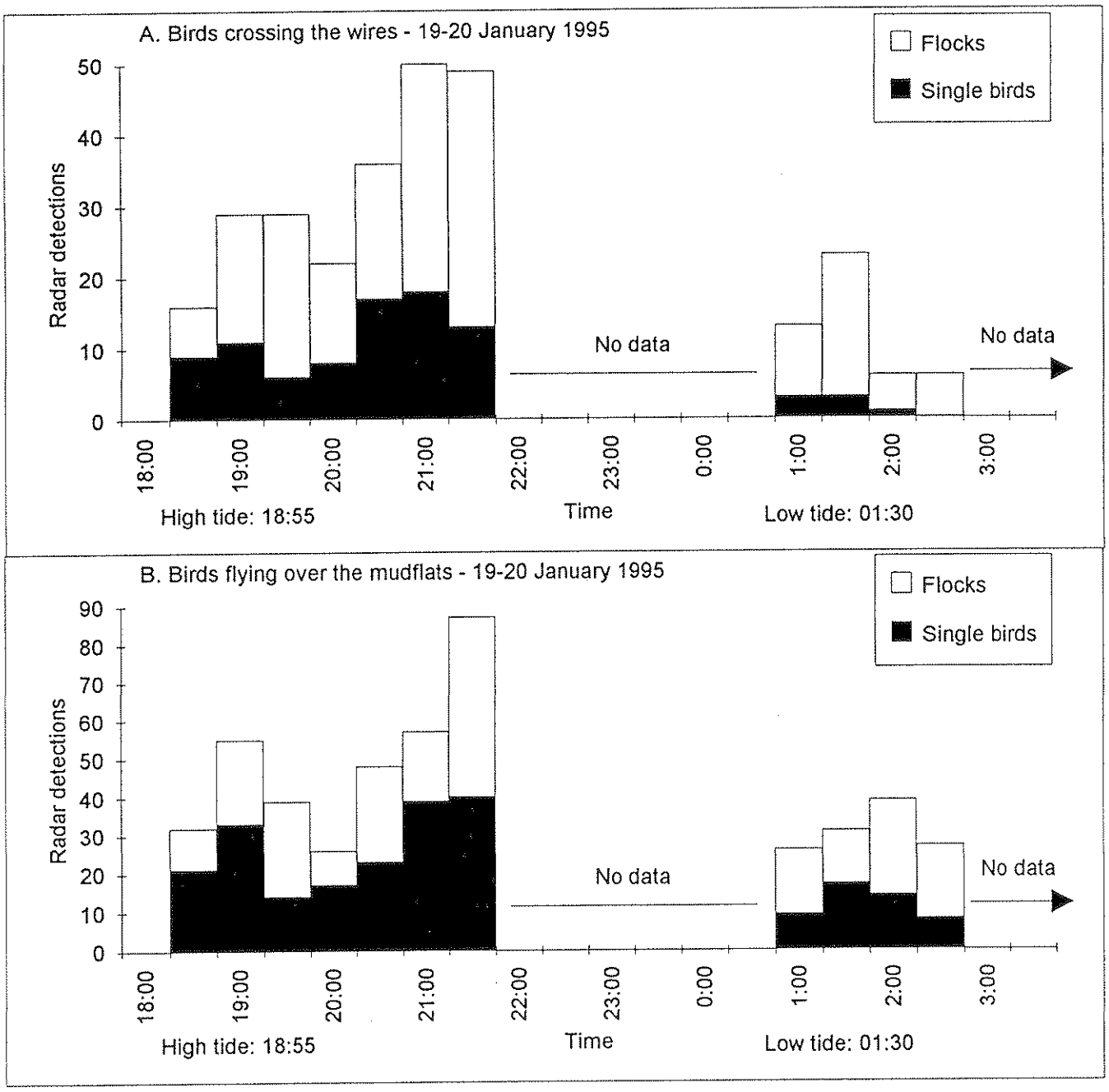

Figure 7. Radar images of birds flying at Roberts Bank on 19-20 January 1995, including birds which crossed the wires (A) and birds that remained over the mudflats and water (B).

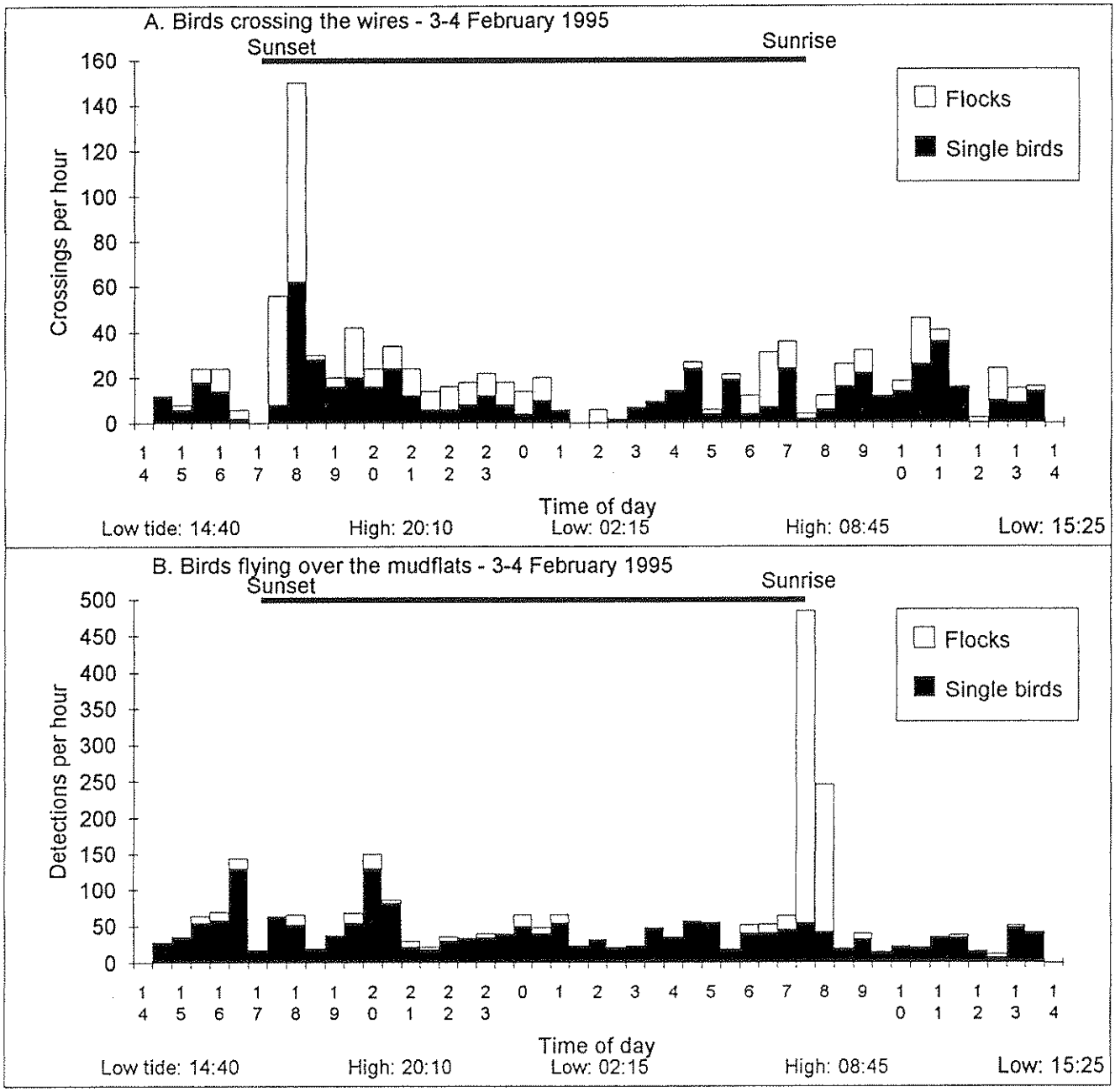

Figure 8. Radar images of birds during the 24-hour period 3-4 February 1995, including birds crossing the wires (A), and those flying over the mudflats and water (B). The horizontal line represents the period of darkness.

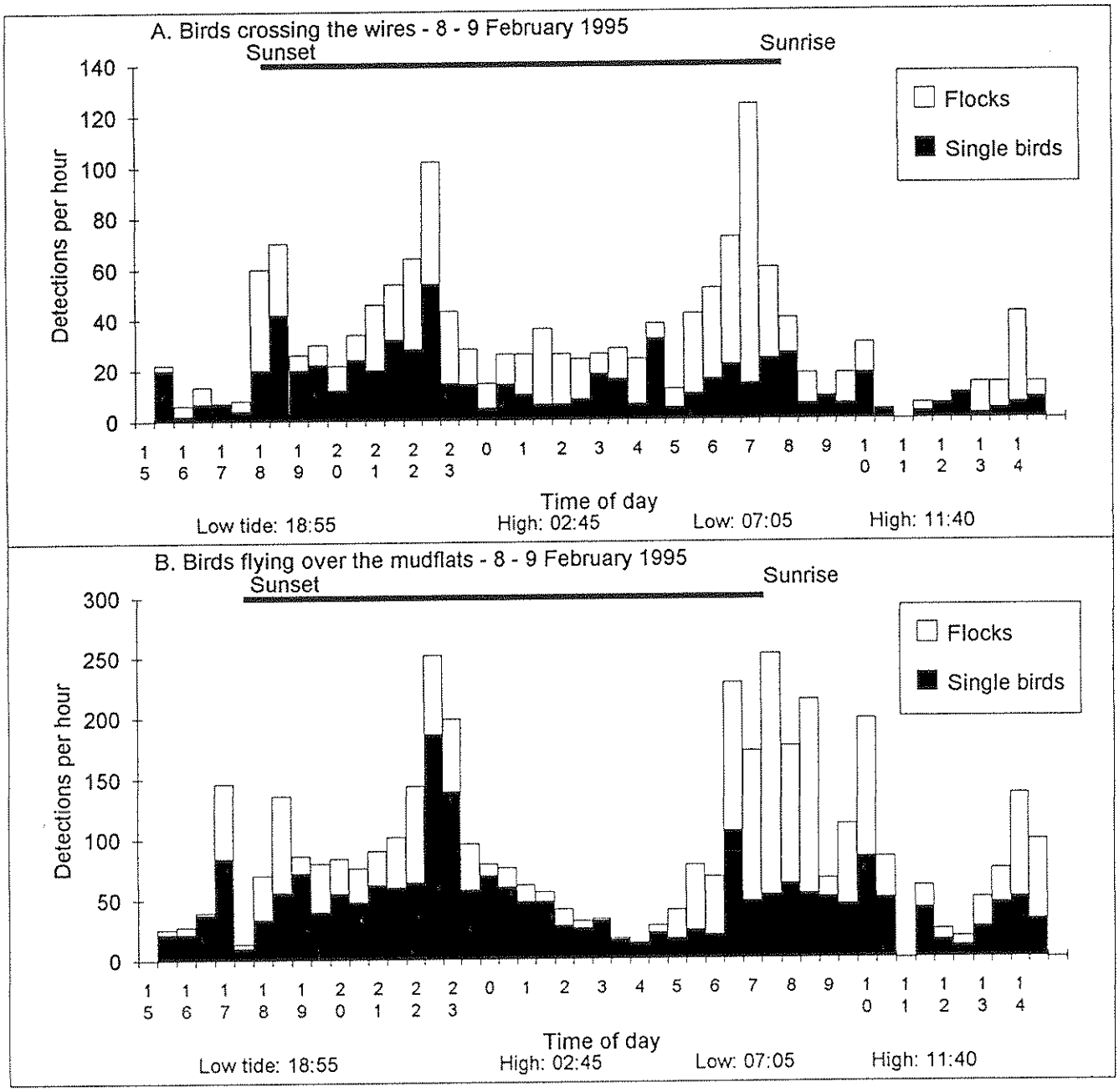

Figure 9. Radar images of birds during the 24-hour period 8-9 February 1995, including birds crossing the wires (A), and those flying over the mudflats and water (B). The horizontal line represents the period of darkness.

the entire day. The behaviour of birds when crossing the wires at night could not be determined with radar.

6. DENSITIES OF CARCASSES

6.1. Background

In this section we report results from systematic searches made for dead or injured birds along the entire length of the causeway (sectors 1-70), and less frequently along the northwestern power line and within the loading terminal. These data provided the basis for estimating the species, numbers, time and place of birds killed at the causeway.

6.2. Methods

Systematic searches for bird carcasses were concentrated within 20 m on either side of the power line. This "inner zone" was searched at roughly weekly intervals (mean 6.5 days between searches, mode 7 days, range 2-11 days; Figure 10) from 12 May 1994 through 12 May 1995. The "outer zone", from 20-40 m on either side of the line, was searched less frequently, at roughly one month intervals. Searches covered the entire causeway (sectors 1-70) but in the first few months fewer searches were made in sectors 52-70 (Figure 11). Overall, each sector was searched for an average of 55 times (range 43-63) in the inner zone and 12 times (5-15) in the outer zone. Since more than 90% of all carcasses were obtained from the inner zone (see below) we calculated carcass densities as carcasses per inner zone search for each sector.

We also did six searches of the inner zones of the 16 sectors of the northwestern branch of the power line (31 August, 23 November, 13 January, 4 February, 25 and 30 March). Intensive ground searches within the loading terminal were made on 12 July, 17 January and 19 April. These covered most of the coal loading and storage areas where there were light standards and other potential hazards to flying birds. We also made partial searches of the northern side of this area each time we searched the northwestern power line.

Nearly all (>95%) the carcass searches were made by the same three people (AEB, ALEVC, and A.D. Lawrence), but a few by other assistants.

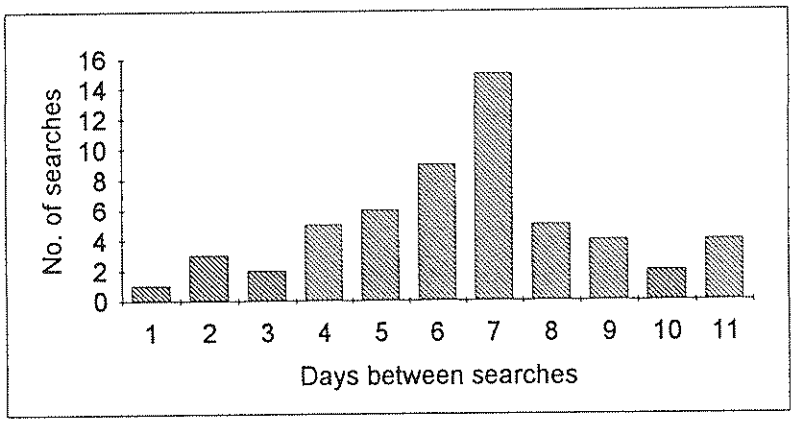

Figure 10. Frequency distribution of complete or near-complete searches for carcasses in the inner zone of sectors 1-70 (N = 57 search days). In addition, partial searches were made on 15 days.

