Exxon Valdez Oil Spill
Restoration Project Annual Report

Distribution, Abundance, and Composition of Harlequin Ducks in Prince William Sound, Alaska

Restoration Project 96427
Annual Report

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Study History: Restoration Project 96427 continues harlequin duck (*Histrionicus histrionicus)* studies initiated by the Alaska Department of Fish and Game in 1992 with Bird Study Number 11 (Assessment of Injury to Sea Ducks from Hydrocarbon Uptake in Prince William Sound and the Kodiak Archipelago, Alaska from the *Exxon Valdez* Oil Spill) and Restoration Study Number 71 (Breeding Ecology of Harlequin Ducks in Prince William Sound, Alaska: Harlequin Duck Restoration and Monitoring). These earlier studies (Bird Study Number 11 currently in draft) conclude that the number of harlequin ducks inhabiting areas in western Prince William Sound (WPWS) declined as a result of the *Exxon Valdez* oil spill in 1989. The decline was attributed to direct mortality caused by oiling, and to subsequently low productivity of ducks that survived or avoided initial exposure. Restoration Project 94427 (Experimental Harlequin Duck Breeding Survey) was initiated in 1994 in response to concerns that post-spill productivity by harlequin ducks in WPWS is not at a level necessary to maintain a viable population. The study developed criteria to differentiate harlequin ducks by age and sex to compare demographic characteristics of populations inhabiting oiled areas in WPWS with non-oiled areas in eastern PWS (EPWS). Variation in population structure between regions would indicate dissimilar extrinsic influences affecting harlequin populations. A survey design was also developed to determine trends in harlequin abundance and production. Restoration Projects 95427 and 96427 (Distribution, Abundance and Composition of Harlequin Ducks in Prince William Sound, Alaska) utilized methods derived from Restoration Project 94427. Results from surveys conducted in 1995 (Restoration Project 95427) demonstrated that the number and composition of harlequin ducks in Prince William Sound varied from May through September because of seasonal movements by ducks into and out of the study area. The pattern of movement was similar between EPWS and WPWS. Differences between regions, however, in the magnitude and timing of movements by harlequin ducks combined with no observations of broods in WPWS indicated potential differences in productivity. Results from surveys conducted in 1996 (Restoration Project 96427) confirmed the seasonal pattern in movements by ducks observed in 1995. Variation in population characteristics (e.g., sex and age ratios, breeding population, molt chronology), were detected between years, regions, and among survey periods.

Abstract: We used the number of breeding pairs, age and sex composition of the population, chronology of molt and the number of brood observations to determine whether harlequin ducks *(Histrionicus histrionicus)* in western (WPWS) and eastern (EPWS) Prince William Sound exhibit similar demographic characteristics. The number and composition of harlequin ducks in PWS varied among survey periods because of seasonal movements by ducks into and out of the study area. A relatively greater proportion of breeding pairs departed EPWS than WPWS. The relatively small number of paired females remaining in study areas suggests that local breeding females contribute substantially less to annual production than do non-local breeding females. A significantly lower proportion of paired females in WPWS coupled with a greater proportion of flightless females earlier in fall suggest that breeding propensity of female harlequin ducks may be lower in WPWS than EPWS. Numerically, however, the relatively larger number of non-

paired females in WPWS can be attributed to sexually immature birds as opposed to non-breeding adults. The small number of local breeding pairs in WPWS combined with the absence of broods for the third consecutive year suggest that suitable breeding habitat is limiting breeding activity in our WPWS study area.

Key Words: Harlequin duck, *Histrionicus histrionicus,* oil spill, population monitoring, Prince William Sound, restoration, sea ducks.

Project Data: *Description of data* - Data on sex, age, breeding status, and flight status were recorded for each flock of harlequin ducks observed in PWS. These data are in Microsoft Excel spreadsheet format and DBASE IV format. GIS coverage of PWS showing the location of each flock, survey transects, broods and streams are presented in ARC/INFO format and archived at ADF&G regional headquarters in Anchorage. Contact Dan Rosenberg at ADF&G, 333 Raspberry Road, Anchorage, Alaska 99518 (907-267-2453) for information.

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EXECUTIVE SUMMARY

Harlequin ducks *(Histrionicus histrionicus)* occur year-round in intertidal and shallow subtidal zones (nearshore waters) of Prince William Sound (PWS), Alaska. Relative to dabbling (Anatini) and diving (Aythyini) ducks, harlequin ducks and other sea ducks (Mergini) are considered *K* selected species in that they exhibit delayed sexual maturity, low annual recruitment, high adult survival and relatively low, but variable breeding propensity. Long-term population stability depends on high adult survival coupled with a relatively few years of successful reproduction. High losses of adults could result in long recovery periods, whereas, long periods without successful reproduction could lead to extirpation.

In 1989, large numbers of harlequin ducks died in western PWS (WPWS) as a direct result of oil exposure following the *Exxon Valdez* oil spill (EVOS). Post-spill studies report a decline in the number and productivity of harlequin ducks inhabiting oiled areas of WPWS. Concern exists that the high incidence of adult mortality directly following the oil spill coupled with successive years of poor production predisposed harlequin ducks in WPWS to either a prolonged period of recovery, or continued reduction and perhaps eventual loss of this resource from WPWS.

This report summarizes results of harlequin duck surveys conducted from May through September in 1995 and 1996. For annual comparisons of abundance we incorporate results obtained from surveys conducted in 1991, 1993 and 1994. The ultimate objective of the study is to determine whether productivity of harlequin ducks in WPWS is at a level necessary to maintain a viable population. Preferably, we would compare pre- and post spill productivity of harlequin ducks in WPWS to make this determination. However, few data on harlequin ducks in WPWS are available prior to the spill. We cannot, therefore, make accurate comparisons with post-spill populations. Consequently, we used characteristics of harlequin ducks utilizing areas not affected by the oil spill in eastern Prince William Sound (EPWS) for comparison with WPWS. We used the number of breeding pairs, age and sex composition of the population, chronology of molt and the number of broods to determine whether harlequin ducks in EPWS and WPWS exhibit similar demographic characteristics. We used annual counts of harlequin ducks to compare population trends for each region. Variation between regions in population structure or growth would indicate dissimilar extrinsic influences acting on harlequin populations.

We surveyed nearshore transects for harlequin ducks from May through September. Surveys were conducted simultaneously in EPWS and WPWS during 3 spring and 3 fall periods. Spring surveys were timed to monitor harlequin ducks during the breeding season, while fall surveys coincided with molting and brood-rearing. Transects were established in areas surveyed in previous years and known to support harlequin ducks. Surveys were conducted from an open skiff within 100 meters of shore at a pace, course, and distance that assured complete coverage of the survey area and maximized the opportunity to observe ducks. We recorded the number of male and female harlequin ducks observed in each flock. During spring surveys we recorded the number of breeding pairs, and classified males as either first year, second year or adult based on plumage. During fall surveys we recorded the number of flightless and flight-capable ducks, and the number and age of ducklings observed in each brood.

To determine whether harlequin ducks in WPWS and EPWS exhibit similar population characteristics, we tested the following null hypotheses:

1. There is no difference between regions in the proportion of paired females. Lower proportions of paired females in WPWS during the spring would indicate that females are less likely to breed.
2. There is no difference between regions in the proportion of males and females. Differences in sex ratios between WPWS and EPWS may suggest variation in survival rates.
3. There is no difference between regions in the proportion of sub-adult males. The ratio of sub-adult to adult males serves as an index of past breeding success.
4. There is no difference between regions in the timing of molt. Variation in molt chronology may indicate variation in breeding activity.

As an index of productivity of harlequin ducks nesting on coastal streams in PWS, we compared the number of broods observed in WPWS and EPWS. Additionally, we used survey data from previous years to compare trends in the abundance of harlequin ducks between regions.

The number and composition of harlequin ducks inhabiting PWS varied among our survey periods because of seasonal movements by ducks into and out of the study area. We detected annual variation in seasonal movements by ducks resulting from annual variation in breeding chronology. Breeding birds in both WPWS and EPWS departed earlier for breeding areas in 1995 than 1996. We have no reason to believe that breeding chronology varied between regions especially for the relatively large non-local segment of the breeding population. Total numbers of harlequin ducks on our transects declined in early spring as breeding pairs moved away from coastal areas to river systems. Departure from our study areas by breeding birds, however, began prior to our first spring survey in early May. A small segment of the total breeding population remained on our study area suggesting that non-local breeding birds contribute substantially more to overall production. A relatively larger number of pairs departed EPWS, but an absolutely larger number of pairs remained on the coast compared to WPWS. Sex ratios were skewed towards males during all our surveys indicating that the composition of the female population contributes most to production.

A relatively larger number of non-paired females were present in WPWS than EPWS during each spring survey and the difference increased as the breeding season progressed. This may suggest lower breeding propensity for females in WPWS. The number of sub-adult males, however, were equal to or greater than the number of non-paired females indicating that, numerically, all non-paired females could be sexually immature rather than non-breeding adults. The relatively larger number of sub-adults in WPWS suggests that non-local breeding females are more productive in WPWS.

Harlequin numbers on our transects began to increase in June when males returned to the coast to molt, presumably after disassociation with females on breeding streams. Females returned to the coast later in the season than males. Consequently, the number and proportion of females steadily increased on our transects beginning in July. The number of females in EPWS began to increase earlier in the season than in WPWS possibly because local breeders were more abundant, and more likely to be observed if they failed or abandoned a breeding attempt. The larger proportion of flightless females earlier in the fall in WPWS is most likely related to the relatively larger number of non-paired birds observed at the end of the first spring survey. During our last fall survey (early September), males comprised a slightly higher proportion of the total population than they did during our earliest spring survey, suggesting that a portion of breeding females had not yet returned to the coast.

No harlequin broods were observed in WPWS for the third consecutive year. We believe the lack of suitable breeding habitat limits breeding by harlequin ducks in PWS overall, but more suitable breeding habitat is available in EPWS. The substantial decrease in the number of breeding pairs during the spring suggests that birds emigrate from PWS to larger, inland breeding streams. Evidence suggests that pre-spill observations of harlequin broods in WPWS were probably flocks of molting adults rather than ducklings. Consequently, pre-spill levels of productivity in WPWS are probably lower than previous estimates.

INTRODUCTION

Harlequin ducks *(Histrionicus histrionicus)* occur year-round in intertidal and shallow, subtidal zones (nearshore waters) of Prince William Sound (PWS), Alaska (Isleib and Kessel 1973). Relative to dabbling (Anatini) and diving (Aythyini) ducks, harlequin ducks and other sea ducks (Mergini) are considered *K* selected species in that they exhibit delayed sexual maturity, low annual recruitment, high adult survival (Goudie et al. 1994) and relatively low, but variable breeding propensity (Bengtson 1972). Long-term population stability depends on high adult survival coupled with a relatively few years of successful reproduction (Goudie et al. 1994). High losses of adults could result in long recovery periods, whereas, long periods without successful reproduction could lead to extirpation (Goudie et al. 1994).

In 1989, large numbers of harlequin ducks died in western PWS (WPWS) as a direct result of oil exposure following the *Exxon Valdez* oil spill (EVOS) (Ecological Consulting Inc. 1991). Post-spill studies report a decline in the number (Klosiewski and Laing 1994, Patten 1995, Patten et al. 1995) and productivity (Patten 1995, Patten et al. 1995) of harlequin ducks inhabiting oiled areas of WPWS. Patten (1995) and Patten et al. (1995) suggested the decline was the result of high initial mortality, continued ingestion of oil resulting in sub-lethal impairment of reproduction, and displacement of birds to non-oiled areas. Detectable levels of hydrocarbons were found in esophageal foods and tissues of harlequin ducks collected in 1989, 1990 and 1993 (Patten 1995, Patten et al. 1995). However, no conclusive evidence exists relating oil ingestion by harlequin ducks with histological and physiological injury. Concern exists that the high incidence of adult mortality directly following the oil spill coupled with successive years of poor production predisposed harlequin ducks in WPWS to either a prolonged period of recovery or continued reduction and perhaps eventual loss of this resource from WPWS.

Population levels of sea ducks are sensitive to adult female survival, breeding propensity (% breeding annually), and the number of breeding individuals (Goudie et al. 1994). Relative measures of age and sex, and the abundance and composition of the breeding population can be used to compare levels of productivity between harlequin populations in WPWS and EPWS. Unfortunately, pre- and post-spill surveys (Dwyer et al. 1976, Sangster et al. 1978, Hogan and Murk 1982, Irons et al. 1988, Hotchkiss 1991, Agler et al. 1994, Klosiewski and Laing 1994, Patten 1995 and Patten et al. 1995) reveal little about these characteristics for harlequin ducks in PWS. Lack of information makes it difficult to predict future population trends, and prevents comparisons of population composition and breeding propensity. Additionally, post-spill surveys (Patten 1995, Patten et al. 1995) were not designed to account for seasonal variation in the number and composition of harlequin populations resulting from seasonal movements by the breeding population. In 1994, the development of sexing and aging criteria and the use of consecutive surveys enabled Rosenberg (1995) to detect seasonal variation in population structure and abundance, thus providing a useful measure for detecting annual and geographic variation in harlequin populations.

This report summarizes results of harlequin duck surveys conducted from May through September in 1995 and 1996 in WPWS and EPWS. For annual comparisons of abundance we incorporate results obtained from surveys conducted in 1991, 1993 and 1994.

OBJECTIVES

The ultimate goal of the study is to determine whether productivity of harlequin ducks in WPWS is at a level necessary to maintain a viable population. To reach this goal we propose the following objectives:

1. Compare the composition of harlequin populations in oiled areas of WPWS and non-oiled areas in EPWS. This includes the number of breeding pairs, the number of sub-adults, and sex and age ratios of the population.
2. Investigate seasonal, annual and geographic variation in the number and composition of harlequin ducks.
3. Compare annual changes in density between regions.
4. Compare relative measures of productivity between regions.

To determine whether harlequin ducks in WPWS and EPWS exhibit similar population characteristics the following null hypotheses will be tested:

1. There is no difference between regions in the proportion of paired females. Lower proportions of paired females in WPWS during the spring would indicate that females are less likely to breed.
2. There is no difference between regions in the proportion of males and females. Differences in sex ratios between WPWS and EPWS may suggest variation in survival rates
3. There is no difference between regions in the proportion of sub-adult males. The ratio of sub-adult to adult males serves as an index of past breeding success.
4. There is no difference between regions in the timing of molt. Variation in molt chronology may indicate variation in breeding activity.

As an index of productivity of harlequin ducks nesting on coastal streams in PWS, we compared the number of broods observed in WPWS and EPWS. We used survey data from previous years to compare trends in the abundance of harlequin ducks between regions.

STUDY AREA AND METHODS

The study was conducted in Prince William Sound (PWS), Alaska (Fig. 1). A general description of the physiography, climate, oceanography, and avian habitats of PWS was described by Isleib and Kessel (1973). We established shoreline transects in areas of western Prince William Sound (WPWS) affected by the *Exxon Valdez* oil spill and in areas of eastern PWS (EPWS) geographically distant from oiled areas (Fig. 1). Transects were subjectively distributed in each region, but in order to maintain a historical perspective for long-term monitoring, transects were established in locations previously surveyed by Patten (1995) and Patten et al. (1995) and known to support harlequin ducks. In WPWS, transects were established in selected areas extending from the north end of Culross Island, south to Jackpot Bay and east to Green Island (Fig. 2). In EPWS, transects were distributed in selected areas from Shoup Bay in Valdez Arm to Simpson Bay, northwest of Cordova, and portions of Hinchinbrook Island (Fig. 3). Transects included nearshore habitats and concomitant offshore rocks.

Survey methods were identical to those conducted in 1995 (Rosenberg et al. 1996); however, slight variation in survey coverage exists between years (Table 1, Appendices A1-A4). Transects were surveyed simultaneously in EPWS and WPWS during 3 spring and 3 fall survey periods at approximately the same time in 1995 and 1996 (Table 2). On average, each completed survey period lasted for approximately 8 days in WPWS and 7 days in EPWS. Spring surveys were timed to monitor harlequin ducks during the breeding season, while fall surveys coincided with molting and brood-rearing.

Surveys were conducted from open skiffs (ca. 6m long) traveling at 2-20 km/hr within 100 meters of shore at a pace, course and distance that assured complete coverage of the survey area and maximized the opportunity to observe ducks. Distance from shore depended on light, weather and tide conditions. One full-time observer and a observer/boat operator continuously surveyed near shore habitats using 10X binoculars. When possible ducks were observed from shore using a 60X spotting scope. No surveys were conducted when wave height, weather, or light conditions compromised accuracy.

During all surveys, we recorded the number of male and female harlequin ducks observed in each flock and marked their location on nautical charts (National Ocean and Atmospheric Administration). Harlequin ducks that could not be identified by sex were classified as unknown. During spring surveys, males were classified as either first year, second year, or adult based on plumage patterns (Rosenberg 1995). Collectively, first and second year males were considered sub-adults. Ducks are in basic plumage during molt (Palmer 1976) prevented our aging of males during fall surveys. No method exists for determining age classes of females during survey procedures. We subjectively classified an adult male and female as a breeding pair when it appeared they were physically closer to each other than either was to the next closest duck when roosting or in flight. During fall surveys, we recorded the number of flightless and flight-capable harlequin ducks in each flock to compare the chronology of molt in WPWS and EPWS. Ducks were considered flightless when they consistently dove or swam away at our approach rather than fly. We solicited flight of apparently flightless ducks in order to accurately asses their flight capability and minimize incorrect classification of resting flocks. Broods were identified by the presence of down on ducklings. Ducklings were aged according to Gollop and Marshall (1954).

Transect length (km) was calculated from The Alaska Department of Natural Resources PWS_ESI ARC/INFO GIS database. Shoreline length of small islands not included in the PWS_ESI ARC/INFO GIS database was calculated using the U.S. Forest Service CNFSHORE Arc Info GIS database.

Expanded Fall Surveys

To increase the likelihood of locating broods we expanded our fall survey coverage to include potential brood-rearing areas not visited during our regular surveys. The expanded survey coverage comprised, for the most part, stream mouths, estuaries, and sheltered bays (Fig. 4, Fig. 5). An additional 8 transects in EPWS and 7 transects in WPWS were added to the fall survey (Appendix B). Substantially more shoreline was added to the expanded fall survey coverage in WPWS than EPWS (Table 3). Harlequin ducks observed on the added transects were recorded (Appendix C), but not included in our totals.

Standardized Survey Effort

When investigating annual and seasonal variation in the abundance and composition of the harlequin population we limited our counts to include only those ducks located in areas of comparable survey coverage. Most variation in survey coverage, however, occurred in WPWS (Appendices A1-A2). For annual comparisons we excluded ducks on transects (Clam Island, Eleanor Island, Herring Bay, Lower Herring Bay, New Years Island, Shoup Bay) or portions of transects (Applegate Island, Naked Island) that were not surveyed in all years during the same survey period (with the exception of spring survey 2 in WPWS in 1995) (see Appendices A1-A2 and D). For seasonal comparisons, we included ducks from partial transects.

On occasion, a transect was begun or ended at a location different (WPWS 1995) than normally surveyed, thereby causing slight variation in transect lengths among survey periods and between years (Appendices A1-A2). Because harlequin ducks were not observed on the portions of transects not common to each survey period, it was not necessary to adjust the number of ducks by differences in survey coverage. Consequently, we used transect lengths surveyed in 1996 as the standard survey coverage when calculating harlequin densities. Survey coverage in EPWS and WPWS was more similar when only comparable areas are considered (Table 4). On average, coverage used for comparing annual and seasonal variation in harlequin ducks was 286.63 km ($n = 6$, $sd = 21.95$) and 301.06 km ($n = 6$, $sd = 0.00$) in WPWS, and 256.97 km ($n = 6$, sd 3.87) in EPWS in 1995 and 1996, respectively.

Statistical Methods

We used a generalized logit model (Agresti 1990) to test for differences between regions (EPWS and WPWS), between years (1995 and 1996), and among 3 spring and 3 fall survey periods for the following ratios:

1) the ratio of male to female harlequin ducks during the spring;
2) the ratio of male to female harlequin ducks during the fall;
3) the ratio of adult males to sub-adult males during the spring;
4) the ratio of paired to non-paired females during the spring; and
5) the ratio of flightless to flight-capable females during the fall.

A test of the hypothesis of no interaction between main effects (i.e., region, year, and survey) was based on a likelihood ratio test (Stokes et al. 1995). The interaction term was excluded from the model when it was not significant, and a reduced model was used to test for significant region, year, or survey effects. When a significant region by survey or year by survey interaction was detected, we used contrasts to test for differences between regions and years for a given survey. Ducks classified as unknown were not included in the analysis.

We used a Poisson regression model with shoreline length as an offset variable (Agresti 1990, Stokes et al. 1995) to test for differences in density of harlequin ducks between years and among surveys during the spring and fall. Shoreline length of transects used during our expanded fall surveys (Table 3) and the numbers of ducks observed on these transects (Appendix C) were not included in our ratio or density estimates.