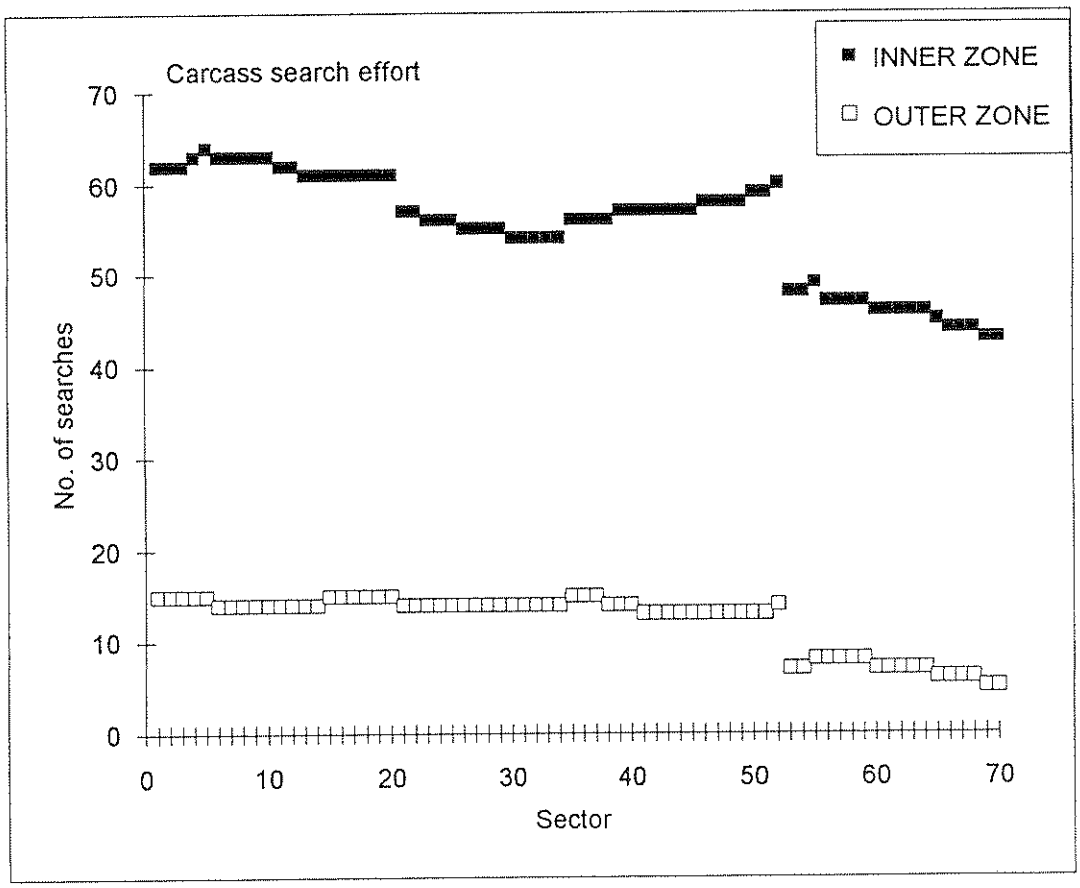

Figure 11. Number of searches made for carcasses per sector along the Roberts Bank causeway between April 1994 and May 1995. More searches were made in the Inner Zone (within 20 m on either side of the power line) than in the Outer Zone (20 - 60 m from the line on either side).

Searchers walked slowly in a zig-zag path, scanning the ground around them. Data were reported on a standard data sheet (Appendix 2), and included the duration of search, vegetation height and other factors affecting the search. For each dead bird found, we recorded the following data (Appendix 2): species; age (when possible); sex; sector number; distance to nearest shoreside pole measured parallel to the wires; perpendicular distance to the wire; location north or south of the wires; condition of carcass (see codes in Appendix 2); estimated number of days since death; degree of scavenging (see codes Appendix 2); and details of injuries or broken bones. We also decided, on the basis of location and injuries, whether the bird was likely to have been killed by collision with the wires (coded as Y for very likely; Y? as possibly; N for probably not, and U for unknown).

Carcasses were identified with the aid of field guides, including one specifically for beached bird remains (Ainley et al. 1980). Partial skeletal remains were also compared with reference skeletons in the Royal British Columbia Museum and the Cowan Vertebrate Museum at UBC. One of us (AEB) had many years experience identifying bird remains from beached bird surveys (Burger 1993).

6.3 Results of carcass searches

6.3.1. Carcasses found and causes of death

We found 590 carcasses that were used for the database. An additional 50 or more very old partial carcass remains (usually only a few disintegrated bones) several years old were discarded. Within the database sample, we identified carcasses which were obviously too old to have been deposited during our study (most were more than a year old and were very decayed and usually partially buried). All carcasses, including the 286 "old" carcasses were included in the spatial distribution analysis, but only the 304 relatively "fresh" carcasses (likely to have been deposited during our study) were used to track seasonal deposition rates and probable causes of death. The "fresh" sample included many carcasses which were months old and decomposed, but were found in the later part of the study period, having been missed in earlier searches.

More than 42 species were represented in the 304 "fresh" and 286 "old" carcasses found on the causeway (Table 4). It proved difficult to determine whether the birds had been killed by collision with the wires. In some cases there were obvious collision injuries, including smashed foreheads and beaks, broken wingbones, traumatised flesh injuries, and broken pectoral girdles on intact birds. However, a large proportion of the carcasses had been scavenged, which produced changes to carcasses which masked or resembled collision injuries (see next section). Among the 304 "fresh" carcasses we recorded 60 as likely wirekills, 60 as possible wirekills, 25 as probably not wirekills and 159 as indeterminate. There were some obvious differences among the types of birds in the sample. The following groups had low proportions of likely or possible wirekills: waterfowl (ducks and geese, but not swans; 21%, N = 149), gulls (33%, N = 12), and passerines (36%, N = 11). Those with high proportions of likely or possible wirekills were: cormorants (50%, N = 4), Great Blue Heron (100%, N = 1), swans (50%, N = 2), shorebirds (71%, N = 90), Caspian Terns (100%, N = 10) and raptors and owls (67%, N = 3). Nine of the 10 "fresh" Caspian Tern carcasses were newly fledged juveniles, the tenth was an adult.

In addition to collisions with the wires, waterfowl and shorebirds might have been killed by raptors (Bald Eagles and Peregrine Falcons in particular), and many waterfowl were probably killed or wounded by hunters and then brought to the causeway to be eaten by eagles, falcons or hawks. It seems probable, however, that most of the cormorants, herons, shorebirds, raptors and owls, and all of the Caspian Terns that were found dead, were killed by collisions with the wires.

6.3.2. Scavenging of carcasses

We considered scavenging as removal of flesh by vertebrates. Most carcasses were also attacked by insects, which in small shorebird carcasses removed virtually all the flesh in 7-14 days. We did not include insect- or microbe-eaten carcasses as scavenged because those carcasses were not removed. Their skeletons and feathers were likely to be found, identified, and included in our mortality estimates.

Table 4. Identification of carcasses found on the Roberts Bank causeway (April 1994 - May 1995). Carcasses likely to have been deposited during the study (Fresh) are separated from those long dead (Old). The number and percentage of "Fresh" carcasses which were definite or probable wire kills is also shown.

			Fresh		Old		Grand total		Wire kills*	
Family	Species	Code	No.	%	No.	%	No.	%	No.	%
Loons	Red-throated loon	RTLO	0	0.0	1	0.8	1	0.2	0	0
Grebes	Western Grebe	WEGR	3	1.1	0	0.0	3	0.7	0	0
	Grebe sp.	GREBE	0	0.0	2	1.6	2	0.5	-	
	Total grebes		3	1.1	2	1.6	5	1.2	0	0
Cormorants	D.-crested Cormorant	DCCO	2	0.7	1	0.8	3	0.7	2	100
	Pelagic Cormorant	PECO	0	0.0	1	0.8	1	0.2	-	
	Cormorant sp.	CORM	2	0.7	0	0.0	2	0.5	0	0
	Total cormorants		4	1.4	2	1.6	6	1.4	2	50
Herons	Great-blue Heron	GBHE	1	0.4	8	6.2	9	2.2	1	100
Rails	American Coot	AMCO	2	0.7	1	0.8	3	0.7	1	50
Waterfowl	Trumpeter Swan	TRUS	1	0.4	1	0.8	2	0.5	1	100
	Swan sp.	Swan	1	0.4	0	0.0	1	0.2	0	0
	Snow Goose	SNGO	2	0.7	0	0.0	2	0.5	1	50
	Brant	BRAN	0	0.0	5	3.9	5	1.2	-	-
	Canada Goose	CAGO	1	0.4	1	0.8	2	0.5	1	100
	Goose sp.	GOOSE	1	0.4	1	0.8	2	0.5	0	0
	Green-winged Teal	GWTE	11	3.9	2	1.6	13	3.1	1	9
	Mallard	MALL	18	6.3	6	4.7	24	5.8	0	0
	Northern Pintail	NOPI	14	4.9	2	1.6	16	3.9	2	14
	Blue-winged Teal	BWTE	1	0.4	0	0.0	1	0.2	0	0
	Eurasian Wigeon	EUWI	1	0.4	0	0.0	1	0.2	0	0
	American Wigeon	AMWI	33	11.6	11	8.5	44	10.6	9	27
	Greater Scaup	GRSC	10	3.5	1	0.8	11	2.7	6	60
	Lesser Scaup	LESC	1	0.4	1	0.8	2	0.5	1	100
	Scaup sp.	SCAUP	3	1.1	6	4.7	9	2.2	0	0
	Oldsquaw	OLDS	1	0.4	0	0.0	1	0.2	1	100
	Surf Scoter	SUSC	4	1.4	1	0.8	5	1.2	0	0
	White-winged Scoter	WWSC	10	3.5	4	3.1	14	3.4	5	50
	Scoter sp.	SCOTER	2	0.7	6	4.7	8	1.9	0	0
	Bufflehead	BUFF	7	2.5	4	3.1	11	2.7	2	29
	Unidentified duck	DUCK	27	9.5	36	27.9	63	15.2	1	4
	Total waterfowl		149	52.3	88	68.2	237	57.2	31	21

Continued .....

Table 4 continued

Family	Species	Code	Fresh No.	Fresh %	Old No.	Old %	Grand total No.	Grand total %	Wire kills* No.	Wire kills* %
Shorebirds	Black-bellied Plover	BBPL	3	1.1	0	0.0	3	0.7	3	100
	Sanderling	SAND	0	0.0	1	0.8	1	0.2	-	-
	Western Sandpiper	WESA	14	4.9	0	0.0	14	3.4	13	93
	Least Sandpiper	LESA	8	2.8	0	0.0	8	1.9	8	100
	Baird's Sandpiper	BASA	2	0.7	0	0.0	2	0.5	2	100
	Dunlin	DUNL	60	21.1	2	1.6	62	15.0	37	62
	Small sandpiper (Peep)	PEEP	1	0.4	2	1.6	3	0.7	0	0
	Red-necked Phalarope	RNPH	1	0.4	0	0.0	1	0.2	1	100
	Shorebird sp.	Shorebird	1	0.4	1	0.8	2	0.5	0	0
	Total shorebirds		90	31.6	6	4.7	96	23.2	64	71
Gulls	Mew Gull	MEGU	0	0.0	1	0.8	1	0.2	-	
	Small gull sp.	MEGU?	1	0.4	0	0.0	1	0.2	0	0
	Ring-billed Gull	RBGU	1	0.4	0	0.0	1	0.2	0	0
	Glaucous-winged Gull	GWGU	8	2.8	7	5.4	15	3.6	3	38
	Gull sp.	GULL	2	0.7	6	4.7	8	1.9	1	50
	Total gulls		12	4.2	14	10.9	26	6.3	4	33
Terns	Caspian Tern	CATE	10	3.5	1	0.8	11	2.7	10	100
Raptors	Bald Eagle	BAEA	1	0.4	0	0.0	1	0.2	1	100
	Northern Harrier	NOHA	0	0.0	1	0.8	1	0.2	-	
Owls	Barn Owl	BNOW	1	0.4	0	0.0	1	0.2	0	0
	Short-eared Owl	SEOW	1	0.4	0	0.0	1	0.2	1	100
	Total raptors & owls		3	1.1	1	0.8	4	1.0	2	67
Passerines	Northwestern Crow	NWCR	2	0.7	1	0.8	3	0.7	1	50
	Corvid sp.	Crow?	2	0.7	0	0.0	2	0.5	0	0
	Winter Wren	WIWR	1	0.4	0	0.0	1	0.2	1	100
	Varied Thrush	VATH	1	0.4	0	0.0	1	0.2	0	0
	European Starling	EUST	4	1.4	4	3.1	8	1.9	1	25
	Savannah Sparrow	SAVS	1	0.4	0	0.0	1	0.2	1	100
	Total passerines		11	3.9	5	3.9	16	3.9	4	36
Total identified carcasses			285	100	129	100	414	100	119	42
Unidentified			19		157		176		1	
Total all carcasses			304		286		590		120	

* Probable wire kills were assessed for "Fresh" carcasses only.

Carcasses attacked by vertebrates, on the other hand, were likely to be carried away, dismembered or ingested entirely, making it certain that some would not be found and included in the mortality sample.

Scavenging of carcasses was very common and occurred year-round. Overall, 96% of waterfowl carcasses, 68% of shorebirds, and 86% of all birds showed evidence of scavenging. As expected, the proportion of the carcass flesh removed by scavengers increased with estimated time since death, but a high proportion of very fresh carcasses (average estimate 2.5 days since death) were also scavenged (Figure 12).

The high incidence of scavenging indicated that many carcasses disappeared between our searches. Accurate mortality estimates, therefore required some estimate of the loss of carcasses due to scavenging (see section 8). The high proportion of scavenging among waterfowl carcasses, including 90% of very fresh carcasses (Figure 12), supports the hypothesis that many of those carcasses were brought to the causeway by raptors (see also section 5.3.5).

6.3.3. Distribution of scavenger birds along the causeway.

Throughout the year, we recorded the location of all raptors, corvids, owls and shrikes seen during all our visits to the causeway. These frequencies are plotted in Figure 13, along with the distribution of all pellets and non-avian prey remains (mainly fish and crabs, but also clams, oysters, seastars, voles, rats, rabbits and unidentified mammals) found during carcass searches. Predatory/scavenger birds and their prey remains were found along the entire causeway. This result had several implications: predator-killed carcasses might have been deposited in any sector; wire-kills and raptor-kills could not be separated on the basis of their distribution along the causeway; and removal of wire-killed carcasses by scavenging birds was likely throughout the causeway.

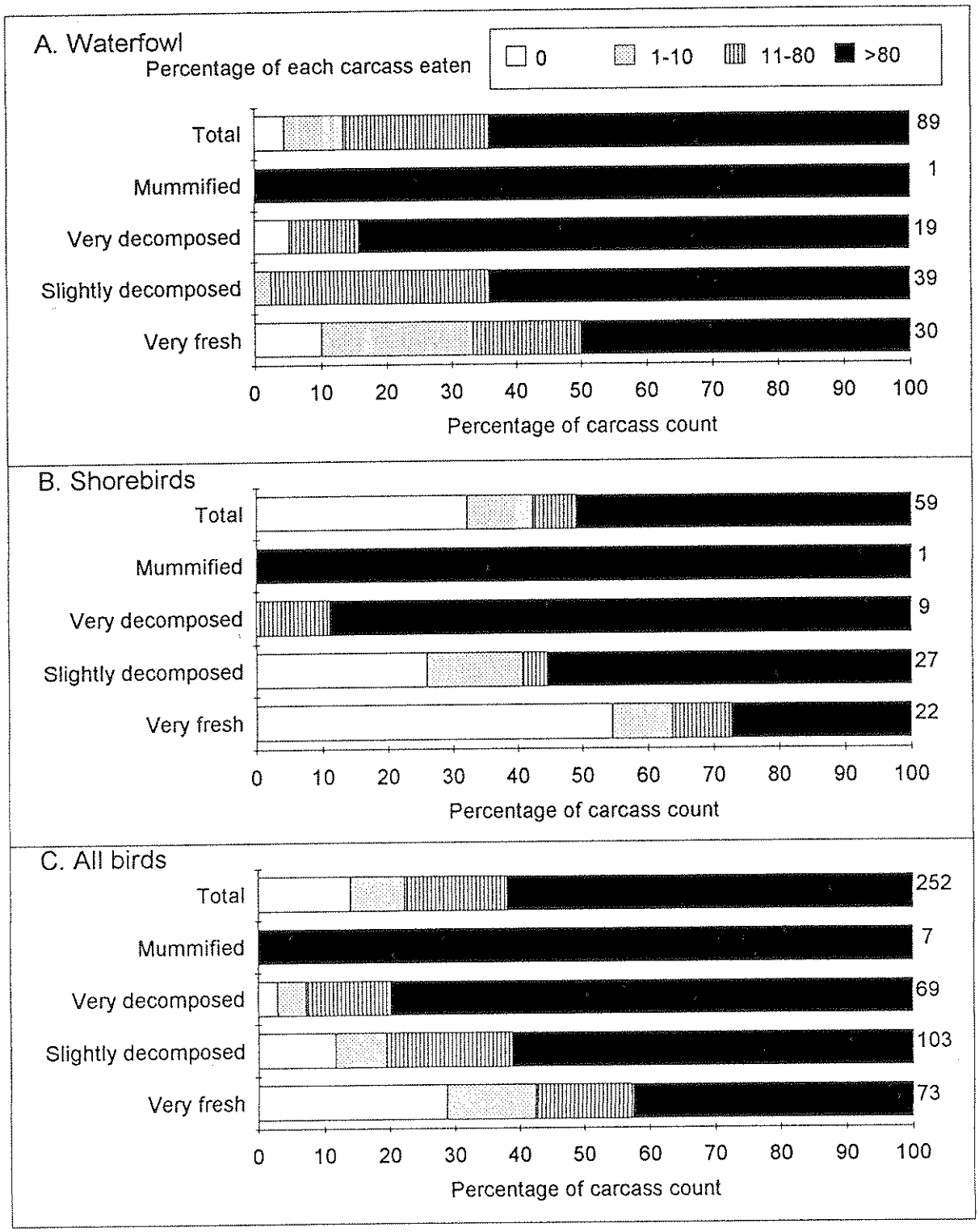

Figure 12. Plot of the percentage of carcass counts showing various degrees of scavenging (very old skeletons excluded). Scavenging categories were 0 (intact carcass), 1 (1-10% of the flesh eaten), 2 (11-80% eaten) and 3 (>80% eaten). The carcasses were grouped according to time since death, showing increasing degrees of decomposition. The number at the end of each bar is the sample size.

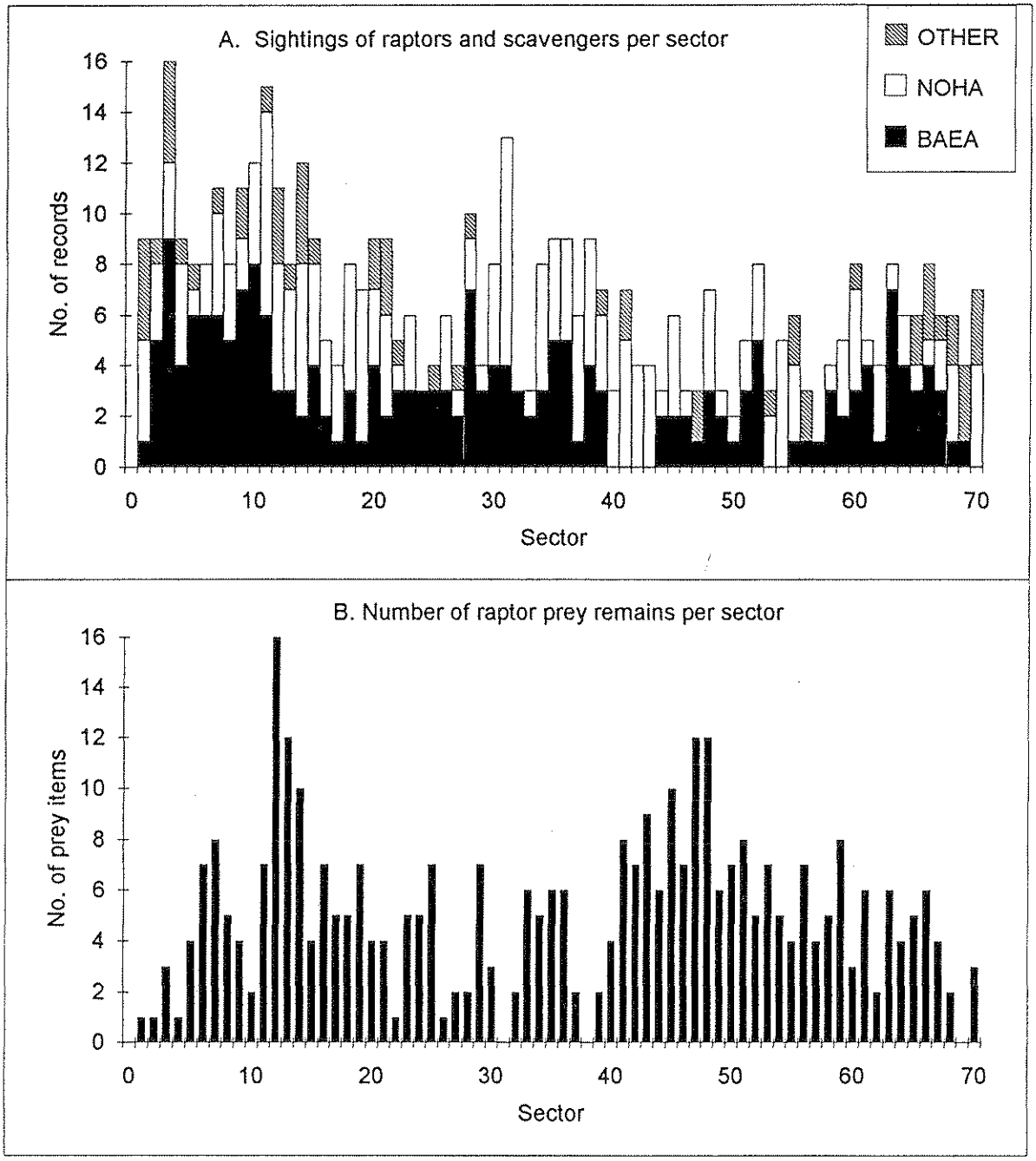

Figure 13. Distribution of sightings of raptors and scavenging birds and their prey remains along the Roberts Bank causeway in 1994-1995. The bird sightings represent all records of Bald Eagles (BAEA), Northern Harriers (NOHA), and other raptor/scavengers (Peregrine Falcons, Red-tailed Hawks, Gyrfalcons, Rough-legged Hawks, Common Ravens, Northwestern Crows etc.) seen during all our visits to Roberts Bank.

6.3.4. Distribution of carcasses along the causeway

Carcass distribution varied among the bird groups (Figure 14), and in some bird groups reflected the variations in flight patterns discussed above. The carcass distribution of shorebirds (concentrated in the first 40 sectors) and Caspian Terns (in sectors 60-70) was strongly clumped. In both groups, carcass distribution (Figure 14; "fresh" carcasses only) was significantly correlated with the distribution of crossing events (Figure 4) when data were pooled into 5-sector intervals to reduce zero values ($r = 0.598$, $P<0.05$ and $r = 0.954$, $P<0.001$, $N = 14$ in both cases). This is consistent with the idea that most of these carcasses resulted from collisions and not raptor kills.

Carcasses of waterfowl and gulls were distributed relatively evenly along the causeway (Figure 14) and there was no correlation between the distributions of "fresh" carcasses and crossing events ($r = 0.135$ and $r = 0.215$, respectively, $P>0.05$, $N = 14$). The sample of gull carcasses might have been insufficient to adequately test this correlation. The distribution of waterfowl carcasses was significantly correlated with the sightings of Bald Eagles (Figure 13) when pooled into 5-sector intervals ($r = 0.669$, $P<0.01$, $N = 14$). These results are consistent with the idea that many of these carcasses were brought in by these large raptors and were not wire-kills.

6.3.5. Carcasses in the coal terminal and on the northwestern power line

Only 30 carcasses were found in the searches along the northwestern branch line, and nine (30%) of these had been deposited during our study (Table 5, Figure 15). The relatively high values of carcasses per search shown in Figure 15 is misleading because the sectors were searched infrequently, but the birds found were larger species which did not often disappear between searches. More frequent searches would not likely have yielded many more carcasses, but would have lowered the value of carcasses per search. Most of the carcasses, and all but one of the identified "fresh" carcasses were waterfowl, and a considerable proportion of these were likely to have been raptor kills.

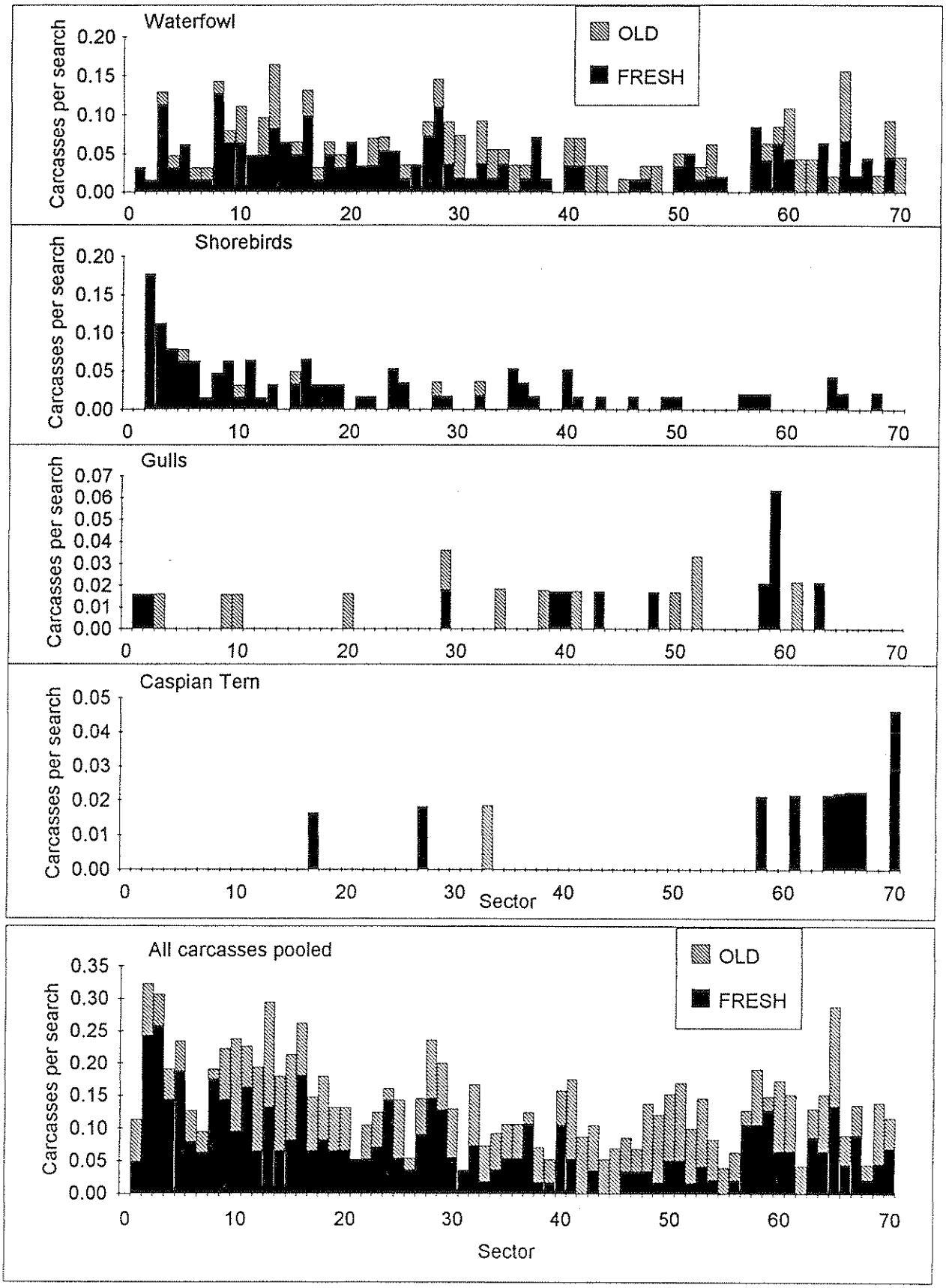

Figure 14. Distribution of carcasses per 60 m sector along the Roberts Bank Superport causeway. The data shown are numbers of carcasses per search for each sector. Data from April 1994 - May 1995. "Fresh" and "Old" carcasses were those probably deposited during or before the study, respectively.