We used survey data from previous years to compare trends in the abundance of harlequin ducks between regions. Comparable survey coverage for 25 transects in EPWS for the years 1991, 1993, 1995, and 1996, and for 33 transects in WPWS for the years 1994, 1995, and 1996 were used in our comparisons. We only used counts of ducks from our first two fall surveys; one in July and one in August. To estimate the rate of change among years for each region, we fit a simple linear regression model (y = density, x = year) for each transect to estimate the slope and variance. The mean slope for each location was weighted by the total number of ducks counted for that period. A two-sample t-test was used to determine whether the rate of change in duck density is the same in WPWS and EPWS. The power of the test was then calculated for several levels of difference in slopes between regions.

RESULTS

Variation in Survey Coverage

Within Regions

Variation in survey coverage within regions existed between years and among survey periods (Appendices A1-A4). We excluded 5 transects surveyed in 1995 from 1996 surveys in WPWS because they contained relatively small numbers of harlequin ducks. On average, only 27 ducks/survey period were observed for the 5 transects combined. Consequently, it was our goal to survey 23 and 18 transects in WPWS in 1995 and 1996, respectively, and 33 transects in EPWS in both years (Appendix A). On occasion, however, some transects were not surveyed, or not surveyed in their entirety because deteriorating weather conditions precluded their completion. An extreme example occurred in WPWS during the second spring survey in 1995 when a prolonged period of high winds, rain, and rough seas limited our survey coverage to only 4 transects (Appendix A1).

Between Regions

Even though a larger number of transects were surveyed in EPWS than WPWS, we surveyed more shoreline in WPWS during all completed surveys (Table 1). Transect length was longer in WPWS averaging 16.7 km (n = 18; s. d. = 19.6 km) (Appendix A2) compared to 7.9 km in EPWS (n = 33; s. d. = 7.5 km) (Appendix A3). On average, survey coverage during each survey period was 318.61 km (n = 11, sd = 27.58) in WPWS and 258.55 km (n = 11, sd = 0.00) in EPWS.

Harlequin Duck Distribution

Harlequin ducks were observed during at least one survey period on all transects surveyed (Appendix D). For all survey periods combined, harlequin ducks were absent on 14% (18/125 transects) and 6% (6/108 transects) of transects surveyed in WPWS and 13% (26/197 transects) (Appendices D1-D2) and 10% (19/198 transects) in EPWS in 1995 and 1996, respectively (Appendices D3-D4). Transects which consistently supported large numbers of harlequin ducks included Green Island, Foul Bay, Channel Island, Falls Bay, Culross Island, Crafton Island and Totemoff Creek in WPWS, and Hell's Hole, Olsen Bay, Port Etches, Port Gravina (SE), and Sheep Bay (east) in EPWS (Appendix C). Green Island and nearby Channel Island, combined, accounted for 40% and 32% of the total ducks counted in WPWS in 1995 and 1996, respectively, whereas the number of harlequin ducks in EPWS were relatively more evenly distributed among our transects. The number of harlequin ducks varied considerably among transects, and within transects among survey periods (Appendix D). For the most part, however, harlequin ducks utilized particular segments of transects (e.g. emergent rock, rocky point) with a high degree of regularity regardless of survey period, thereby, creating a patchy distribution throughout PWS (Appendix E).

General Pattern of Seasonal Movements

The number and composition of harlequin ducks in WPWS and EPWS varied among survey periods because of seasonal movements by ducks into and out of the study area. The total number of harlequin ducks declined during the spring, reaching their lowest numbers in early June, then progressively increased during fall surveys (Fig. 6). The net decline in harlequin numbers during the early spring can be attributed to a decrease in the number of breeding pairs (Table 5). Numbers of both male and female ducks declined during early spring (late May), as paired birds emigrated from the coast to breeding streams (Fig. 7). The increase in the number of harlequin ducks on our transects (relative to the first survey) as the season progressed suggests that departure by pairs for breeding areas occurred prior to our first spring survey (Fig. 6). Consequently, a portion of the breeding population was not counted until later in the season.

The increase in the number of harlequin ducks observed on our transects began when males return to the coast to molt, after disassociation from females on breeding streams (Fig. 7) (Table 5). A relatively large proportion of the male population was counted on the coast by early August (Fig. 7). Female harlequin ducks returned to the coast later than males, and progressively increased on our transects throughout the fall (Fig. 7). With the exception of EPWS in 1996, our greatest harlequin counts were recorded during the last fall survey (Fig. 7). We believe, however, that our fall surveys end prior to the return of all ducks to the coast. Harlequin ducks have been observed on inland rivers in mid-September. Consequently, an unknown number of breeding females and young-of-the-year probably arrive on the coast after our last fall survey.

Variation Among Spring Surveys

Abundance of Harlequin Ducks

We observed more harlequin ducks during the first spring survey in 1996 than 1995 in both WPWS and EPWS (Fig 6). In WPWS, 842 and 956 harlequin ducks were counted during the first spring survey in 1995 and 1996, respectively, while 878 and 1144 ducks were counted in EPWS during these periods (Table 5). The relative increase in 1996, however, was greater in EPWS (Fig. 8). Conversely, we observed fewer harlequin ducks during the third spring survey in 1996 than 1995. In WPWS 884 and 752 harlequin ducks were observed in 1995 and 1996, respectively, while 820 and 681 were observed in EPWS (Table 5). The relative decrease in 1996 was also greater in EPWS (Fig. 8). Less annual variation was observed during the second survey; at least in EPWS (Fig. 8).

Densities of harlequin ducks were variable among our spring surveys, between years (Table 6), and among our transects (Appendix F). We detected significant variation in densities of harlequin ducks among our spring survey periods ($\chi^2 = 201.454$, df = 2, $p < 0.01$), and by a year * survey interaction ($\chi^2 = 34.23$, df = 2, $p < 0.001$). Densities of harlequin ducks were lower during each successive survey period, ranging from 3.4 to 2.5 ducks per kilometer of shoreline in WPWS, and 4.4 to 2.6 ducks per kilometer of shoreline in EPWS (Table 6).

Sex Ratios

We did not detect significant variation in sex ratios between WPWS and EPWS ($\chi^2 = 1.10$, df = 1, $p = 0.2944$), or between 1995 and 1996 ($\chi^2 = 0.47$, df = 1, $p = 0.4933$). The ratio of male to female harlequin ducks, however, did vary among survey periods ($\chi^2 = 245.00$ df = 2, $p < 0.001$). Sex ratios were skewed towards males during each spring survey with the smallest ratio occurring during the first survey (range: 1.6:1-2.0:1), and the largest ratio occurring during the third spring survey (range: 3.6:1-4.5:1) (Fig. 9).

Male Age Composition

More adults than sub-adult male harlequin ducks were always present during our spring surveys (Table 5) (Fig. 10). We could not investigate variation in the sub-adult component of the male population because age class (first and second year) could not be determined for many of sub-adults (Fig. 11). Consequently, we only compared sub-adult to adult ratios. The ratio of sub-adult to adult males varied by region ($\chi^2 = 19.32$ df = 1, $p < 0.001$), survey ($\chi^2 = 38.26$ df = 2, $p < 0.001$), and by a year * region interaction ($\chi^2 = 4.99$ df = 1, $p = 0.0255$) (Fig. 9). The largest sub-adult to adult ratio occurred in WPWS during the second spring survey in 1996 (0.60:1), while the smallest ratio occurred in EPWS during the first spring survey in 1995 (0.22:1) (Fig. 9). When we restrict our analysis to evaluate the effect of year in the year * region interaction, we detect a significant difference in 1996, when a higher ratio of sub-adult : adult males was detected in WPWS than EPWS. Greater variability, however, in the number of adult males during spring surveys compared to sub-adults, indicates that adult males contributed more to the observed variability in age ratios. The number of sub-adult males counted during the spring was larger in WPWS than EPWS ranging from 119 to 172 and 84 to 157 in WPWS and EPWS, respectively (Table 5).

Breeding Pairs

The number of paired harlequin ducks declined in WPWS and EPWS from May through June with the progression of nest initiation (Fig 12). We observed a larger number of breeding pairs in EPWS than WPWS during each spring survey period (Table 5). As the number of pairs declined, non-paired females composed a larger proportion of the female population (Fig. 9). The ratio of non-paired to paired females varied by year ($\chi^2 = 19.32$ df = 1, $p < 0.001$), region ($\chi^2 = 19.32$ df = 1, $p < 0.001$), and survey ($\chi^2 = 19.32$ df = 1, $p < 0.001$). Even though a region * survey interaction was not significant ($\chi^2 = 5.16$ df = 2, $p = 0.075$), removing the interaction from the model resulted in a poorer fit of the data. A greater proportion of non-paired females occurred in 1995 than 1996, in WPWS than EPWS, and later than earlier in the spring with a greater difference between regions occurring later in the spring (Fig. 9). The female population in WPWS contained a significantly higher ($p < 0.001$) proportion of non-paired females during each spring survey (Fig. 9). The largest non-paired to paired ratio occurred during the third spring survey in 1995 in WPWS (20.25:1), and the smallest ratio occurred during the first spring survey in 1996 in EPWS (0.17:1) (Fig.9).

Variation Among Fall Surveys

Abundance of Harlequin Ducks

The number of harlequin ducks increased progressively during our fall survey period (Fig. 6) (Table 7). Consequently, densities of harlequin ducks varied significantly among our survey periods ($\chi^2 = 57.68$, df = 2, $p < 0.001$) (Table 6). We did not, however, detect differences in harlequin densities between 1995 and 1996 ($\chi^2 = 0.35$, df = 1, $p = 0.5542$). Densities in the fall were greater than what was observed during the spring, increasing from 2.6 to 4.6 ducks per kilometer of shoreline in WPWS, and from 4.7 to 6.6 ducks per kilometers of shoreline in EPWS (Table 6). Densities increased during the 35 day period between our last spring survey and the first fall survey; however, this increase was more apparent in EPWS (Table 6).

Sex Ratios

During the fall survey period, sex ratios varied by year ($\chi^2 = 13.92$ df = 1, $p < 0.001$), region ($\chi^2 = 101.46$ df = 1, $p < 0.001$), survey ($\chi^2 = 396.46$ df = 2, $p < 0.001$), and by a survey * region interaction ($\chi^2 = 26.75$ df = 2, $p < 0.001$). Sex ratios were skewed more towards males in 1995 than 1996, WPWS than EPWS, and earlier than later in the fall with a greater difference between regions occurring during the first fall survey as opposed to the second and third (Fig. 13). The male : female ratio was significantly higher in WPWS than EPWS during each fall survey ($p < 0.05$), but differences between region diminished as the fall progressed (Fig. 13).