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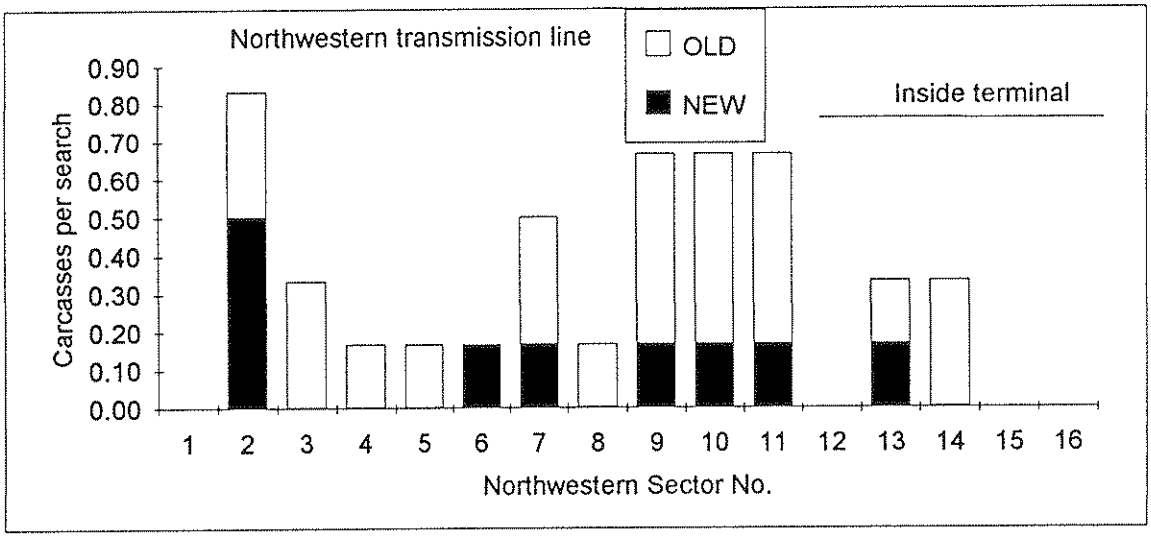


Figure 15. Density of carcasses found in six searches on the northwestern section of the transmission line leading into the coalport terminal. Sectors 12-16 lie within the terminal.

Table 5. Carcasses found on the northwestern section of transmission line leading into the coalport terminal, and in searches made in other parts of the terminal in 1994-1995. "New" and "Old" carcasses were those deposited during and before the study, respectively.

Family	Species	New	Old	Total
A. Along transmission line				
Herons	Great-blue Heron	0	2	2
Waterfowl	Snow Goose	1	0	1
	American Wigeon	1	1	2
	Greater Scaup	2	0	2
	Scaup sp.	1	1	2
	Scoter sp.	1	1	2
	Unidentified duck	1	5	6
Shorebirds	Dunlin	0	1	1
Gulls	Glaucous-winged Gull	0	1	1
	Unidentified gull	0	1	1
Passerines	Northwestern Crow	1	0	1
Unidentified birds		1	8	9
Total along transmission line		9	21	30
B. Within coalport terminal				
Passerines	European Starling	3	0	3

The portions of the power line within the coal terminal yielded even fewer carcasses than the rest of the northwestern sectors, even though these areas were generally open, with little vegetation, making it unlikely that carcasses were missed. Similarly, three complete searches within the coal terminal yielded only three European Starlings, all found on 17 January 1995.

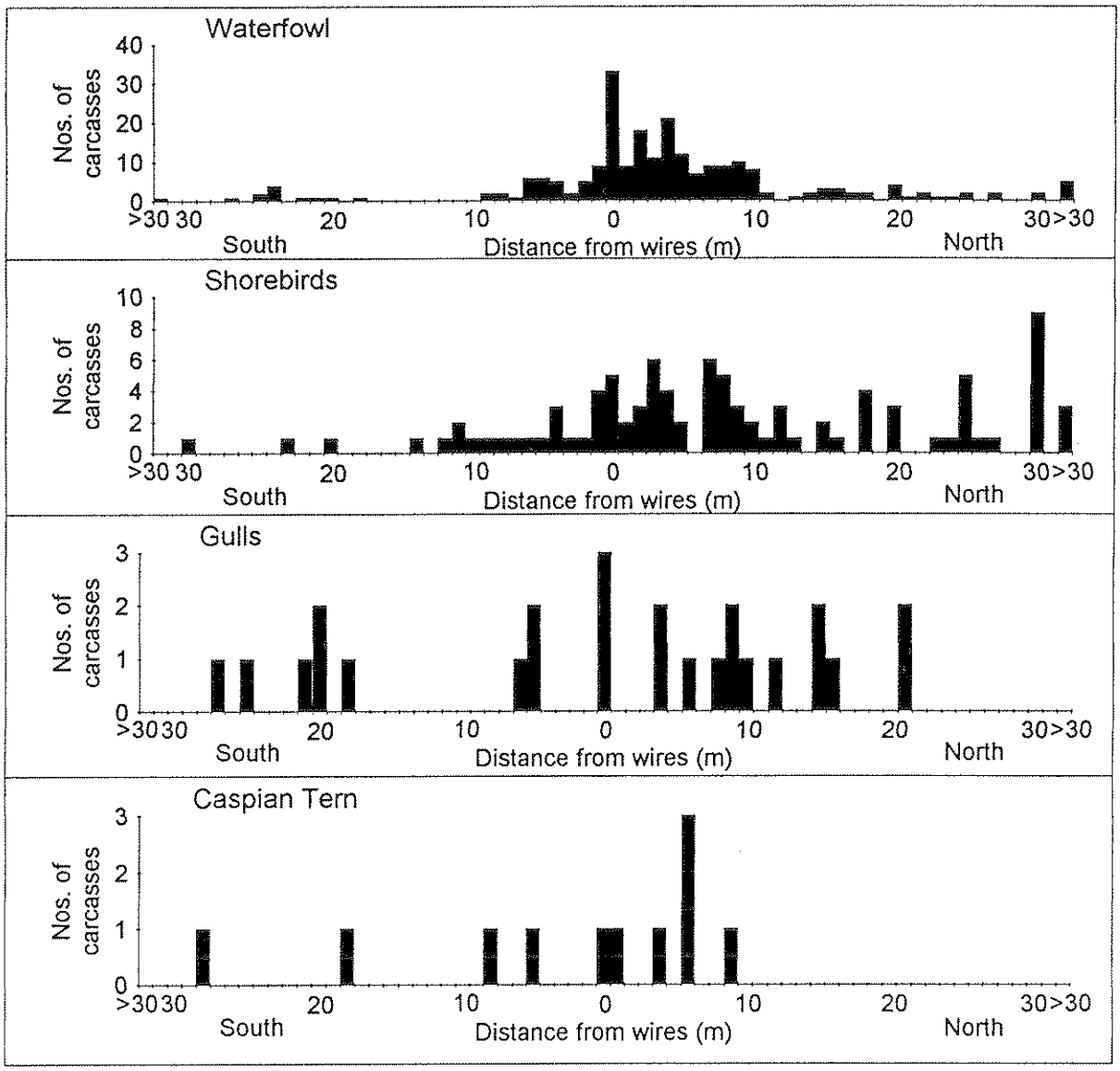
These data suggest that few carcasses were deposited within the coal terminal. Terminal personnel also told us that they did not find dead birds during their cleaning and other operations.

6.3.6. Carcass locations relative to wires and poles

Knowing the distribution of carcasses relative to the wires and poles is useful for identifying possible causes of death (e.g. raptor victims are likely to be dropped near poles) and possible mitigation procedures.

Carcasses were concentrated close to the wires: 74% of the total found was within 10 m of the wires, and 49% within 5 m (Figure 16). Fewer birds were found on the south side of the power line, probably because this area had less vegetation with a road and two train tracks, making it easier for scavengers to find and remove carcasses. A few carcasses undoubtedly fell into parked train cars and disappeared. There were some differences among bird groups. Waterfowl tended to be very tightly clustered near the wires, probably because a large proportion were raptor victims dropped near poles. The cluster of shorebird carcasses found about 30 m north of the power line appeared to be due to scavenging by Northern Harriers, that carried the small birds there for plucking and eating.

When carcass distribution along the line was plotted against distance from the nearest pole, some interesting differences emerged among bird groups (Figure 17). Waterfowl were tightly clustered near the poles, suggesting that many were raptor kills dropped off the poles. We saw Bald Eagles eating waterfowl on the tops of poles on at least three occasions during our visits to Roberts Bank. Shorebirds, gulls and



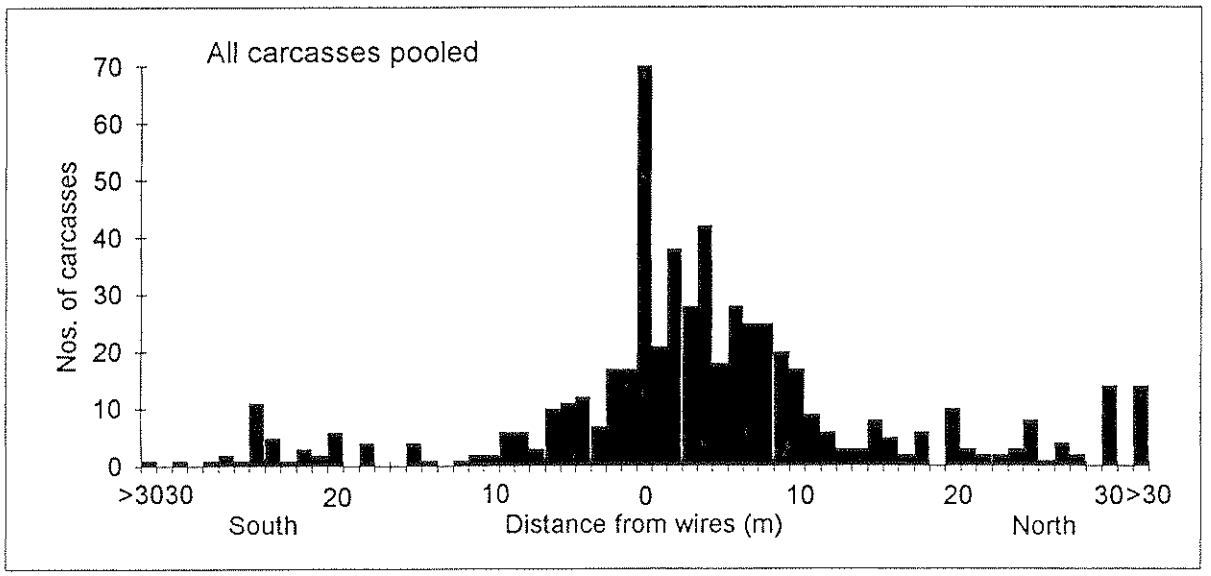
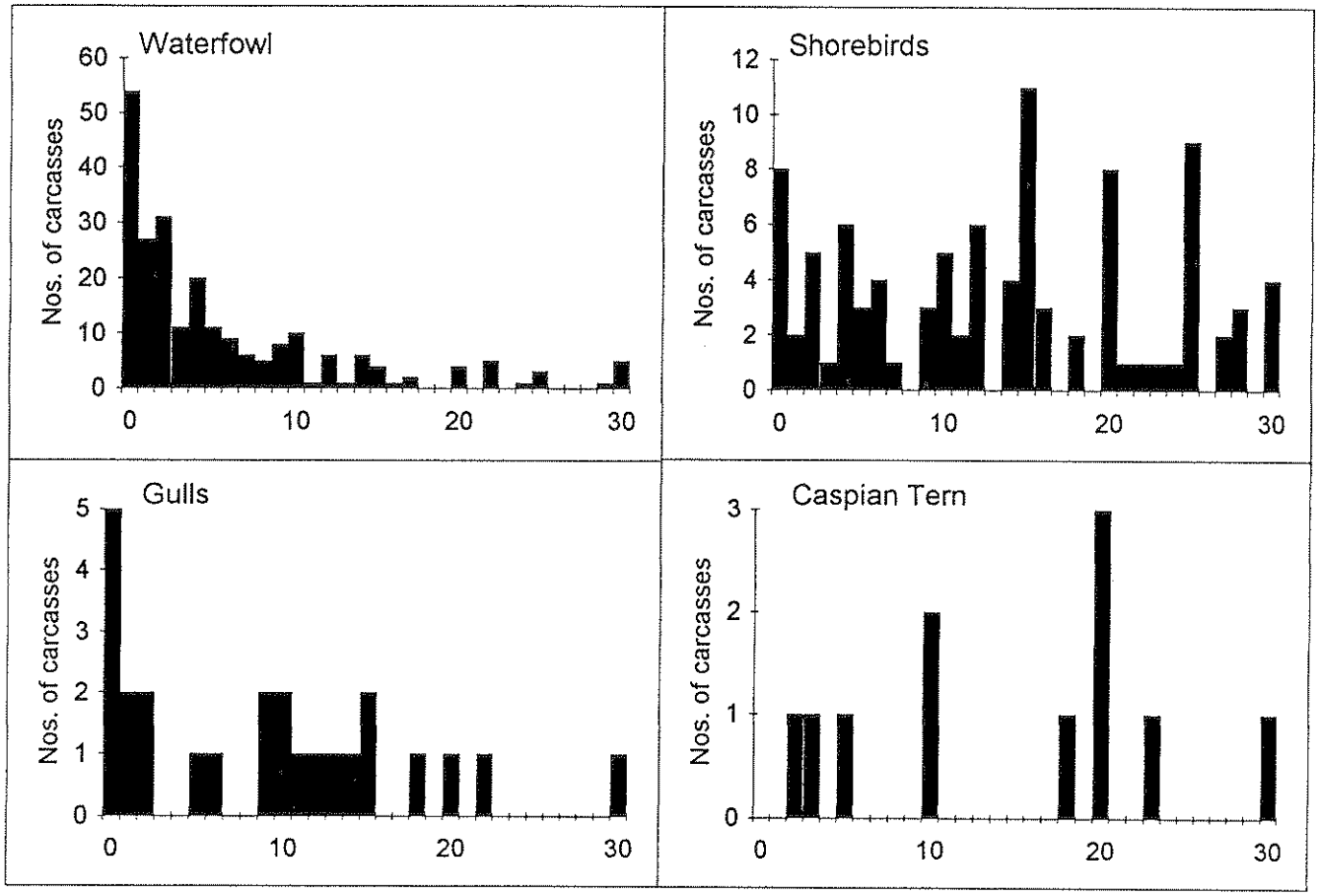


Figure 16. Distribution of carcasses on either side (North or South) of the transmission wires on the Roberts Bank causeway. The transmission line is at 0.



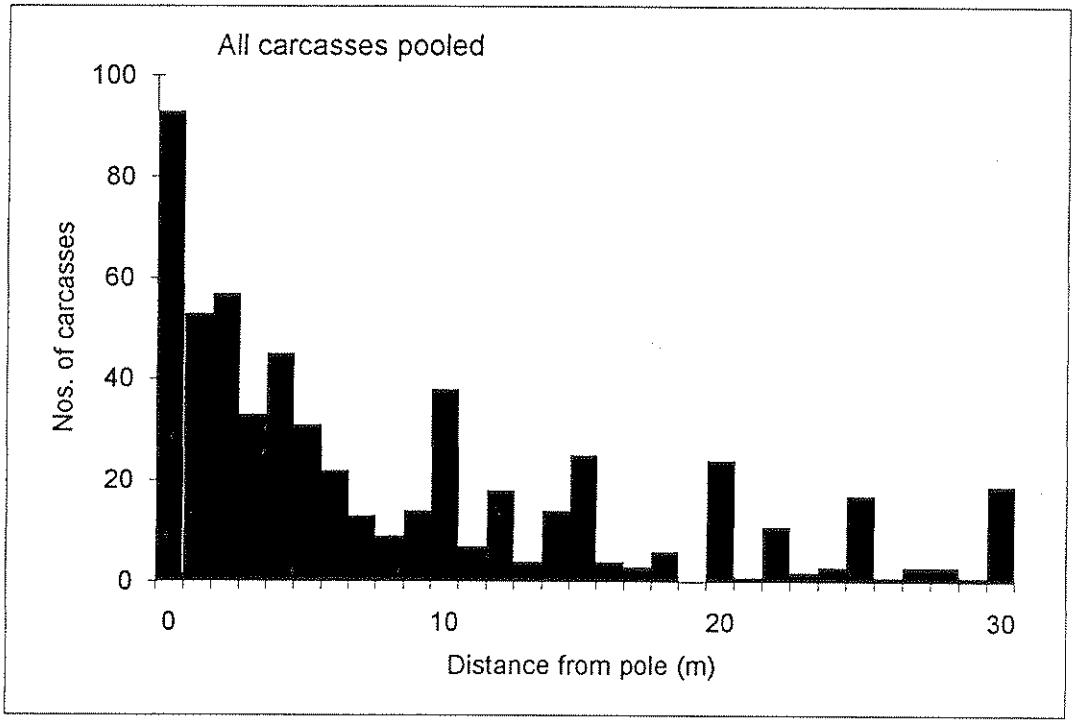


Figure 17. Distribution of carcasses relative to the distance from the nearest pole along the transmission wires, Roberts Bank causeway.

Caspian Terns were more evenly spaced along the wire spans suggesting that they were mostly wire kills.

The effects of raptor predation and scavenging were obvious when the distribution of intact carcasses was compared with those that had been partly eaten (Figure 18). Intact carcasses were evenly spread along the wire span, whereas eaten carcasses were clumped close to the pole (Chi-squared test using raw numbers in 10 m intervals, $X^2 = 27.12$, df = 2, $P<0.001$).

6.3.7. Seasonal deposition of carcasses

Carcasses thought to have been deposited during the study (i.e. "fresh") were plotted according to the month in which they were found. In a few cases these birds died in earlier months, but since it was difficult to accurate gauge time since death, we made no attempt to back-date carcass death.

As expected carcass deposition (Figure 19) tracked the population densities of the various groups seen in our census data (Figure 2). The only exception was the high densities of Western Sandpiper and other sandpiper carcasses found during the late summer migration (July and August), but as discussed above (section 3.2.1) we appeared to have underestimated the size of this migration pulse. Overall, the greatest mortality occurred over winter (October through March), with additional peaks during the late summer and spring migration.

7. CARCASS SEARCH EFFICIENCY

7.1. Background

We conducted a series of tests to derive a search efficiency index (e), a measure of the proportion of the carcasses present which was detected during a search. The index was then applied to the carcass counts to estimate the total numbers of carcasses present at the time of each search, including those carcasses not found.

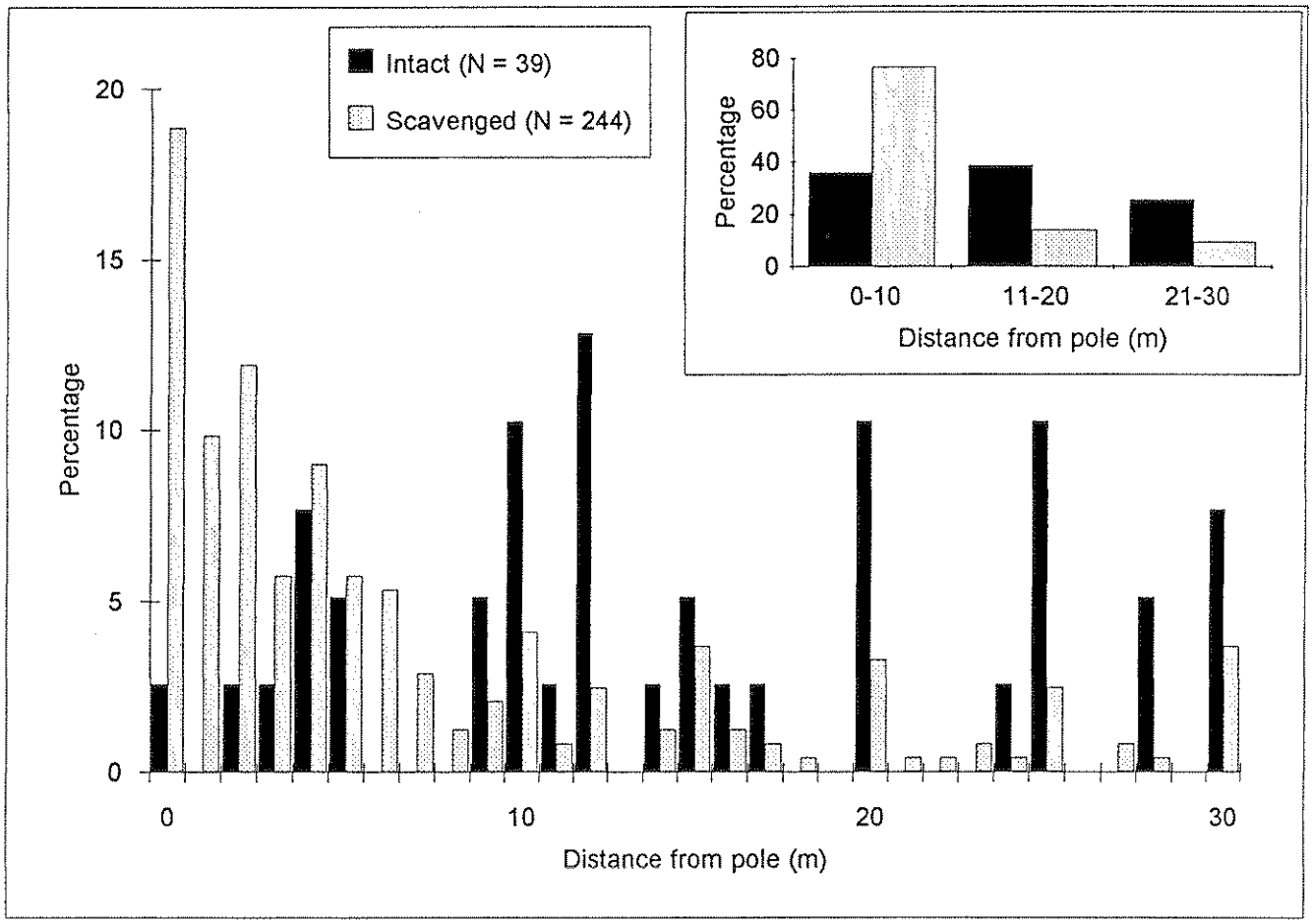


Figure 18. Comparison of the distance from the nearest pole for intact vs. scavenged carcasses. The inset shows the same data in 10 m intervals.

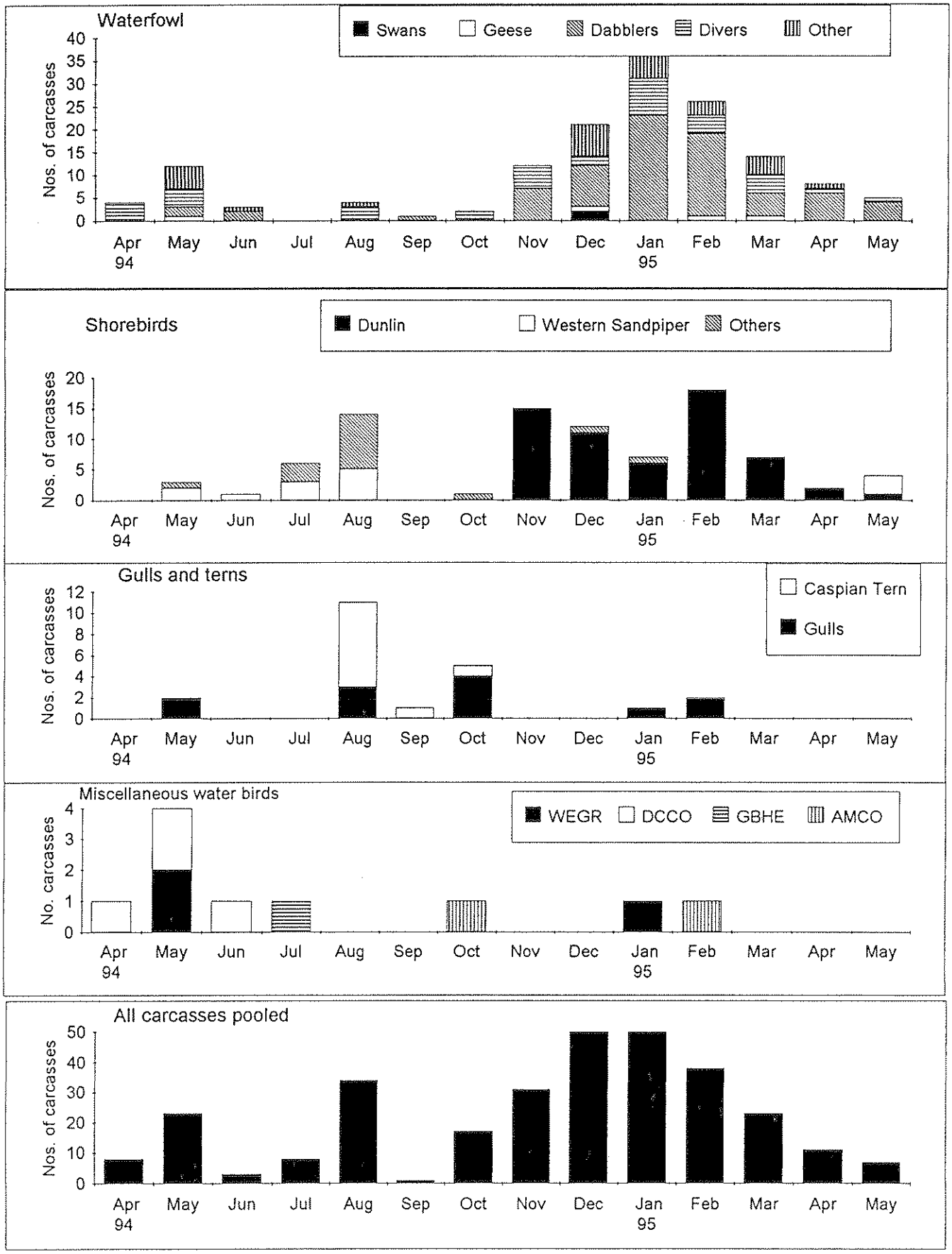


Figure 19. Monthly distribution of carcass deposition. Very old carcasses excluded.

7.2. Methods

Four sets of tests were done, in summer (17 August), fall (20 October), winter (9 February) and spring (12 April), to cover the varying conditions in each season (vegetation height, background coloration etc.). Each set involved the three people who undertook virtually all the carcass searches. Several replicate tests were done on each day using the same sample of carcasses, but laid out in different parts of the causeway. Each sample consisted of 20 intact, fresh carcasses, including 10 shorebirds or shorebird-sized birds (dull-coloured passerines were used when insufficient shorebird carcasses were available) and 10 larger birds (ducks, alcids, gulls and a northwestern crow). Gulls, which were much more conspicuous (having pale grey or white plumge) than the others in this group, were subsequently grouped separately. The carcasses were obtained as wire-killed birds on the causeway or under other power lines near Vancouver, or from beached bird surveys, gill-net bycatches, road kills or birds found dead. No birds were killed for these experiments. For each pair of tests, one person distributed the carcasses randomly along 20 sectors (1.2 km), within 10 m on either side of the power line, and the other two people conducted carcass searches independently. Test carcasses were marked by attaching inconspicuous cable-ties or strands of string around the wing at the humerus. Individual birds were identified with numbers on the cable ties or by uniquely clipping small portions of the wing feathers. After the last efficiency test of the day, the carcasses were left in place for persistence tests (see section 8).

7.3. Results of carcass search efficiency tests

With all species pooled, search efficiency ranged between 25-75% and averaged 55% in 22 tests (Table 6). There were no significant differences in the efficiencies of the three searchers (means and SDs were 49% $\pm$ 10, 56% $\pm$ 19 and 58% $\pm$ 10; ANOVA, $F_{2,21} = 1.025$, $P>0.05$), and so their results were pooled for analysis. There were no significant differences between the tests done in the four different seasons for mid-sized water birds, gulls or for all birds pooled (Table 6). A significantly smaller proportion of shorebird carcasses were found in summer and fall (using small shorebirds and shorebird-like species),

Table 6. Proportion of carcasses found in each of 22 replicate search efficiency tests at Roberts Bank causeway.

	Group of birds				
Date and test no.	Dunlin	Other shorebirds and similar birds	Waterfowl, alcids etc.	Gulls	All birds pooled
17 August 1994		(N = 10)	(N = 6)	(N = 4)	(N = 20)
Test 1	-	0.20	0.83	1.00	0.55
Test 2	-	0.20	0.83	1.00	0.55
Test 3	-	0.10	0.67	1.00	0.45
Test 4	-	0.10	0.67	1.00	0.45
Test 5	-	0.10	0.67	1.00	0.45
20 October 1994		(N = 10)	(N = 8)	(N = 2)	(N = 20)
Test 6	-	0.30	0.75	1.00	0.55
Test 7	-	0.20	0.38	1.00	0.35
Test 8	-	0.10	0.50	0.00	0.25
Test 9	-	0.30	1.00	1.00	0.65
Test 10	-	0.30	1.00	0.50	0.60
9 February 1995	(N = 10*)		(N = 7)	(N = 3)	(N = 20*)
Test 11	0.78	-	0.57	1.00	0.74
Test 12	0.44	-	0.43	1.00	0.53
Test 13	0.60	-	0.86	1.00	0.75
Test 14	0.50	-	0.86	1.00	0.70
Test 15	0.10	-	0.71	0.67	0.40
Test 16	0.60	-	0.43	0.67	0.55
12 April 1995	(N = 10*)		(N = 8)	(N = 2)	(N = 20*)
Test 17	0.56	-	1.00	0.50	0.74
Test 18	0.44	-	0.63	0.50	0.53
Test 19	0.38	-	0.88	1.00	0.67
Test 20	0.29	-	1.00	1.00	0.71
Test 21	0.30	-	0.25	0.50	0.30
Test 22	0.30	-	0.75	1.00	0.55
Mean	0.44	0.19	0.71	0.83	0.55
SD	0.18	0.09	0.22	0.28	0.14
No. of tests	12	10	22	22	22
Variation among dates					
ANOVA F-value	1.47	4.54	0.26	1.31	1.69
df	1, 10	1, 8	3, 18	3, 18	3, 18
P	>0.05	>0.05	>0.05	>0.05	>0.05

* The following Dunlin were removed by scavengers (Northern Harriers and Common Ravens) during tests and were not included in the sample sizes: one during tests 11, 12, 17, and 18, two during test 19 and three during test 20.