Molt Chronology

Male harlequin ducks exhibited a more synchronous and earlier molting period than did females (Fig. 14). We detected significant variation in the ratio of flight-capable to flightless male harlequin ducks between EPWS and WPWS ($\chi^2 = 65.84$, df = 1, $p < 0.001$), and among surveys ($\chi^2 = 2668.15$, df = 2, $p < 0.001$) (Fig. 13). A significant year * region ($\chi^2 = 19.59$, df = 1, $p < 0.001$), year * survey ($\chi^2 = 8.32$, df = 2, $p = 0.0156$), and region * survey ($\chi^2 = 67.85$, df = 2, $p < 0.001$) interaction complicates any meaningful interpretation. However, during the first and second fall survey, most males were flightless in WPWS (95.3% and 95.6%) and EPWS (96.6% and 93.1%) in 1995 and 1996 (Fig 14). By the end of our third fall survey, however, most males had regained flight (Fig. 14).

For females, we detected a significant difference in flight-capable to flightless ratios between years ($\chi^2 = 17.46$, df = 1, $p < 0.001$), regions ($\chi^2 = 12.99$, df = 1, $p < 0.001$), and among survey periods ($\chi^2 = 116.73$, df = 2, $p < 0.001$). A year * survey ($\chi^2 = 10.94$, df = 2, $p = 0.0042$), region * survey ($\chi^2 = 36.04$, df = 2, $p < 0.001$), and year * region * survey ($\chi^2 = 18.36$, df = 2, $p < 0.001$) interaction was detected. An insignificant year * region interaction ($\chi^2 = 0.68$, df = 1, $p = 0.4085$), was kept in the model because it provided a better fit to the data. A greater difference in the ratio of flight to flightless females between WPWS and EPWS occurred during the first and third fall survey periods (Fig. 13).

Brood Observations

Harlequin duck broods were only observed in EPWS (Fig. 13). No harlequin broods were observed in WPWS for the third consecutive year. Ten broods, totaling 26 ducklings (mean = 2.6, sd = 1.35) were observed at 7 locations during fall surveys in 1995, and 14 broods totaling 54 ducklings (mean = 4.2, sd = 2.36) were observed at 9 locations in 1996 (Table 8). All broods were observed at the mouth of, or in close proximity to, coastal streams (Fig. 15).

Trends in Abundance

The mean slope (slope = 0.2246, S.E.= 0.09286) for 25 transects in EPWS over a four year period (1991, 1993, 1995, and 1996) was significantly different from 0 ($t = 2.418, p = 0.0235$) suggesting a slight increase in the harlequin population during this period. For 33 transects in WPWS over a 3 year period (1994, 1995, and 1996) the mean slope (slope = -0.21733, S.E. = 0.87360) was not significantly different from 0 ($t = 0.2487, p = 0.8051$), indicating no change in the abundance of the harlequin population. We did not detect significant variation between slopes (t=0.503, $p = 0.618$). At $\alpha = 0.05$, with the observed difference in slopes of 0.4419, we would correctly reject the null hypothesis that there is no difference in the rate of change of harlequin populations between WPWS and EPWS 7.6% of the time (Fig. 16). At $\alpha = 0.10$ our power is 13.9% (Fig. 16). This suggests that we do not have the ability to detect small rates of change between harlequin populations in WPWS and EPWS with any certainty. The observed difference, however, in terms of ducks is only 175. The following example demonstrates the change in ducks needed to increase our power for detecting changes.

Based on the power curve generated from our analysis, we would correctly reject the null hypothesis that there is no difference in the rate of change between EPWS and WPWS (α=0.10) 79% of the time if the slopes differed by 2.2 (Fig. 16). For this example we split this difference between regionss. In other words, we set the slope in EPWS to 1.1, and -1.1 in WPWS. The amount of change needed to increase the observed slope in EPWS from 0.2246 to 1.1 is 0.874. Because the slope represents an average change in density, we can extrapolate from shoreline coverage to project differences in terms of number of ducks. Thus, a change of 0.874 ducks/km over 226 km of shoreline represents an increase of 198 ducks in EPWS. For WPWS, the amount of change needed to decrease the observed slope from -0.21733 to -1.1 is -.8827. A change of 0.8827 ducks/km over 564 kilometers of shoreline represents a decrease of 499 ducks in WPWS. Therefore, given the hypothetical differences in slopes, we would need to detect a total change of 697 ducks to say with approximately 80% certainty that the rate of change in harlequin abundance differed between WPWS and EPWS. For 1996, the change would have been observed from a population consisting of 1067 ducks in EPWS and 1655 ducks in WPWS.

The power of our test increased with the inclusion of 1996 survey data. We expect the power of our ability to detect changes will increase further with the addition of 1997 survey data.

DISCUSSION

Variation Among Survey Periods

Consecutive surveys, conducted throughout the spring and fall, enabled us to document seasonal variation in the number and composition of harlequin ducks otherwise undetectable by fewer surveys. Movements by harlequin ducks into and out of the study area were related to breeding activity, and directly influenced the number and composition of ducks we observed during each survey period.

Spring

The harlequin duck population in PWS during the spring is composed of breeding and non-breeding birds. The substantial decline in the number of breeding pairs (Fig. 12) indicates that a relatively large segment of the breeding population emigrate from the coast, probably to nest on larger, inland river drainages. Consequently, the largest number of ducks we observed during the spring was, for the most part, during the first survey (Table 5), as the largest proportion of the breeding population is present at this time. We suspect the local (on our study area) population of breeding birds to be relatively smaller, but more likely to be present during subsequent survey periods. Once non-local breeding birds leave the study area, local breeding and non-breeding birds comprise a substantially larger proportion of the harlequin population on our transects, and explains why the non-paired to paired female ratio increased during the spring (Fig. 9).

Male-biased sex ratios are typical for sea ducks (Goudie et al. 1994) and were observed for harlequin ducks on our surveys. Sex ratios were skewed towards males during all spring surveys (Fig. 9). During the first spring survey, however, the proportion of male and female ducks was more similar than other spring surveys (Fig. 9) due to the presence of relatively more breeding pairs (Fig. 12). The increasing proportion of males during the spring can be explained by a disproportionate return rate to the coast between the sexes. During the period between the first and second survey we observed a decline in the number of harlequin ducks because of the net movement of breeding birds out of the study area. Between the second and third survey, however, the number of adult males began to increase, while at the same time the number of females continued to decline (Fig. 7). The increase in adult males may be attributed to the break-down of pair-bonds on breeding streams. Adult males return to the coast when females become more attentive at the nest site (Bengtson 1972). The continued decline in females is probably the result of breeding females moving to nest sites. The return of adult males to the coast, however, marks the end of the net movement by harlequin ducks from our transects.

We believe that variation in the number of adult males rather than sub-adults was responsible for the observed variation in male age ratios among surveys (Fig. 12). Relative to adults, the number of sub-adults varied less among our spring survey periods. The number of sub-adults, relative to the total breeding population is probably a more accurate measure of recruitment.

Fall

Whereas the number and composition of harlequin ducks we observed during the spring can be explained mostly by movements of the breeding population out of the study area, variation in the number and composition of harlequin ducks during the fall can be explained by an asynchronous return to the coast by males and females.

The number of post-breeding males began to increase during the third spring survey (Fig. 7). By the completion of our first fall survey, however, the number of post-breeding males had substantially increased on our transects, resulting in a notable net increase in harlequin ducks (Fig. 7). Females did not contribute to the increase in WPWS during this time, but a slight increase in EPWS was the first indication of females returning to the coast (Fig. 7).

The number of male harlequin ducks remained relatively constant during the first and second fall survey, but an overall increasing trend is apparent during the third survey (Fig. 7). We believe the increase in male numbers is probably more the result of survey methodology rather than actual movements by ducks. We are more likely to count the same duck more than once during the third survey because males have regained flight. Consequently, we would argue that the majority of males returned to the coast by the end of the first fall survey. The principal factor explaining the increase in harlequin ducks during the second and third surveys was the increasing return of females (Fig. 7).

Sex ratios were skewed towards males during each fall survey (Fig. 13). The ratio of males to females, however, became increasingly smaller as more females returned to the coast. Sex ratios during the third fall survey were similar to ratios during the first spring survey suggesting that a large proportion of the pre-breeding population had returned to the coast. However, from a distance fledged young cannot be distinguished from females. Consequently, the number and proportion of females may be inflated during the third fall survey. A relatively greater proportion of males in the fall than the spring suggests that a proportion of the females have not returned to the coast by the end of our last fall survey.

Male ducks do not assist with nesting or brood-rearing activities. Therefore, we should expect an earlier and more synchronous return to the coast by males as compared to females. Once on the coast males exhibit a relatively earlier and more synchronous molting period (Fig. 14). The majority of males observed during the first and second fall surveys were flightless (Fig. 14). By the end of our third survey no less than 80% of males had regained flight capability (Fig. 14). In contrast, the return of females is less predictable (Fig. 14). Females that are successful in hatching a clutch and raising a brood to fledging age probably return to the coast later than females that failed at their nesting attempt. However, because females that were obviously not attending a nest or a brood were observed on breeding streams after males have departed for the coast (Bengtson 1972), we cannot say with certainty that late arriving females were successful nesters. Sexually immature females, however, are not as likely to depart the coast in search of breeding streams (Bengtson 1972), therefore molt should begin earliest for this segment of the female population. The variable ratio of flightless to flight-capable females among the fall surveys represents differences in molt chronology between breeding and non-breeding females, in addition to difference between successful and unsuccessful breeders.

Variation Between Years

Factors Affecting Counts

Several factors can explain the variation in the number and composition of harlequin ducks we observed on our transects between 1995 and 1996 in PWS. Because the number and composition of harlequin ducks varies seasonally, annual variation in seasonal movements may disguise true differences in abundance. Variability in climatic factors such as snowfall and temperature can influence the timing of breeding activity, resulting in annual variation in breeding chronology, and consequently, the number of ducks we observe during a particular survey. Actual differences between years in abundance, however, are related to variation in productivity, mortality and rates of immigration and emigration. Although we did not measure these parameters specifically, we can make inferences about their contribution to annual variation observed in the harlequin population. An additional factor that may contribute to perceived variation in harlequin counts is measurement error. We cannot quantify the degree of measurement error; however, we are relatively certain in what direction and during which survey our data may be biased. We address this uncertainty when appropriate. Additionally, the number of ducks classified as unknown was relatively high during certain surveys. Erroneous interpretation may result if we ignore unknown ducks when comparing the abundance of specific components of the population. Consequently, when discussing relative abundance we partitioned unknown birds among the appropriate age, sex, flight and breeding categories based on observed proportions.