The inclusion of Dunlin with other shorebirds produced a significant difference among sample dates (ANOVA, df = 3, 18, F = 6.86, P<0.01), and so Dunlin were treated as as a separate group.

than in winter and spring (using only Dunlin). Dunlin were therefore treated separately (Table 6).

Overall, the search efficiency indices (e) were:

0.44 for Dunlin;

0.19 for other small shorebirds;

0.71 for mid-sized birds (applied to grebes, loons, cormorants, ducks, corvids and owls); and

0.83 for gulls (and also applied to Caspian Terns).

Herons, swans, geese and similar large birds were assumed to have an index of 1.0 (all would be found if present during a search).

8. PERSISTENCE OF CARCASSES

8.1. Background

Once the total number of carcasses present was estimated (including those found and not found), it was still necessary to account for those that had been scavenged or had disappeared (removed by scavengers or people) between carcass searches. We therefore undertook carcass persistence tests to determine the rate and timing of carcass disappearance and persistence.

8.2. Methods

The 20 carcasses (10 shorebird types and 10 larger birds) used in each search efficiency test were left in place at the end of the last test in each of the four series (see section 7.2). These were then checked at 2 day intervals for the first 10 days, and weekly thereafter for a month. We made detailed notes of the location and body condition (proportion scavenged or decomposing). When a carcass was not in its original site, we searched the surrounding area thoroughly within a 30 m radius.

We considered the persistence of these carcasses over one month, but many marked carcasses were still present after more than 6 months. In a few cases carcasses were reported as disappeared, but re-appeared later at another location nearby, having been carried away by scavengers. These birds were then re-entered into the tally of carcasses present. Carcasses which had been attacked by insects or microbes were not

considered to be scavenged, because these were not moved and were still likely to be re-discovered and identified.

8.3. Results of carcass persistence tests

Rates of persistence and scavenging differed between shorebird types and larger birds, and there were also differences among the four tests (Figure 20). Within each bird group, relatively few birds disappeared in summer and fall (August and October), but rates of disappearance were much higher in winter and spring (February and April). During this latter period, when many scavenging birds were visiting the causeway, only 20% of shorebird carcasses and 60% of larger carcasses were present after 10 days. There was relatively little change after 10 days. Based on the seasonal densities of the most common scavengers, raptors (Figure 2), we applied the pooled data from August and October to the period May through October and the pooled data from February and April to the period November through April.

We tried several survival equations to model persistence during the first 10 days, including Weibull curves used in similar work on the persistence of dead birds (Tobin and Dolbeer 1990), but the best fit was obtained with second-order polynomial equations (Figure 21). These equations predicted the proportion of carcasses present (N_t) as a function of time (t) in days. The relevant equations were:

i) for shorebirds from May through October (from August and October data):

$$N_t = 1.004 - 0.056t + 0.003t^2 \quad (r^2 = 0.989, df = 9, P<0.001)$$

ii) for shorebirds from November through April (February and April data):

$$N_t = 1.063 - 0.186t - 0.010t^2 \quad (r^2 = 0.988, df = 9, P<0.001)$$

iii) for larger birds from May through October (August and October data):

$$N_t = 1.000 \quad \text{(no birds lost during first 10 days)}$$

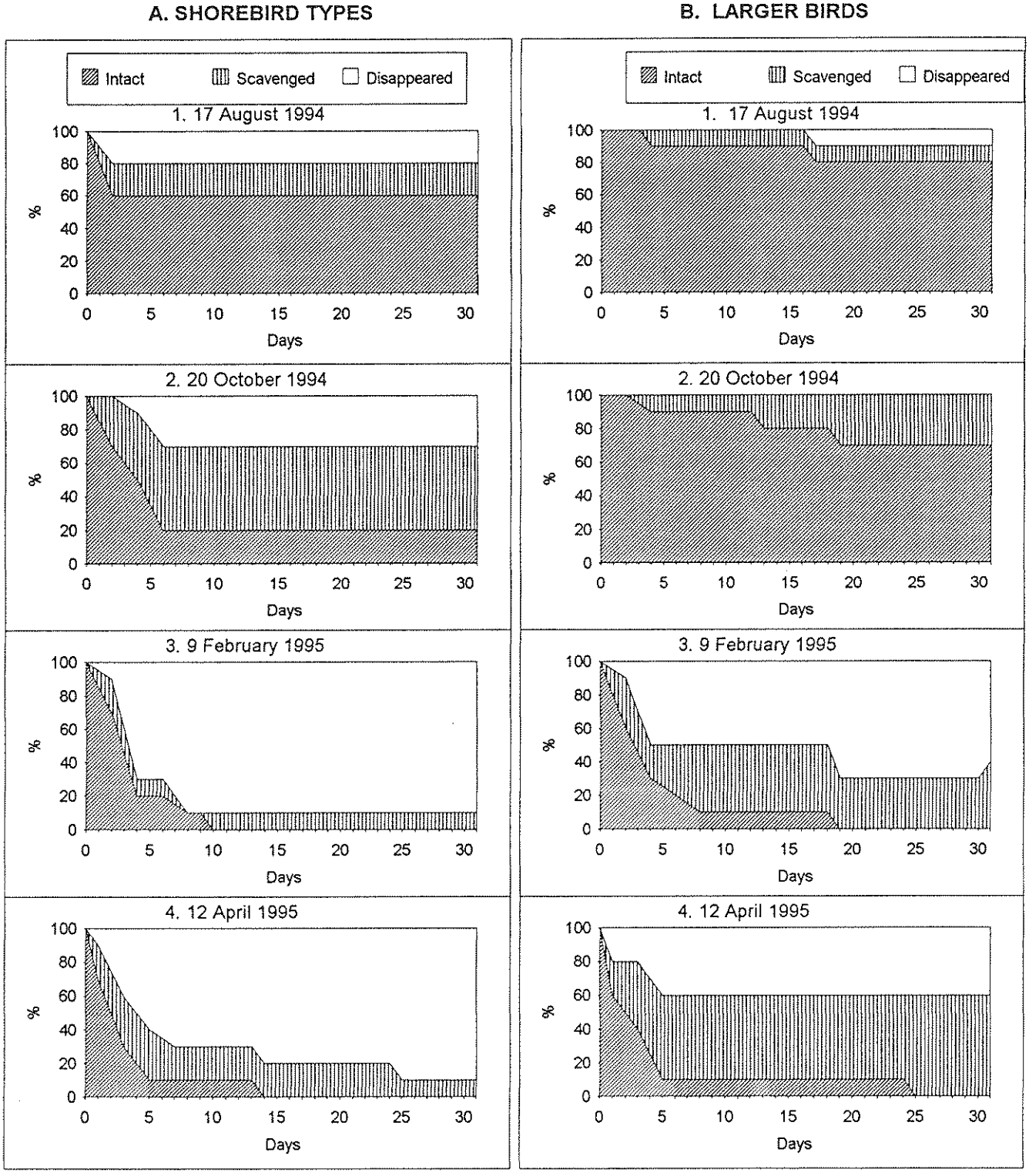


Figure 20. Results of four carcass persistence experiments made in summer (starting 17 August 1994), fall (20 October), winter (9 February 1995) and spring (12 April). Results from shorebirds (including a few small non-shorebird species) and larger birds (waterfowl, gulls etc.) are plotted on the left and right columns, respectively. Sample size was 10 carcasses for each group in each experiment.

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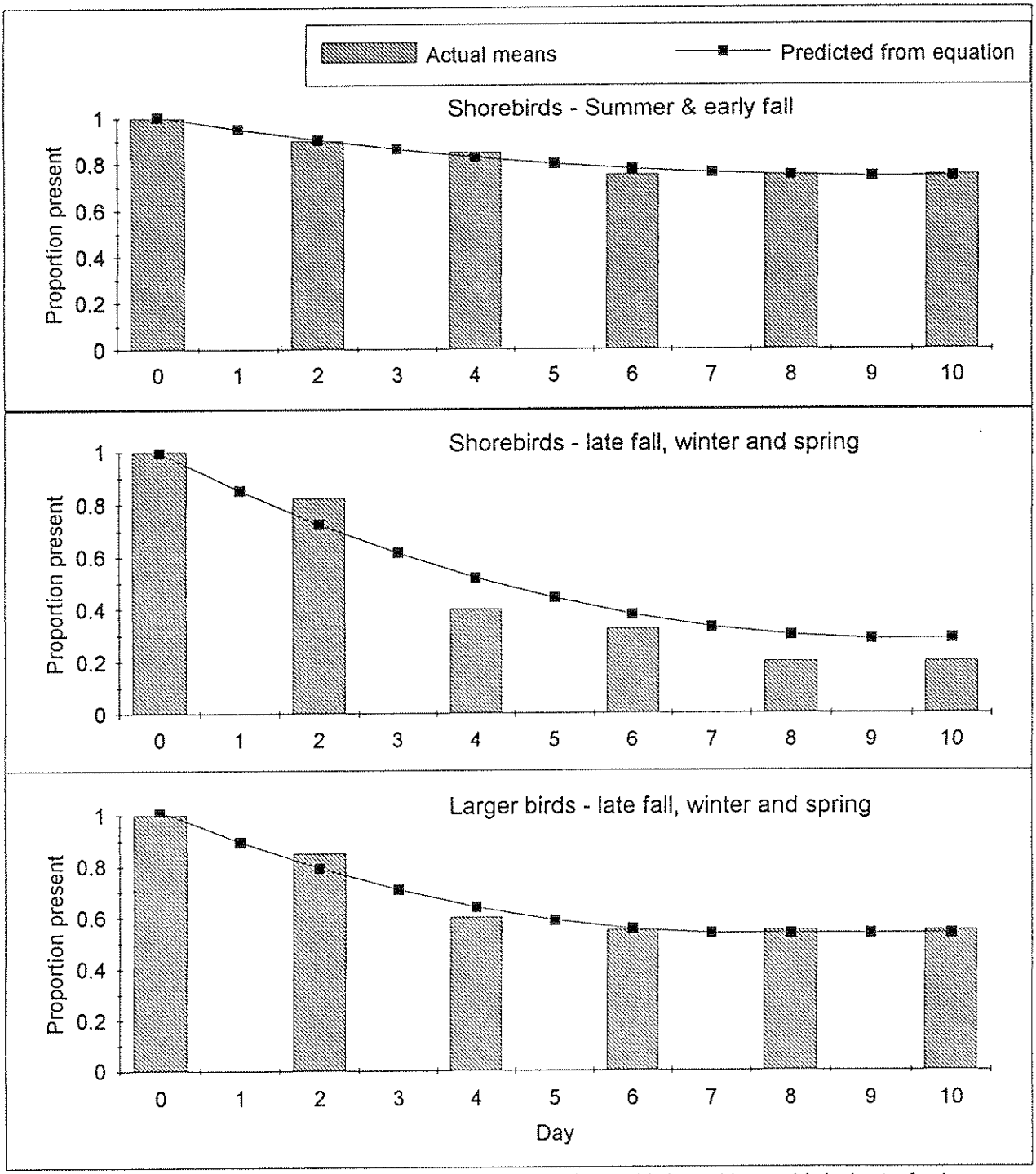

Figure 21. Actual and predicted persistence of carcasses of shorebirds and larger birds (waterfowl, gulls etc.) for the first 10 days after death at the Roberts Bank causeway. The predicted curves were derived from the data using second-order polynomial functions. No larger birds disappeared in tests made in August and October and so these data were not plotted.

iv) and for larger birds from November through April (February and April data):

$$N_t = 1.016 - 0.128t + 0.009t^2 \quad (r^2 = 0.984,\ df = 9,\ P<0.001)$$

Carcass searches through the year were made every seven days on average. We therefore applied the equations for days 0,1,2,3,4,5 and 6 (days between searches) and derived the following mean persistence index (**p**) between searches:

- shorebird types: 0.87 for May through October;
  0.65 for November through April;
- all larger birds: 1.00 for May through October;
  0.74 for November through April.

This meant, for example, that in November 65% of all shorebird carcasses deposited in days 0-6 between searches would have persisted to be present on the search day.

9. ESTIMATING TOTAL MORTALITY ON THE CAUSEWAY

9.1. Background

In this section we bring together data from the carcass counts, search efficiency tests and carcass persistence tests, to derive an estimate of the total number of carcasses deposited along the causeway in one year.

9.2. Methods

We considered carcass deposition for the 12 months, May 1994 through April 1995. For each species, we calculated the monthly total carcass deposition (C_{tot}) as:

$$C_{tot} = C_f/(e.p)$$

where C_f was the number of "fresh" carcasses (deposited during the study period) found in that month, **e** was the search efficiency index for that type of bird (see section 7.3) and **p** was the carcass persistence index for that type of bird in that month (see section 8.3). Initially, we included all "fresh" carcasses, even those which were not likely to have been wire kills.

9.3. Results

9.3.1. Estimated total carcass deposition

Calculations for four representative species are shown in Table 7. Caspian Tern, a conspicuous large bird, had high **e** and **p** values and the estimated total carcass deposition (12) therefore differs little from the number actually found (10). Other large, conspicuous birds (e.g. gulls) had similar treatments. American Wigeon, representing ducks and other medium sized birds, had intermediate **e** and **p** values and the estimated total carcass deposition was about twice the number found. Dunlin had low **e** and **p** values and the total carcass deposition was 3.5 times the number found. Finally, Western Sandpipers, with the lowest **e** and **p** values, had total carcass deposition six times the number found. This was typical of small peep sandpipers.

Similar calculations were performed to determine the total carcass deposition for all species using the 304 "fresh" carcasses found through the year (Table 8). These yielded an estimate of 710 carcasses deposited on the causeway in 12 months, of which 678 were projected to species or family. The most affected species were Dunlin (206 carcasses or 30%), Western Sandpipers (67 or 10%), American Wigeon (58 or 9%), Least Sandpiper (48 or 7%), and Mallard (31 or 5%).

These estimates represent minimum numbers for many species, since we were unable to account for birds which were injured by collisions, but flew away to die elsewhere, or were crippled and hid where we were unlikely to find them. On the other hand, the total of 710 birds includes a portion that were not wire-killed. It is likely that most of the ducks and a small number of gulls and shorebirds were raptor kills, or birds killed or wounded by nearby hunters and brought to the causeway by raptors. We have therefore used the total carcass deposition as an approximation of total mortality.