Spring Surveys

The general pattern in the number of harlequin ducks observed in the spring can be explained, for the most part, by the number of ducks observed during the first survey. In 1996, when relatively more ducks were counted there was a greater rate of decline during the subsequent two survey periods (Fig. 6). We believe this pattern is related to annual variation in breeding chronology and driven by the number of breeding pairs. The net decline in harlequin ducks we observed early in the spring was caused by a decline in the number of pairs (Fig. 14). We observed fewer ducks during the first spring survey in 1995 in both WPWS and EPWS because breeding pairs departed earlier for nesting areas and could not be counted during our surveys. Consequently, a smaller proportion of the breeding population was present to be counted during the next two surveys. We attribute the greater non-paired to paired female ratio detected in 1995 to be the result of annual variation in breeding chronology.

Additional evidence supporting earlier breeding activity in 1995 was an earlier return to the coast by males. The number of males began to increase earlier during our surveys in 1995 than 1996 suggesting earlier disassociation between males and females on breeding streams, resulting from earlier arrival and nesting.

Sex ratios were similar during the spring even though annual variation existed in breeding chronology because sex ratios of non-paired ducks in 1995 and 1996 were similar for each survey period and remained similar irrespective of the number of breeding pairs.

Large fluctuation in numbers, combined with annual variation in breeding chronology indicates that long-term monitoring is necessary for meaningful comparisons of abundance during the spring.

Fall Surveys

We did not detect annual variation in the density of harlequin ducks during the fall in either WPWS or EPWS. The slight variation that did exist during the first and second surveys can be attributed to relatively more ducks in WPWS in 1995, and relatively more ducks in EPWS in 1996 (Fig. 8). At most, a difference of only 55 ducks caused the discrepancy between years. During the third survey, however, annual variability was more pronounced (Fig. 8). More ducks were counted in 1995 in both regions (Fig. 8) (Table 7), mostly due to an increase in the number of males (Fig. 17). We are uncertain why there were more males during the third fall survey in 1995 than 1996 in both WPWS and EPWS, especially when male numbers were relatively similar between years during the first and second fall survey, and we expected all males to have returned to the coast by the end of the first fall survey period. A possible explanation for the greater number of males in 1995 may be related to the timing of our surveys.

No less than 90% of the males observed during the first and second fall surveys in WPWS and EPWS were flightless (Fig 14). By the end of the third fall survey, however, most males were flight-capable. The probability of repeatedly counting the same individuals is more likely to occur when birds are flight-capable. We believe this potential bias in our data is greatest during the third fall survey than any other survey period (spring and fall) because birds have recently regained flight and are relatively more sensitive to our presence, thus more likely to flush. Consequently, the number of males on our third survey may be inflated. That we counted relatively more males in 1995 suggests that the probability of repeat-counting is disproportionate between years. Alternatively, males may be more transient after the molt than females. Esler (pers. comm.) reported that female harlequin ducks exhibit a high degree of fidelity to molting sites and remain in that general vicinity during the winter. However, male movements after molt have not been monitored. Consequently, the disproportionate increase in males in 1995 may be the result of annual variation in rates of emigration and immigration. Whatever the reason, the greater number of males during the third fall survey in 1995 probably explains why sex ratios were skewed more towards males that year. If this was a true increase in abundance we believe it should have occurred during the first two fall surveys.

Annual variation in seasonal movements by harlequin ducks resulting from variation in breeding chronology is more pronounced and easier to detect during the spring than fall survey periods. Fall movements, and consequently, abundance of harlequin ducks, are related to the return of ducks to the coast. Earlier breeding chronology in spring will result in an overall earlier return of post-breeding males and females during the late spring and fall. However, factors influencing breeding success (e. g., depredation, flooding) probably contribute more to the annual variability we observed in the return rate of post-breeding females than does variation in breeding chronology alone. The majority of the male population returned to the coast prior to our first fall survey (Fig. 7). Any annual variation in breeding chronology for males is probably only detectable during our last spring survey. The majority of males have begun to molt and are flightless during the first and second fall surveys. Flightless ducks are easier to count and provide a more accurate measure of abundance than flight-capable ducks. The predictable return of the male population to the coast by early August, and our ability to accurately count them, makes flightless males a better indicator of the overall trend in population abundance.

Variation Between Regions

Breeding Chronology

The general pattern of harlequin duck movements was similar between WPWS and EPWS (Fig. 7). We have already resolved that fewer breeding pairs earlier in the spring of 1995, combined with an earlier return to the coast by males, indicated an earlier breeding season that year compared to 1996 for harlequin ducks in both regions. Differences in these same parameters between regions would undoubtedly exist if breeding chronology varied between WPWS and EPWS. We have no reason to believe that breeding chronology varies between regions, especially for non-local breeding pairs that depart the study area. We cannot critically test this hypothesis, however, because we cannot adjust for differences in absolute abundance without knowing the size of the total population. Departure by a large proportion of breeding birds prior to our first spring survey precludes an estimate of the pre-migratory population. By comparing the number of paired females to the total number of females during the first spring survey we can determine whether the variation in breeding chronology exhibited between 1995 and 1996 was proportional between WPWS and EPWS. The relationship of paired to total females was similar between regions (Fig. 18) suggesting that differences in breeding chronology between years was the same in WPWS and EPWS.

Abundance

Between year comparisons of harlequin abundance is simplified because comparable survey coverage (Table 4) allowed us to compare absolute numbers of ducks. We cannot compare absolute numbers of harlequin ducks between regions because more shoreline was surveyed in WPWS than EPWS in both years and during most surveys (Appendix A). Additionally, transect locations were, for the most part, arbitrarily selected and harlequin ducks were not uniformly distributed. We believe we were more selective in EPWS at avoiding areas with no or little harlequin use. Consequently, density comparisons between regions are also inappropriate. Relative measures of abundance, however, partitioned among the following demographic components of the population provide a meaningful statistic for geographic comparisons.

Breeding Population

Movement by breeding birds contributed most to the variability we observed in the number and composition of harlequin ducks during the spring. A surplus of adult males in both WPWS and EPWS suggests that the number of females, rather than males, regulates the abundance of the breeding population, as is the case in most sea duck populations (Goudie et al. 1994). Consequently, geographic differences in the composition of the female population may indicate differences in productivity.

Females observed during our surveys were classified as either paired or non-paired. For the purpose of this discussion we assume that paired females will attempt to breed and non-paired females will not attempt to breed. We compared the number and proportion of paired and non-paired females between WPWS and EPWS to determine whether the composition of the female population differs between regions. The proportion of non-paired females increased in both WPWS and EPWS as non-local breeding pairs departed the study area (Fig. 12). The number of non-paired females in WPWS, however, comprised a greater proportion of the female population during each spring survey in 1995 and 1996 (Fig. 9). The difference between regions became increasingly greater as the season progressed (Fig. 9). By the end of the third survey, we observed 20 and 8 non-paired females to every paired female in WPWS in 1995 and 1996, respectively, compared to a 2.5:1 and 3.5:1 ratio in EPWS.

Based on the nest initiation curve for coastal breeding females in EPWS (Crowley 1996) (Fig. 12), we believe all non-local breeding females depart our study areas before the third spring survey. Consequently, the composition of the female population at the time of our third survey is comprised of local breeding and non-breeding females. The relatively larger number of non-paired females in WPWS suggests that the local female population is comprised of relatively fewer breeding females compared to EPWS. This implies, however, that: 1) more breeding females occur in EPWS prior to initial departure to breeding areas; 2) a relatively greater proportion of paired females depart the EPWS study area; 3) the number of non-paired females vary proportionately between regions among our spring surveys. We do not know if relatively more breeding females depart the EPWS study area because an unknown number of paired females depart prior to our first survey. The larger number of pairs and the greater rate of decline we observed in EPWS indicates that relatively more pairs did inhabit EPWS prior to our surveys and a greater proportion departed the study area (Fig. 12). Additionally, the relationship between total females and paired females during the first spring survey suggests that departure rates did not vary with respect to population size (Fig. 18). The numeric pattern exhibited by non-paired females varied between regions among our surveys (Fig. 19). However, the number of non-paired females was always lower in EPWS (Fig. 19). Consequently, we believe that the relatively larger number of non-paired females in WPWS during the third spring survey represents an absolutely smaller local breeding population and a relatively larger local non-breeding female population.

We indicated in the past (Rosenberg et al. 1996) that the relatively larger non-paired population in WPWS indicated lower breeding propensity by females in that region. However, the number of non-paired females was always equal to or less than the number of sub-adult males in both WPWS and EPWS (Fig. 19). If we assume that survival rates of sub-adult males and sub-adult females are similar, then all non-paired females could theoretically be sub-adults. Consequently, all females of breeding age were paired and presumably attempted to breed.

Molting Population

The number of male harlequin ducks increased in both WPWS and EPWS during the period between our last spring survey and our first fall survey (Fig. 7). The larger number of males in EPWS most likely represents a proportional increase to the larger breeding population that departed the survey area prior to our first survey, not an earlier return to the coast. Unlike the spring, the number of males remained relatively similar among our fall surveys suggesting no major movements in or out of the study area (Fig. 7). We believe males observed in the fall probably represent the entire pre-breeding male population. Most of the males in both regions were undergoing molt during the first and second fall surveys and were consequently easier to count. By the third fall survey, however, most males had regained flight capability in both regions.

Differences between regions during the fall were more apparent for females than males. The number of females increased in EPWS during the period between our third spring survey and the first fall survey, while female numbers slightly declined in WPWS (Fig. 7). A greater proportion of females in WPWS, however, were flightless during the first fall survey (Fig. 14). We attribute the relatively larger number of flightless females in WPWS during the first fall survey to the composition of the female population at the end of our third spring survey. A greater proportion and number of females were not paired during the third spring survey in WPWS. Consequently, we would expect these birds to molt earlier than breeding females. In EPWS, the increase in females by the end of our first fall survey probably represents breeding females that were nesting on coastal streams during the third spring survey failed at breeding but had not initiated molt by our first fall survey. Less variation between regions in the proportion of flightless females was observed during the second and third fall survey. These later variations are attributed to initial differences during the first fall survey, combined with different return rates back to the coast to molt.

Productivity

For populations of harlequin ducks on our study areas in PWS, productivity is partitioned among local and non-local breeding females. Because a substantially large proportion of breeding females depart both WPWS and EPWS, non-local females undoubtedly contribute more to overall production than do local females. That a relatively small number of breeding pairs remain on our study areas suggests that suitable nesting or brood-rearing habitat is limiting the number of breeding birds. The comparably smaller number of breeding pairs in WPWS indicates that suitable breeding habitat is even more limiting in that region. Crowley (1994) reported that harlequin ducks prefer to nest on coastal streams in EPWS with relatively high volume discharge and low gradients. Rosenberg et al. (1996) reported that substantially fewer kilometers of streams in WPWS than EPWS may represent differences between regions in the availability of suitable breeding habitat. The fact that we observed no harlequin broods in WPWS for the third consecutive year supports the idea that suitable breeding habitat is lacking in WPWS. Pre-spill observations of harlequin broods are reported in WPWS (Sangster et. al. 1978, Oakley and Kuletz 1979), suggesting that the current absence of broods may be related to the adverse effects of oiling. However, a more critical evaluation as to the reliability of pre-spill observations of broods in WPWS leads us to believe that flocks of molting females rather than ducklings were reported (see next section).

In terms of population growth, the number of young returning to the coast after fledging probably represents the most meaningful measure of recruitment. Similar numbers of sub-adults were observed in WPWS and EPWS (Fig. 19). However, relative to the number of breeding pairs, the number of sub-adults in WPWS represents a substantially greater proportion of the total population. Thus, non-local pairs emigrating from the WPWS study area contributed relatively more to annual recruitment than did local and non-local pairs in EPWS. This assumes, however, that sub-adults return to molting areas with females. This may not be the case since females have been observed to abandon the brood prior to fledging (Bengtson 1972). The distribution of sub-adults may be random with respect to the origin of the female and might be variable if sub-adults exhibit a greater tendency to disperse.

Pre- and Post-Spill Brood Observations in WPWS

Detecting harlequin duck broods has been a major component of monitoring efforts since the spill. Prior to the spill, however, no inclusive brood surveys were conducted in WPWS making comparisons with post-spill surveys difficult. A few incidental brood observations were reported (Sangster et. al. 1978, Oakley and Kuletz 1979, Patten 1995), and "Isleib has seen scores of broods during July and August along the shorelines, especially in Prince William Sound" (Isleib and Kessel 1973). After the spill (1989-1993), only 14 harlequin duck broods were observed in oiled areas of WPWS leading Patten (1995), and Patten et al. (1995) to conclude that reproduction by harlequin ducks declined in oiled areas. However, this conclusion was based on a comparative measure of brood production with EPWS, and reports of large aggregations of ducklings prior to the spill (Oakley and Kuletz 1979). Estimates of expected productivity in WPWS, based on observed nesting and brood-rearing activity in EPWS are tenuous because there has not been a comprehensive habitat evaluation that compares amount of suitable nesting and brood-rearing habitat between the two regions. We believe it is necessary to reevaluate pre-spill observations of broods to determine whether we have good evidence to support a dramatic decline in productivity within WPWS since the spill.

Isleib was known to have spent many years in PWS, however, his observations of harlequin broods cannot be used for comparative purposes because no indication of time of season, location, number or age of ducklings is reported. Sangster et al. (1978) reported a brood of nine in Outside Bay and 3 adults in Cabin Bay in a complete survey of Naked and Storey Islands on July 29, 1977. No adults were recorded with the brood. Oakley and Kuletz (1979) reported six brood aggregations along Naked Island totaling 72 young and one aggregate brood of 20 at Little Storey Island from surveys conducted July 20, July 26, August 24, and August 29, 1978. They also observed 36 young in 2 groups around an offshore rock along the coast of Eleanor Island. Holbrook (pers. comm. in Patten 1995) reported a brood on Otter Creek, Knight Island in 1982. Because the majority of pre-spill brood observations come from the two studies on Naked Island, we evaluated these surveys with respect to our observations of harlequin ducks from 1994-1996.

For our surveys of Naked Island, the total number of harlequin ducks observed in July ranged from 0-61 and from 35-67 in August. The number of ducks observed by Sangster et al. (1978) and Oakley and Kuletz (1979) fell within these ranges during these time periods. However, the majority of harlequin ducks observed on Naked Island prior to the spill were supposedly ducklings (Sangster et al. 1978, Oakley and Kuletz 1979), whereas all harlequin ducks observed during our surveys were adults, the majority of which were flightless. We believe that molting flocks of adult harlequin ducks were mistakenly classified as ducklings during pre-spill surveys of Naked Island, and ducks were only categorized as adults based on the ability to fly. Additional evidence that suggests molting flocks were mistakenly classified as ducklings include: 1) ducklings were not attended by females at Naked Island as they have been on all our brood observations in EPWS; 2) brood size was excessively large and is more consistent with the size of molting flocks; aggregations of harlequin duck broods have not been observed elsewhere in PWS nor are they reported for other locations; 3) based on the average size of broods reported in July and August for EPWS (Crowley 1996), Naked Island would have supported one brood for every 5.3 km of shoreline; we know of no other coastal area that supports such densities of harlequin broods; 4) Naked Island has only 2 small anadromous streams (ADF&G 1994a, 1994b), and most pre-spill brood observations were not associated with these streams; brood observations in EPWS have almost always been associated with anadromous streams (Dzinbal 1982, Crowley 1996, Rosenberg et al. 1995, this study).

For similar reasons (mentioned above), we suspect that other pre-spill brood observations, especially in areas that are not likely brood-rearing habitat (e.g. Eleanor Island), were also mistakenly identified. Consequently, pre-spill estimates of productivity by harlequin ducks in WPWS are most likely inflated. We believe the lack of suitable breeding habitat explains the small number of brood observations after the spill.

Future Analysis

We believe counts during the second fall survey most accurately approximate the true abundance of the male population. Most males have returned to the coast by this time and are undergoing molt, ensuring an accurate count. A large proportion of females, however, have yet to return. We hope to eliminate a large proportion of the variability associated with our power analysis for detecting trends by limiting our analysis to only males, with the assumption that the relative abundance of females remains proportional irrespective of male abundance. We will also plan to investigate the appropriateness of analyzing our data with respect to broader areas, rather than transects. Combining several transects in the same general vicinity may reduce our within-transect variability, and provide a more appropriate unit of measure for detecting variation at the population level.

CONCLUSIONS

We detected seasonal, annual, and geographic variation in harlequin populations inhabiting PWS. Our data suggest that a large proportion of the breeding population depart both WPWS and EPWS study areas during the spring when they move to breeding streams. A larger proportion of breeding pairs depart the EPWS study area than WPWS, but more pairs remain in EPWS. The small number of local breeding pairs suggests that suitable breeding habitat, either nesting or brood-rearing, may be limiting in both regions. That no harlequin broods were observed in WPWS for the third consecutive year supports the idea that breeding habitat is less available in WPWS than it is in EPWS. Evidence suggests that pre-spill observations of harlequin broods in WPWS were probably flocks of molting adults rather than ducklings. Consequently, pre-spill levels of productivity in WPWS are probably lower than previous estimates.

The number of sub-adult males comprised a relatively greater proportion of the spring population in WPWS than in EPWS, suggesting that relatively more young are produced by non-local pairs originating in WPWS. Thus, the non-local breeding population in WPWS contributes substantially more to overall production than does the breeding population in EPWS. However, using the number of sub-adults as an index to productivity may be inappropriate because we do not know if fidelity to geographic location by sub-adults is related to female origin.

The number of non-paired females comprised a relatively greater proportion of the female population in WPWS than EPWS. However, the number of sub-adult males was equal to or greater than the number of non-paired females during each spring survey in both years and in both regions, suggesting that, numerically, all non-paired females can be sub-adults.

ACKNOWLEDGMENTS

Special thanks to Dave Crowley, Tom Crowe, Doug Hill and Rick Raymond for their assistance during surveys. Thanks to D.W. Crowley for his comments and suggestions for improving this report. Earl Becker and Pat Hansen conducted the statistical analysis. Thanks to Celia Rozen, ADF&G librarian, for her editing assistance and for her exceptional ability to obtain literature no matter how obscure and to Carol Barnhill for her skills and patience in producing the GIS database and maps. Tom Rothe, Joe Sullivan, Jean Fults, Felicia Smith, Melanie Bosch, and Susan Rose all provided much additional support to our project for which we are grateful.

We thank the U.S. Forest Service, Glacier Ranger District, for permitting us to establish a field camp on Knight Island and use of the Picturesque Cove cabin and the Cordova Ranger District for use of the Green Island and Jack Bay cabins.

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Table 1. Kilometers of shoreline surveyed for harlequin ducks in eastern (EPWS) and western (WPWS) Prince William Sound, Alaska in 1995 and 1996.

		Spring Survey Period			Fall Survey Period		
Region	Year	1	2	3	1	2	3
WPWS	1995	296.76	60.59[a]	338.82	370.04	364.87	327.87
WPWS	1996	301.06	*	*	*	*	*
EPWS	1995	258.55	*	*	*	*	249.08
EPWS	1996	258.55	*	*	*	*	*

[a] Incomplete survey because of foul weather.
* Indicates no change from previous survey period.

Table 2. Dates of spring and fall surveys conducted in eastern (EPWS) and western (WPWS) Prince William Sound, Alaska in 1995 and 1996.

		Spring Survey Period			Fall Survey Period		
Region	Year	1	2	3	1	2	3
WPWS	1995	5/10-5/20	5/26-5/27[a]	6/09-6/16	7/25-8/01	8/10-8/18	9/05-9/14
WPWS	1996	5/08-5/14	5/24-5/30	6/11-6/18	7/23-7/30	8/08-8/15	9/05-9/13
EPWS	1995	5/10-5/17	5/23-5/31	6/10-6/16	7/25-7/30	8/11-8/17	9/06-9/12
EPWS	1996	5/09-5/14	5/23-5/27	6/11-6/16	7/24-7/30	8/09-8/17	9/06-9/10

[a] Incomplete survey because of foul weather.

Table 3. Additional kilometers of shoreline surveyed during expanded[a] fall survey coverage in eastern (EPWS) and western (WPWS) Prince William Sound, Alaska in 1995 and 1996.

		Fall Survey Period		
Region	Year	1	2	3
WPWS	1995	144.10	129.29	106.37
WPWS	1996	105.96	*	*
EPWS	1995	52.66	*	17.09
EPWS	1996	52.66	*	48.73

[a] Coverage expanded to incorporate potential brood-rearing areas. Coverage not used when comparing seasonal and annual variation in harlequin ducks.

[*] Indicates no change from previous survey period.

Table 4. Kilometers of shoreline used to compare annual and seasonal variation in the number and composition of harlequin ducks in eastern (EPWS) and western (WPWS) Prince William Sound, Alaska in 1995 and 1996.

		Spring Survey Period			Fall Survey Period		
Region	Comparison	1	2	3	1	2	3
WPWS	Annual	248.98	299.12	*	301.06	*	270.43
WPWS	Seasonal	301.06	*	*	*	*	*
EPWS	Annual	258.55	*	*	*	*	249.08
EPWS	Seasonal	258.55	*	*	*	*	*

* Indicates no change from previous survey period.

Table 5. Number and composition of harlequin ducks in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska used to compare annual, seasonal and geographic variation in harlequin populations during the spring in 1995 and 1996.