Table 7. Sample calculations of total monthly and annual mortality at Roberts Bank, for the period May 1994 through April 1995.

	May 94	Jun 94	Jul 94	Aug 94	Sep 94	Oct 94	Nov 94	Dec 94	Jan 95	Feb 95	Mar 95	Apr 95	Annual total
A. American Wigeon													
No. carcasses found (Cf)	1	0	0	1	0	1	2	11	8	3	3	1	31
Search efficiency (e)	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	
No. carcasses present at search (Cf/e)	1.4	0.0	0.0	1.4	0.0	1.4	2.8	15.5	11.3	4.2	4.2	1.4	44
Carcass persistence (p)	1.00	1.00	1.00	1.00	1.00	1.00	0.74	0.74	0.74	0.74	0.74	0.74	
No. carcasses deposited (Cf/(e . p)	1.4	0.0	0.0	1.4	0.0	1.4	3.8	20.9	15.2	5.7	5.7	1.9	58
B. Dunlin													
No. carcasses found (Cf)	0	0	0	0	0	0	15	11	6	18	7	2	59
Search efficiency (e)	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	
No. carcasses present at search (Cf/e)	0.0	0.0	0.0	0.0	0.0	0.0	34.1	25.0	13.6	40.9	15.9	4.5	134
Carcass persistence (p)	0.87	0.87	0.87	0.87	0.87	0.87	0.65	0.65	0.65	0.65	0.65	0.65	
No. carcasses deposited (Cf/(e . p)	0.0	0.0	0.0	0.0	0.0	0.0	52.4	38.5	21.0	62.9	24.5	7.0	206
C. Western Sandpiper													
No. carcasses found (Cf)	2	1	3	5	0	0	0	0	0	0	0	0	11
Search efficiency (e)	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	
No. carcasses present at search (Cf/e)	10.5	5.3	15.8	26.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58
Carcass persistence (p)	0.87	0.87	0.87	0.87	0.87	0.87	0.65	0.65	0.65	0.65	0.65	0.65	
No. carcasses deposited (Cf/(e . p)	12.1	6.0	18.1	30.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67
D. Caspian Tern													
No. carcasses found (Cf)	0	0	0	8	1	1	0	0	0	0	0	0	10
Search efficiency (e)	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	
No. carcasses present at search (Cf/e)	0.0	0.0	0.0	9.6	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	12
Carcass persistence (p)	1.00	1.00	1.00	1.00	1.00	1.00	0.74	0.74	0.74	0.74	0.74	0.74	
No. carcasses deposited (Cf/(e . p)	0.0	0.0	0.0	9.6	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	12

Table 8. Estimated numbers of carcasses deposited monthly and annually at Roberts Bank causeway from April 1994 through May 1995. The estimates were based on the numbers of carcasses found divided by the product of search efficiency and carcass persistence in each month (see Table 00 for examples).

SPECIES	May 94	Jun 94	Jul 94	Aug 94	Sep 94	Oct 94	Nov 94	Dec 94	Jan 95	Feb 95	Mar 95	Apr 95	Annual total
WEGR	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	5
DCCO	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
CORM	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
GBHE	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
AMCO	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	1.9	0.0	0.0	3
TRUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1
TRUS?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1
SNGO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.9	0.0	4
CAGO	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
GOOSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	2
GWTE	0.0	0.0	0.0	0.0	0.0	4.2	1.9	5.7	1.9	0.0	3.8	1.9	19
BWTE	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
MALL	0.0	0.0	0.0	0.0	0.0	4.2	1.9	9.5	11.4	1.9	0.0	1.9	31
NOPI	0.0	0.0	0.0	0.0	0.0	0.0	9.5	5.7	5.7	1.9	1.9	1.9	27
EUWI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	2
AMWI	1.4	0.0	0.0	1.4	0.0	1.4	3.8	20.9	15.2	5.7	5.7	1.9	58
GRSC	4.2	0.0	0.0	2.8	0.0	0.0	1.9	1.9	1.9	1.9	1.9	0.0	17
LESC	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
SCAUP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.9	0.0	0.0	4
SUSC	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	1.9	6
WWSC	0.0	0.0	0.0	0.0	0.0	2.8	3.8	1.9	3.8	0.0	0.0	0.0	12
SCOTER	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	3
BUFF	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	3.8	1.9	5.7	0.0	13
OLDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	2
DUCK	7.0	1.4	0.0	1.4	0.0	0.0	0.0	13.3	9.5	5.7	7.6	1.9	48
BBPL	0.0	0.0	0.0	0.0	0.0	2.6	0.0	3.5	3.5	0.0	0.0	0.0	10
BASA	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
LESA	0.0	0.0	18.1	30.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48
WESA	12.1	6.0	18.1	30.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67
PEEP	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6
DUNL	0.0	0.0	0.0	0.0	0.0	0.0	52.4	38.5	21.0	62.9	24.5	7.0	206
RNPH	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6
Shorebird	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6
MEGU?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	2
RBGU	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	1
GWGU	0.0	0.0	0.0	3.6	0.0	3.6	0.0	0.0	1.6	1.6	0.0	0.0	10
GULL	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
CATE	0.0	0.0	0.0	9.6	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	12
NWCR	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	3
SAVS	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	6
VATH	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	8
WIWR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	8
BAEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
BNOW	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
SEOW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	2
UN	0.0	0.0	1.4	4.2	0.0	0.0	1.9	5.7	9.5	5.7	0.0	3.8	32
Total	45	9	39	104	1	29	89	112	98	100	61	22	710

9.3.2. Interpreting the total carcass deposition

How significant was the loss of 710 birds every year? This question was addressed in several ways.

First, we compared the estimated number of carcasses deposited in one year per species with the mean numbers counted per census during the main period of occupancy of the area for that species (Table 9). This was restricted to the more common species. For most species, the carcass deposition represented less than 2% of the mean occupancy count. Perhaps a more realistic option was to compare carcass deposition with the maximum count for each species, because that would have been the number of birds exposed to collisions, and the population that have contributed the carcasses. The carcass deposition made up less than 1% of the maximum count for most species (Table 9). In several cases, high carcass:bird count percentages were artefacts caused by inadequate censusing of local populations by our methods. These include diving ducks, which normally forage in deeper water (scaup, Surf Scoter, White-winged Scoters, Bufflehead), and Snow Geese, which seldom forage near the causeway, but do fly over it. Relatively high proportions were also recorded for Western Grebes, Double-crested Cormorants, Great-blue Herons, swans, Black-bellied Plover, Glaucous-winged Gull and Caspian Tern. These were all species that often crossed close to the wires and were therefore at risk of collision (Figure 5; no data for Western Grebes). We feel that the two estimates given for each species represent the probable range of the percentage of the local populations killed by collisions with the wires. Although Dunlin and Western Sandpipers contributed the bulk of the carcasses, these represented less than 2% of the mean occupancy counts and 1% or less of the maximum counts.

Second, we compared the percentage contribution of each species to the total sample of censused birds and birds crossing the wires (Table 10). This revealed species that crossed more often than expected relative to their local population. These included Great Blue Heron (crossing % was 7x higher than census %), gulls (2.5x), Caspian Tern (5x) and Raptors (10x). Clearly, these were species that were exposed to higher risks of collision than most other species. Crossings by grebes and waterfowl

Table 9. Comparison within the more common species of the number of birds crossing the Roberts Bank causeway with the estimated number of carcasses deposited. The last two columns show the number of carcasses deposited as percentages of the mean census count during the main period of occupancy for each species, and of the maximum count.

Species	Species code	Birds crossing		Carcasses deposited		Carcasses as % of mean count during main occupancy*	Carcasses as % of maximum count*
		No.	%	No.	%		
Common Loon	COLO	12	0.02	0	0.00	0.0	0.0
Horned Grebe	HOGR	0	0.00	0	0.00	0.0	0.0
Western Grebe	WEGR	0	0.00	5	0.78	3.6	0.8
Double-crested Cormorant	DCCO	272	0.54	4	0.63	6.4	1.5
Great Blue Heron	GBHE	222	0.44	1	0.16	5.4	1.1
Tundra & Trumpeter Swan	SWAN	28	0.06	2	0.31	2.2	1.3
Snow Goose	SNGO	642	1.27	4	0.60	13.3	3.1
Brant	BRAN	64	0.13	0	0.00	0.0	0.0
Canada Goose	CAGO	81	0.16	1	0.22	1.3	0.3
Green-winged Teal	GWTE	8	0.02	19	3.04	2.2	0.6
Mallard	MALL	1039	2.05	31	4.83	2.1	0.4
Northern Pintail	NOPI	653	1.29	27	4.17	1.0	0.3
American Wigeon	AMWI	466	0.92	58	8.99	1.8	0.6
Scaup spp.	SCAUP	18	0.04	22	3.44	16.5	1.7
Black Scoter	BLSC	0	0.00	0	0.00	0.0	0.0
Surf Scoter	SUSC	5	0.01	6	0.89	12.9	3.1
White-winged Scoter	WWSC	27	0.05	12	1.93	51.4	12.6
Common Goldeneye	COGO	10	0.02	0	0.00	0.0	0.0
Bufflehead	BUFF	12	0.02	13	2.08	38.4	9.5
Red-breasted Merganser	RBME	5	0.01	0	0.00	0.0	0.0
Unidentified ducks	DUCK	3675	7.25	53	8.28	13.7	1.7
Bald Eagle	BAEA	50	0.10	0	0.00	0.0	0.0
Northern Harrier	NOHA	99	0.20	0	0.00	0.0	0.0
Black-bellied Plover	BBPL	525	1.04	10	1.50	15.0	2.2
Killdeer	KILL	29	0.06	0	0.00	0.0	0.0
Western Sandpiper & Peeps	WESA/PEEP	9584	18.90	138	21.57	1.0	0.1
Dunlin	DUNL	28545	56.29	206	32.25	1.8	0.6
Unidentified Dowitcher	DOWIT sp.	28	0.06	0	0.00	0.0	0.0
Mew Gull	MEGU	426	0.84	2	0.25	2.5	0.5
Ring-billed Gull	RBGU	373	0.74	1	0.19	0.3	0.1
California Gull	CAGU	420	0.83	0	0.00	0.0	0.0
Glaucous-winged Gull	GWGU	1497	2.95	10	1.64	26.9	2.6
Unidentified Gull	GULL SP.	1404	2.77	2	0.38	0.3	0.0
Caspian Tern	CATE	490	0.97	12	1.88	15.1	2.9
Total		50709	100	640	100	1.7	0.5

* See Table 1 for mean and maximum counts during main occupancy period of each species.

Table 10. Comparison of the percentage composition of bird types in the mean annual census count, the sample of birds seen crossing the causeway, and the estimated number of carcasses deposited during the study.

	Percentage of sample		
Bird type	Mean annual count	Birds crossing causeway	Estimated carcass deposition
Loons	0.04	0.02	0.00
Grebes	0.16	0.00	0.78
Cormorants	0.36	0.54	0.63
Great Blue Heron	0.06	0.44	0.16
Swans	0.1	0.1	0.3
Geese	0.7	1.6	0.8
Dabbling ducks	30.4	4.3	21.0
Diving ducks	1.1	0.2	8.3
Total waterfowl	*34.7*	*13.3*	*38.8*
Black-bellied Plover	0.4	1.0	1.5
Dunlin	43.9	56.3	32.2
Western Sandpiper	16.9	18.9	21.6
Total shorebirds	*61.3*	*76.3*	*55.3*
Gulls	3.2	8.1	2.5
Caspian Tern	0.2	1.0	1.9
Raptors	0.03	0.29	0.00
Total	100.0	100.0	100.0

were far fewer than expected and shorebird crossings were roughly in proportion to local populations.

Third, we compared percentage composition of carcasses with % crossing and % of census counts (Table 10). Birds which contributed exceptionally high proportions of carcasses, relative to crossing counts, were grebes, dabbling and diving ducks, and Caspian Terns. Many of the grebe and duck carcasses were presumed to be raptor victims, which would explain this discrepancy. The high proportion of Caspian Terns, however, reflects genuine vulnerability of this species to collisions, particularly the newly fledged juveniles which made up the bulk of the carcasses. The birds that crossed the power line most often (Dunlin, Western Sandpiper and gulls) appeared to contribute carcasses roughly in proportion to their crossing rates (Table 10). Herons and raptors appeared proportionately less in the carcass sample than in the crossing sample.

Comparison of mortality rates with other studies is difficult because of differences in methods of measuring and reporting mortality, and the paucity of quantitative published data. Table 11 compares mortality rates in five North American study sites, expressed as the estimated number of birds dying as a percentage of total bird-crossings during the study periods. In addition, Thompson (1978, quoted in Faanes 1987) reviewed several studies and reported collision rates of 0.01-0.05%. Mortality at Roberts Bank (0.004%) is relatively low, compared with other areas in which collisions were identified as a real or potential problem.

10. MITIGATION

10.1. Other studies and common problems

Published reports were reviewed to suggest mitigation methods for Roberts Bank. The bibliography by Avery et al. (1980) and reviews by Avery (1978), Beaulaurier (1981) and Bevanger (1994) contain many useful references. Several factors emerge as common themes in studies of bird collisions with overhead power lines. Studies that illustrate these themes well are cited here.

Table 11. Comparison of the rates of mortality of birds from collisions with power lines, expressed as the number of birds killed as a percentage of the total number crossing the lines during the study periods.