			Number						
Region	Year	Spring Survey	Adult Males	Sub-adult Males	Unk.[a] Males	Females	Unclassified	Total	Breeding[b] Pairs
WPWS	1995	1	384	119	2	274	63	842	155
WPWS	1995	2[c]	22	6	0	21	0	49	8
WPWS	1995	3	448	172	2	170	92	884	8
EPWS	1995	1	390	84	4	309	91	878	258
EPWS	1995	2	336	157	2	239	109	843	166
EPWS	1995	3	428	153	33	141	65	820	40
WPWS	1996	1	407	158	0	344	47	956	232
WPWS	1996	2	261	157	0	213	54	685	79
WPWS	1996	3	332	140	0	106	174	752	12
EPWS	1996	1	522	139	5	453	25	1144	388
EPWS	1996	2	340	129	12	236	60	777	185
EPWS	1996	3	379	107	41	145	9	681	32

[a] Age of males unknown.
[b] Included in adult male and female totals.
[c] Incomplete survey coverage because of foul weather.

Table 6. Density (ducks/km shoreline) of harlequin ducks on nearshore transects[a] in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

			Spring			Fall		
Region	Year		1	2	3	1	2	3
WPWS	1995							
		Density[b]	2.9	0.8[c]	2.6	2.6	3.1	4.6
		Average[d]	3.9	1.8	4.9	4.3	5.3	5.4
		S. D.[e]	4.2	2.4	8.2	11.3	10.9	6.2
WPWS	1996							
		Density	3.4	2.3	2.5	3.0	3.4	4.1
		Average	5.3	3.6	8.4	7.9	7.9	5.0
		S. D.	5.9	4.0	22.9	14.3	14.4	5.4
EPWS	1995							
		Density	3.4	3.3	3.2	4.7	5.0	6.6
		Average	6.8	5.4	13.7	12.1	13.5	9.8
		S. D.	9.0	8.2	47.7	24.7	25.7	11.2
EPWS	1996							
		Density	4.4	3.0	2.6	4.9	5.8	5.7
		Average	11.4	5.4	5.9	12.0	13.5	8.8
		S. D.	18.3	7.8	11.6	17.9	22.9	10.1

[a] Slight variation in survey coverage exists between years and survey periods (see Appendix A).
[b] Total ducks/total shoreline for each survey period.
[c] Incomplete survey because of foul weather.
[d] Average density per transect for each survey period.
[e] Standard deviation.

Table 7. Number and composition of harlequin ducks in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska used to compare annual, seasonal, and geographic variation in the harlequin population during the fall in 1995 and 1996.

			Number of Harlequin Ducks			
Region	Year	Fall Survey	Males	Females	Unclassified	Total
WPWS	1995	1	809	119	11	939
WPWS	1995	2	800	271	13	1084
WPWS	1995	3	862	445	115	1422
EPWS	1995	1	910	276	24	1210
EPWS	1995	2	874	401	30	1305
EPWS	1995	3	852	557	245	1654
WPWS	1996	1	758	127	6	891
WPWS	1996	2	728	300	13	1041
WPWS	1996	3	697	423	112	1232
EPWS	1996	1	917	305	42	1264
EPWS	1996	2	924	528	50	1502
EPWS	1996	3	837	574	74	1485

Table 8. Region, date, and composition of harlequin duck broods observed in eastern Prince William Sound, Alaska in 1995 and 1996.

Transect	Year	Region	Date	Brood Size	Age[a]
Sawmill Bay	1995	Stellar Creek	30 July	1	IC
Port Etches	1995	Etches Creek	14 Aug.	3	IIB
Constantine Harbor	1995	Constantine Harbor	14 Aug.	2	IIB
Constantine Harbor	1995	Constantine Harbor	14 Aug.	4	IIC
Hell's Hole	1995	Hell's Hole	15 Aug.	2	IIC
Galena Bay	1995	Millard Creek	17 Aug.	1	IIC
Sawmill Bay	1995	Stellar Creek	17 Aug.	2	IIC
Beartrap Bay	1995	Beartrap Creek	6 Sep.	5	IIC
Constantine Harbor	1995	Constantine Harbor	9 Sep.	4	IIC
Landlocked Bay	1995	Banzer Creek	11 Sep.	2	IIC
Port Etches	1996	Etches Creek	27 July	4	IC
Constantine Harbor	1996	Constantine Creek	27 July	8	IC
Constantine Harbor	1996	Constantine Creek	27 July	3	IC
Constantine Harbor	1996	Constantine Creek	27 July	1	IIA
Beartrap	1996	Beartrap Creek	9 Aug.	3	IIB
Sheep Bay (east)	1996	Sahline Lagoon	11 Aug.	4	IIA
Fish Bay	1996	Fish Creek	12 Aug.	4	IIA
Constantine Harbor	1996	Constantine Creek	13 Aug.	5	IIB
Constantine Harbor	1996	Constantine Creek	13 Aug.	4	IIB
Galena Bay	1996	Millard Creek	17 Aug.	5	IIA
Vladnoff River	1996	Vladnoff River	17 Aug.	4	IIB
Galena Bay	1996	Indian Creek	17 Aug.	5	IIC
Constantine Harbor	1996	Constantine Creek	7 Sep.	2	III
Surf Creek	1996	Surf Creek	8 Sep.	2	IIC

[a] Gollop and Marshall 1954

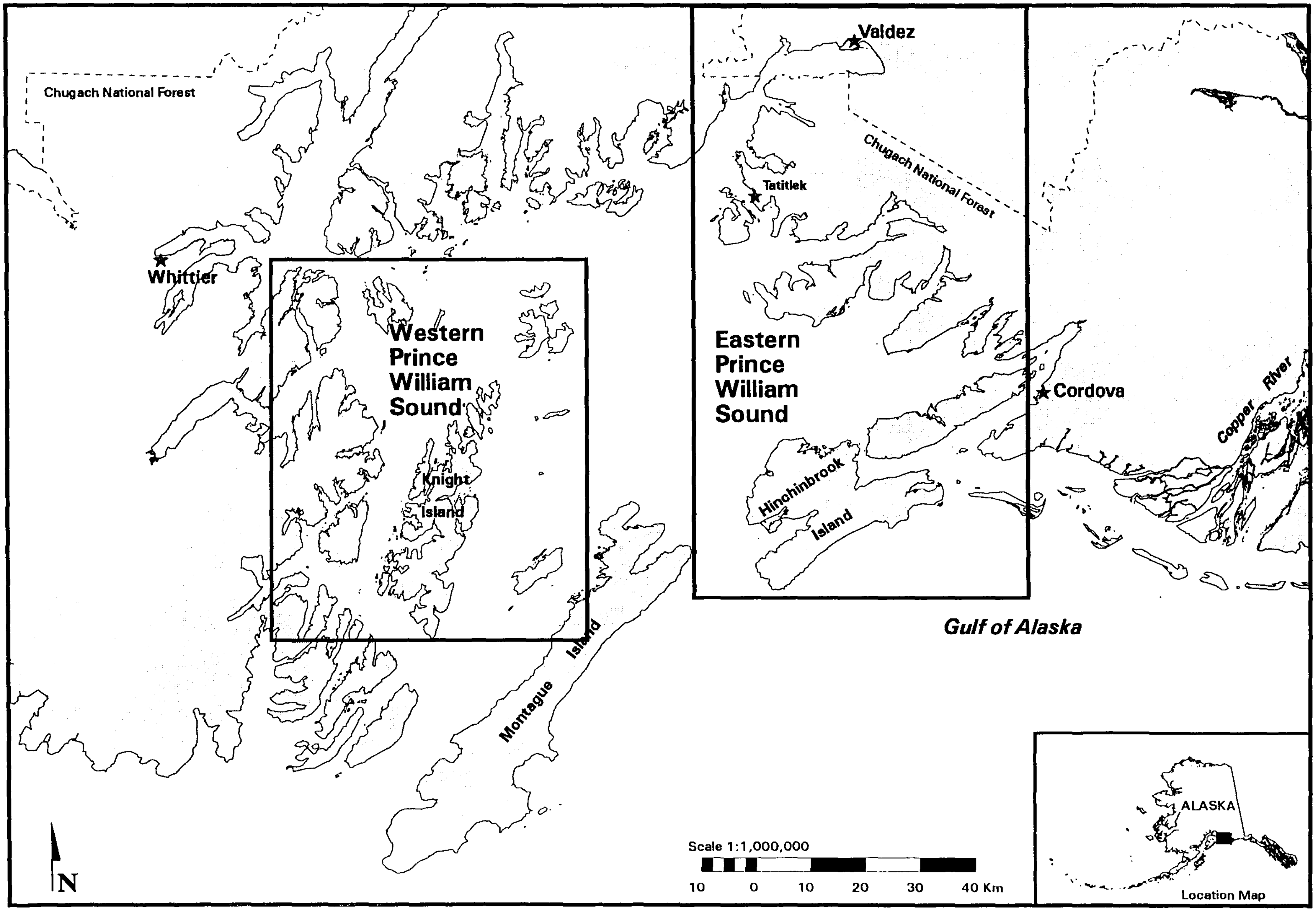


Figure 1. Map of Prince William Sound, Alaska showing the location of western and eastern study areas used to monitor harlequin ducks during surveys in 1995 and 1996.