	Transmission line		Percentage of all birds crossing that were killed			
Study sites	Voltage (kV)	Tower height (m)	Ducks	Gulls	All birds	Reference
Roberts Bank	60	18	0.012	0.001	0.004	This study
Bybee Lake, Oregon*	230	50	0.182	0.023	-	Beaulaurier 1981
Crab Creek, Washington*	500	41	0.091	-	-	Beaulaurier 1981
Crow Butte Is., Wash./Oregon	500	37-109	0.014	-	-	Willdan Associates 1982
North Dakota (7 prairie sites)	12-400 (most 230)	Not given	-	-	1.163	Faanes 1987

* Percentages quoted in Beaulaurier (1981) were of birds approaching at the ground wire level, the values calculated here are for all birds.

i) **Birds often hit wires because they do not see them in time to avoid them.**

Birds rely extensively on vision for navigation and orientation in flight, but often appear unable to distinguish thin, horizontal wires, which may be not contrast with the background if the bird is at the same altitude. The ability to judge distance and focus on objects directly in front of the bird varies among species, but even raptors with highly binocular forward vision collide with wires. Thin wires cause more mortality than thick ones, or those with markers attached to them (Bevanger 1994).

ii) **Collisions are more likely to occur in low light conditions such as twilight, night, fog or heavy rain.** Although most birds are diurnally active, they often migrate at night. Waterfowl and shorebirds also forage at night and regularly fly between roosts and feeding sites or among feeding sites. Bright lights often confuse birds and increase collision rates.

iii) **Collisions regularly occur in sunny daylight.** Even though wires may be clearly visible, some approaching birds are evidently unable to judge their distance, and become confused.

iv) **Birds in flocks are more likely to collide than single birds.** Most of the species for which collisions were a major concern tend to travel in flocks (pelicans, cranes, ducks, shorebirds). It is believed that the birds in the rear of the flock do not always respond quickly enough when the leaders rise to clear the wires (Scott et al. 1972).

v) **Age and sex affect collision rates.** Juveniles have been found to have higher rates of collision than adults (93% of pelicans killed by power lines in Greece were immatures, 69% first-year birds; Crivelli et al. 1988). Juvenile Caspian Terns made up 90% of the carcasses found at Roberts Bank. Cornwell (1971) found that male dabbling ducks were found to have higher mortality in breeding areas, which was linked to their "reckless" pursuit flights after females.

vi) **The highest wires pose the greatest risk.** Approaching birds usually climb to avoid wires (as was found in our study), but may not gain

sufficient height to clear the uppermost wires. Approximately 80% of fatal collisions involved uppermost wires in three studies reviewed by Beaulaurier (1981) and 94% in Faanes' (1987) study.

vii) **The uppermost wire is particularly dangerous if it is thinner and less conspicuous than the lower wires.** This is usually the case in high-voltage transmission lines, where most collisions occur with thinner ground wires strung above the conductors (Scott et al. 1972, James and Haak 1979, Willdan Associates 1982). Removal of upper ground wires was found to reduce collisions (Beaulaurier 1981).

viii) **Conductors arranged in a horizontal plane pose less risk than those arranged vertically or in a triangular configuration.** A series of horizontal wires tends to create a single, more obvious image to an approaching bird, whereas vertical or triangular arrangements appear to cause confusion, even if the birds are aware of the wires (Bevanger 1994). Anecdotal evidence from Norway suggests that triangular configurations (as at Roberts Bank) are particularly liable to cause bird collisions (Bevanger 1994). One study in Holland found reduced mortality when multiple conductors and earth wires were re-arranged into two horizontal layers (Renssen et al. 1975)

ix) **Conductors arranged in bundles are more visible than single wires.** In transmission lines with duplex, triplex or quadriplex configurations, the single wires of each phase are kept apart by spacers. This configuration and the presence of spacers make the line more visible (Renssen et al. 1975, Bevanger 1994), but we could not find quantitative tests on how much this arrangement reduced bird mortality.

x) **Birds may habituate to the presence of power lines.** There is circumstantial evidence, but no quantitative analysis, that suggests that birds learn to avoid power lines or learn how to cross them safely. Mortality was found to be higher at newly erected lines (Scott et al. 1972). Habituation may also explain the differences between adults and juveniles.

10.2. Review of possible mitigation methods

Mortality of birds from collisions with human-built structures (e.g. power lines, TV and radio towers, lighthouses) has been documented in hundreds of studies (e.g. bibliography by Avery et al. 1980), but there have been few tests of methods to prevent or reduce this (Beaulaurier 1981, Bevanger 1994). Most of the suggested methods have been field tested in only one or a few situations, and there does not seem to be a single solution to meeting the conflicting demands of safe, uninterrupted power supply at a reasonable cost on the one hand, and preventing unnecessary deaths of birds on the other. Potential solutions applicable to the Roberts Bank power line are discussed below.

10.2.1 Burying the power cables

This is the most obvious and most effective way to prevent bird collisions entirely, but it is also the most expensive and poses severe technical problems in high-voltage lines. A study by Madsen (1979) showed that for 50 kV lines (similar to those at Roberts Bank), the costs of constructing underground lines were 3-4 times more than aerial transmission wires. In general, costs of underground cables rise exponentially above 15 kV. Although buried cables have seldom been used for transmission of high voltage over long distances, they are recommended for sensitive areas in which bird collisions are a serious problem (McNeil et al. 1985, Bevanger 1994).

10.2.2 Marking wires to make them more conspicuous

This is the most common response and various techniques have been tested (summarized in Table 12, updated from Beaulaurier 1981). It seems that any conspicuous objects attached to overhead wires in sufficient densities will reduce collisions. In several quantitative studies, reductions of collisions by 28-60% were reported, and in a few studies collision mortality appeared to cease after attaching markers (Table 12). Markers which move (e.g. streamers) can be expected to be more efficient than stationary devices (e.g. spirals or balls), but detailed comparisons are lacking (Bevanger 1994). The colour of the devices is also likely to affect their success. Research on the eyes and visual pigments of birds indicates that objects reflecting blue-green light

Table 12. Summary of studies in which marking of groundwires or conductors was used to reduce bird collisions.

Study	Marker type	Size/spacing	Collisions reduced	Comments
Scott et al. 1972				
	Black tapes on groundwire	1.5 cm long at 1.9 m intervals	Yes	3 cases cited
	Luminous orange bands on groundwire	5 cm wide 1.2 m intervals	No	Position of line with respect to power station was the most
	Strips on groundwire	5 cm wide 1.2 m intervals	No	important association with the number of birds killed
Renssen et al. 1975				
	White ribbons on groundwire	No details given	Yes	-28% compared to unmarked line
	Black ribbons on groundwire		Yes	-48%
	Black & white ribbons on groundwire		Yes	-52%
	Orange spacers between subconductors		Yes	-60%
	Orange marker balls		No	
Heijnis 1976				
	Black & white strips on groundwire	30 cm long 1.3 cm wide 2 m intervals	Yes	
Heijnis 1980				
	Plastic strips	50 cm long	No	Silhouettes were visible in poor
	Plastic spirals	11 cm wide	No	light while the other methods were
	Raptor silhouettes	100 cm long spacing not given	Yes	not
Kaiser and McKelvey 1978				
	Fishing floats	No size or spacing given	Yes	After marking, the loss of swans was almost eliminated.
Rigby 1978				
	Orange marker balls	No size or spacing given	Yes	No deaths of sandhill cranes recorded after markers were installed
Gylstorff 1979				
	Yellow plastic streamers on conductors	50 cm long 10 cm wide no spacing given	Yes	-37% compared to unmarked lines.
Koops and de Jong 1980		Diam. 10-20 cm	Yes	-87% at 5 m intervals
	PVC spirals	Length not given 5-15 m apart		-57% at 10 m intervals -70% at 15 m intervals
Morkill and Anderson 1991				
	Yellow aviation balls with black stripes	30 cm diameter 100 m apart	Yes	-56% compared to unmarked lines Sandhill cranes reacted earlier to marked lines.
Cochrane et al. 1991				
	PVC streamers and lowered wire	1.0 m long 25 cm wide	Yes	No wire kills of terns recorded after markers were installed and wire lowered by 1 m.
Alonso et al. 1994				
	PVC spirals	1.0 m long 30 cm diameter 10 m intervals	Yes	- 60% compared with unmarked lines. Most decrease attributed to avoidance of marked sectors.

(500 nm wavelength) should be more effective in low light, and yellow-green (560 nm) in daylight (Sillman 1973, Bevanger 1994). There have not been rigorous field tests of the effectiveness of various coloured markers on overhead wires. Similarly, the spacing or density of markers has seldom been systematically tested. Koops (1986, quoted by Bevanger 1994) stressed that collision rates decreased when the space between markers was short, e.g. 5 m, but reduced mortality of Sandhill Cranes was achieved with balls (30 cm diameter) spaced at 100 m intervals (Morkill and Anderson 1991). Where approach distances are short, as they are for many birds at the Roberts Bank causeway, the most effective spacing would be fairly short, e.g. 5 or 10 m.

Markers on wires might create technical problems, particularly if the area is exposed to strong winds or icing. If attached to conductors, devices might promote arcing or formation of a corona, which can affect the power supply or create localized radio interference. This is particularly likely in moist, foggy conditions. Markers may also cause abrasion to wires.

The yellow and black markers placed along the first 10 sectors in Roberts Bank prior to our study were ineffective because they were placed on the lowest wires (below the three main conductors) and most of them blew off within a few years of installation.

10.2.3 Other options

Several other techniques have been suggested which are inappropriate at Roberts Bank. Silhouettes of raptors or models of owls are often used to discourage gulls or perching birds. Heijnis (1980) reduced collision rates using silhouettes of falcons or hawks, and found that the effect did not decrease over time (i.e. no habituation). This is unlikely to be a viable option at Roberts Bank, because of the technical problems of attaching silhouettes in the centre of spans of live conductors, where they would be effective.

Illuminating the power line would increase its visibility at night, but would create additional problems in disorienting birds. Birds regularly

collide with brightly lit structures, particularly when there is fog or a low cloud ceiling. This would also not address the problem of daytime collisions. Low-intensity light tubes, which use the electric field around the conductors as a power source have been considered (Longridge 1986, quoted in Bevanger 1994), but the success of these devices is not known.

Acoustic scaring methods have been developed for keeping birds away from airports, with varying success (Blokpoel 1976). These often involve distress or alarm calls or loud, sharp sounds. These are unlikely to be effective at Roberts Bank, because the collisions involve a wide variety of species, which are unlikely to respond to the same sounds. The logistics of maintaining acoustic devices along the entire causeway year-round are daunting, and the likelihood of habituation is high. There are also strong ethical and conservation arguments for not scaring birds away from the rich feeding grounds surrounding the causeway and port. The birds still need to cross the causeway.

10.3. Suggested mitigation for the Roberts Bank superport

Our study, and that of Roe and Williams (1984), has demonstrated that the power line along the causeway poses the greatest problem to birds. Occasional collisions with overhead wires and illuminated poles and cranes within the coal loading terminal undoubtedly occur, but our searches yielded few birds there, and the frequency of crossing events was clearly lower at the distal end of the causeway. We reported collisions along the entire length of the causeway, and propose that efforts should be made to reduce this throughout. Sectors 60-70, where Caspian Terns were particularly vulnerable, should receive special attention.

There appear to be several viable options for reducing mortality and the most effective and economical procedure might require combining two or more methods.

i) Burial. This is the preferred option, since it removes the problem entirely. This would make the superport causeway equivalent to the

nearby B.C. Ferries causeway (or safer since there would be fewer light standards). Burial is, of course, likely to be the most expensive option, but there should at least be a serious appraisal made of the long-term cost effectiveness, taking into account the fact that other methods are unlikely to be completely effective, and naturalists and conservation groups are likely to continue pressing the issue. Burial of portions of the power line should also be considered (e.g. sectors 60-70 to protect Caspian Terns).

ii) Marking the existing conductors. This is a cheaper option, but is unlikely to be completely effective, based on the studies reviewed above. Markers should be deployed along the entire line. They should be placed on the uppermost line since our observations clearly show that the vast majority of birds fly above the line, often very close to the highest wire, and all observed collisions occurred here. Nearly all birds which reacted to the wires gained altitude to avoid them, making them most likely to hit the top wire. The types of devices that can be attached to the conductors is limited because of the problems of arcing, corona formation and abrasion. The most viable option appears to be Spiral Vibration Dampers or spiral Bird Diverters (Preformed Line Products Ltd.), which appear to have been effective in European studies (e.g. Koops and de Jong 1980, Alonso et al. 1994). The most effective colour would be yellow-green, and they should be spaced 5 m apart. The purchase and testing of these devices has already been discussed with B.C. Hydro personnel. We propose an initial period of testing to determine the optimal density and location of the spirals, in which sectors with marked wires are compared with unmarked sectors and with our data from 1994-1995.

iii) Attaching markers to a new non-conducting upper line. It may seem paradoxical to suggest adding another line to the existing three, but if the costs and problems associated with putting markers on conductors reduce their density and success, then the addition of a higher, non-conducting line should be investigated. The uppermost wire kills most birds and should be made highly conspicuous. Bird mortality would almost

certainly be reduced if numerous, cheap PVC streamers or balls could be attached to this line and replaced as they wear out.

iv) Re-arranging the conductors. Having the three conductors on the same horizontal plane, instead of in a triangular pattern would increase their visibility and reduce the confusion of approaching birds. Ideally, this arrangement should be made in combination with the use of markers, or a non-conducting, highly conspicuous upper line.

v) Planting trees. Bevanger (1994) showed that bird collisions were reduced in situations where the wires were at or below tree-top level. At Roberts Bank, rows of hardy, fast-growing trees, such as Alders *Alnus* spp., would provide a highly visible, but safe barrier which would force birds to gain altitude before they encountered the wires. Rows of trees should be planted on both sides of the causeway and 15-20 m from the power line. Trees have been established on the parking lot of the adjacent B.C. Ferries Terminal despite the inhospitable substrate and microclimate. Obviously this would take 10-20 years to be effective and is suggested as a long-term solution.

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Appendix 1. Flight observations Entered computer ..... Observer..... Date .....

Update every 15 minutes: Tide:Full/Falling/Rising/Low

Time:..... Cloud cover.....%./ Fog patches/ Thick fog. Wind: Force .... Direct .... Ppt.: None/ Misty drizzle/ Drizzle/ Rain. Adjacent <30 m: mud/water. Tide .....

Appendix 2. Carcass Search Datasheet

Date: ..... Time start:..... Time end: .....

Total search time (min): .....

Observer(s):.....

No. people searching .....

Sectors searched ..... to ..... Inner/Outer/Both

No. sectors searched : .....

Mean vegetation height (m): .....

Notes on conditions affecting search (tall veg. etc.)

Notes on scavengers/raptors seen:

Data on birds (use one line per bird)

Species code	Age	Sex	Section no.	Parallel dist. to pole (m)	Dist. to wire (m)	N or S of wire	Condition code	Estim. days dead	Scavenged Use codes	Details of injuries or broken bones	Likely wire kill? Y/Y?/ /N/U	Details of body parts found	Other notes

Codes: SEX: M = male; F = female; U = unknown.
AGE: Adult (AD); Immature (IM); First-, second- , third- year (FY, SY, TY); Unknown (U).
CONDITION: 0 = alive; 1 = very fresh, no smell (hours-1 day dead); 2 = slight decomposition (days - week);
3 = very decomposed (feathers falling off, maggots); 4 = mummified (many weeks - months dead); 5 = skeleton, feathers only
SCAVENGED: 0 = intact; 1 = 1-10% flesh eaten; 2 = 11-80% eaten; 3 = almost completely eaten (>80%); 999 = cannot tell if eaten.
LIKELY WIRE KILL (based on injuries& location): Y - seems very likely; Y? - possible; N - probably not; U - cannot guess.

Section number is based on the number of the shoreside pole.
Parallel distance to pole should be estimated from the shoreside pole of the section. Distance between poles is 60 m.