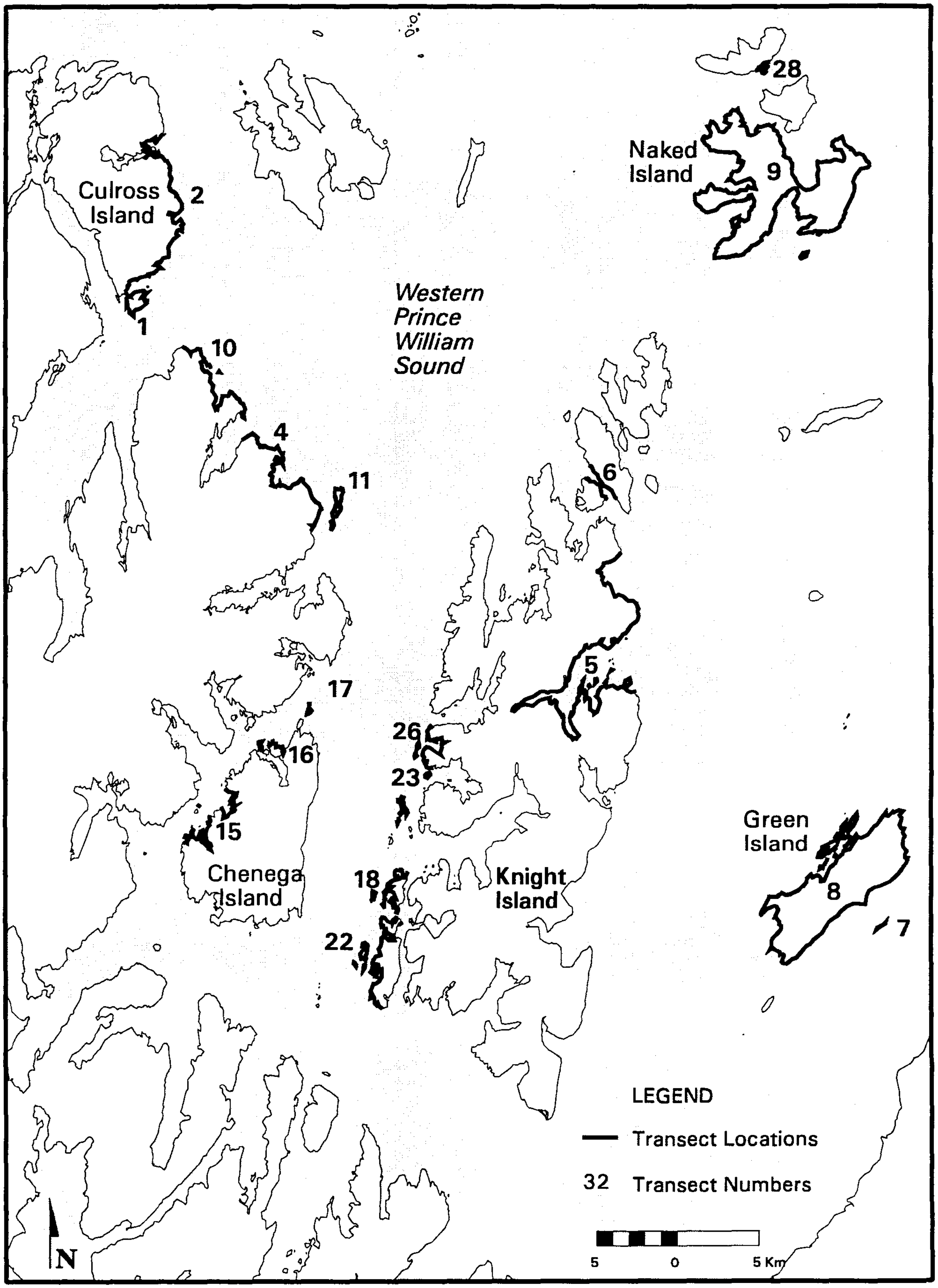


Figure 2. Map of western Prince William Sound study area showing the location of transects used during surveys of harlequin ducks in 1995 and 1996. Not all transects were surveyed in each year (see Appendix A). Numbers refer to transect numbers listed in tables.

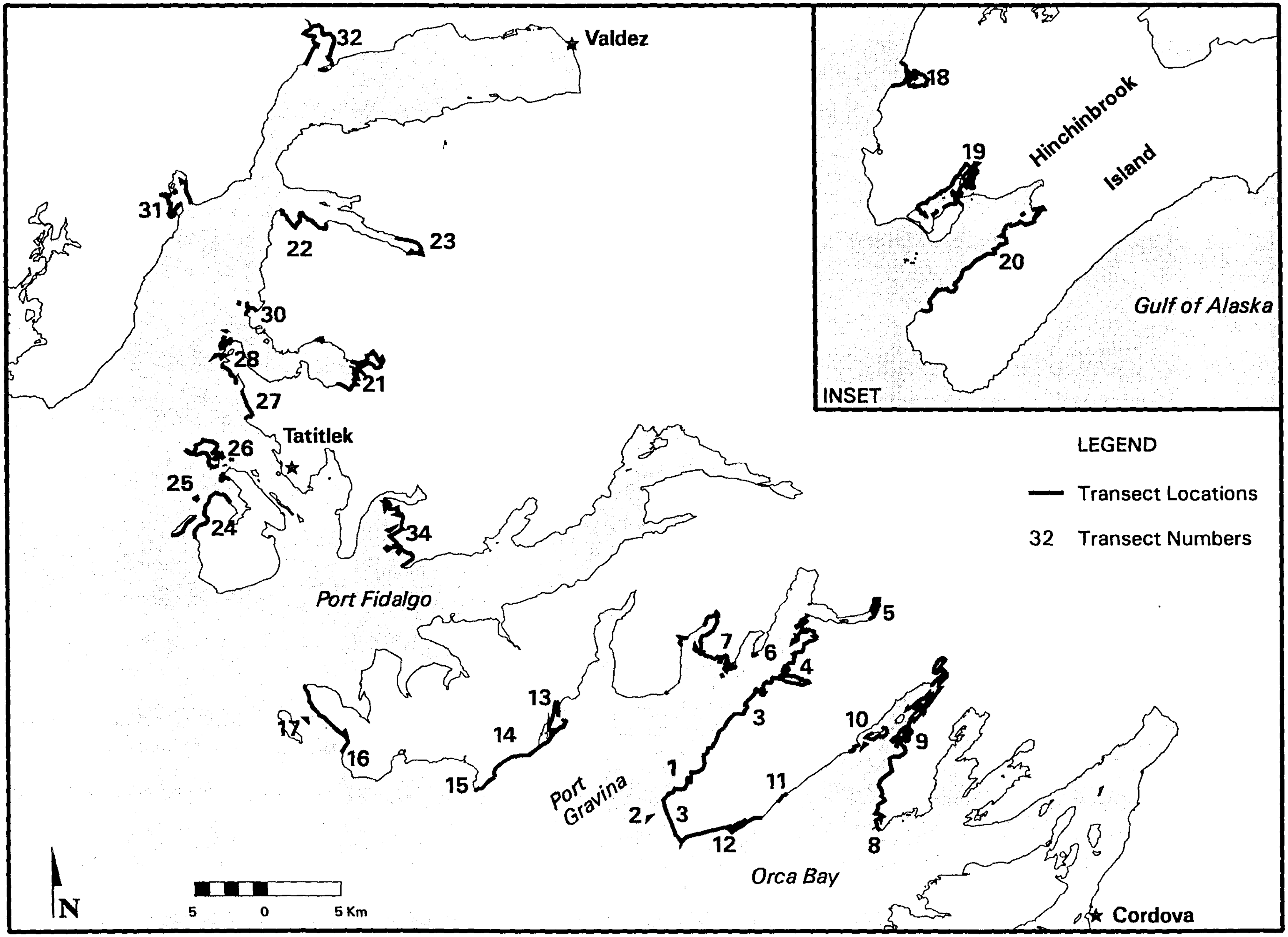


Figure 3. Map of eastern Prince William Sound study area showing the location of transects used during surveys of harlequin ducks in 1995 and 1996. Numbers refer to transect numbers listed in tables.

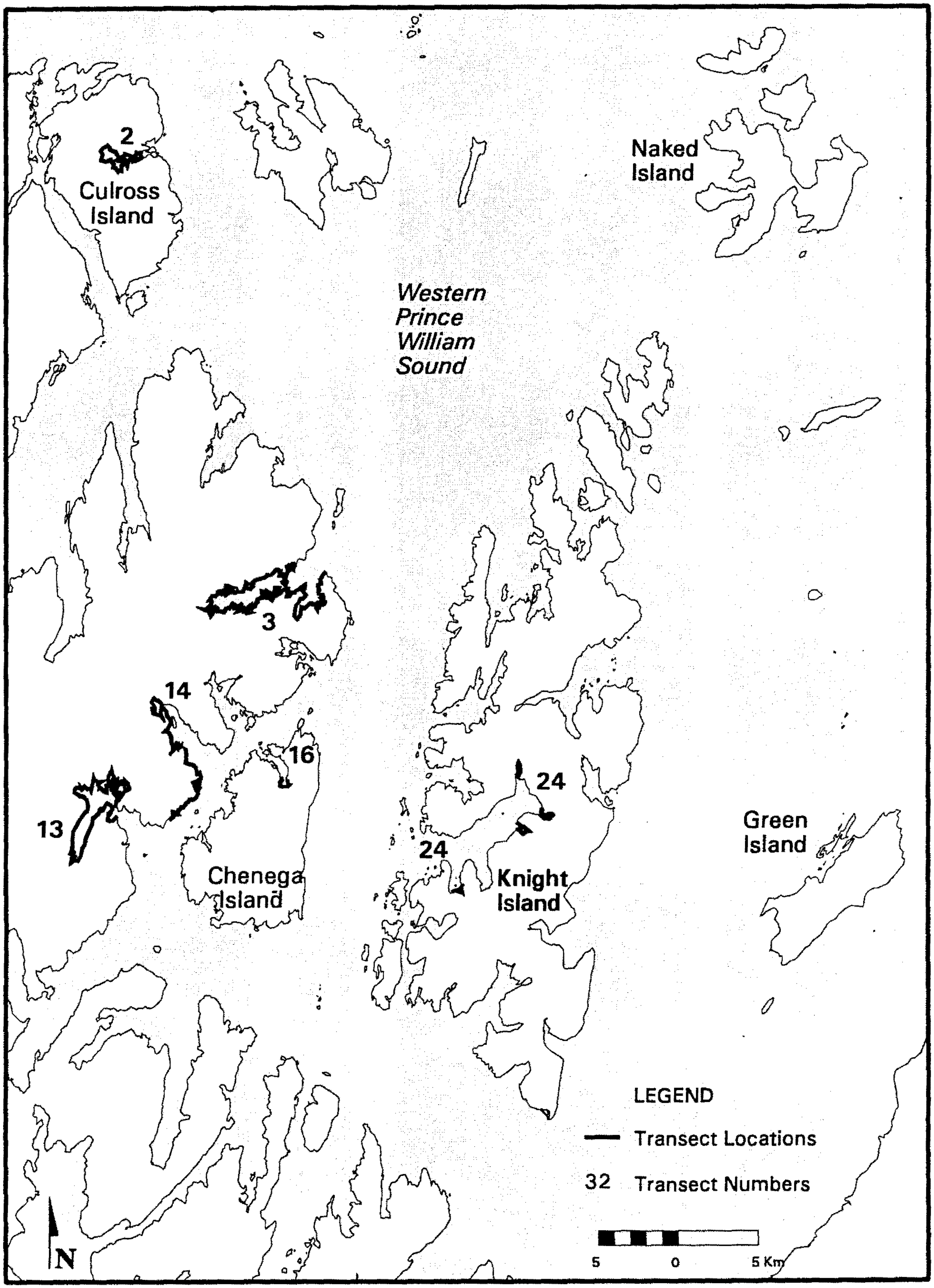


Figure 4. Map of western Prince William Sound study area showing the location of transects used during expanded fall surveys in potential brood rearing areas in 1995 and 1996. Numbers refer to transect numbers listed in tables.

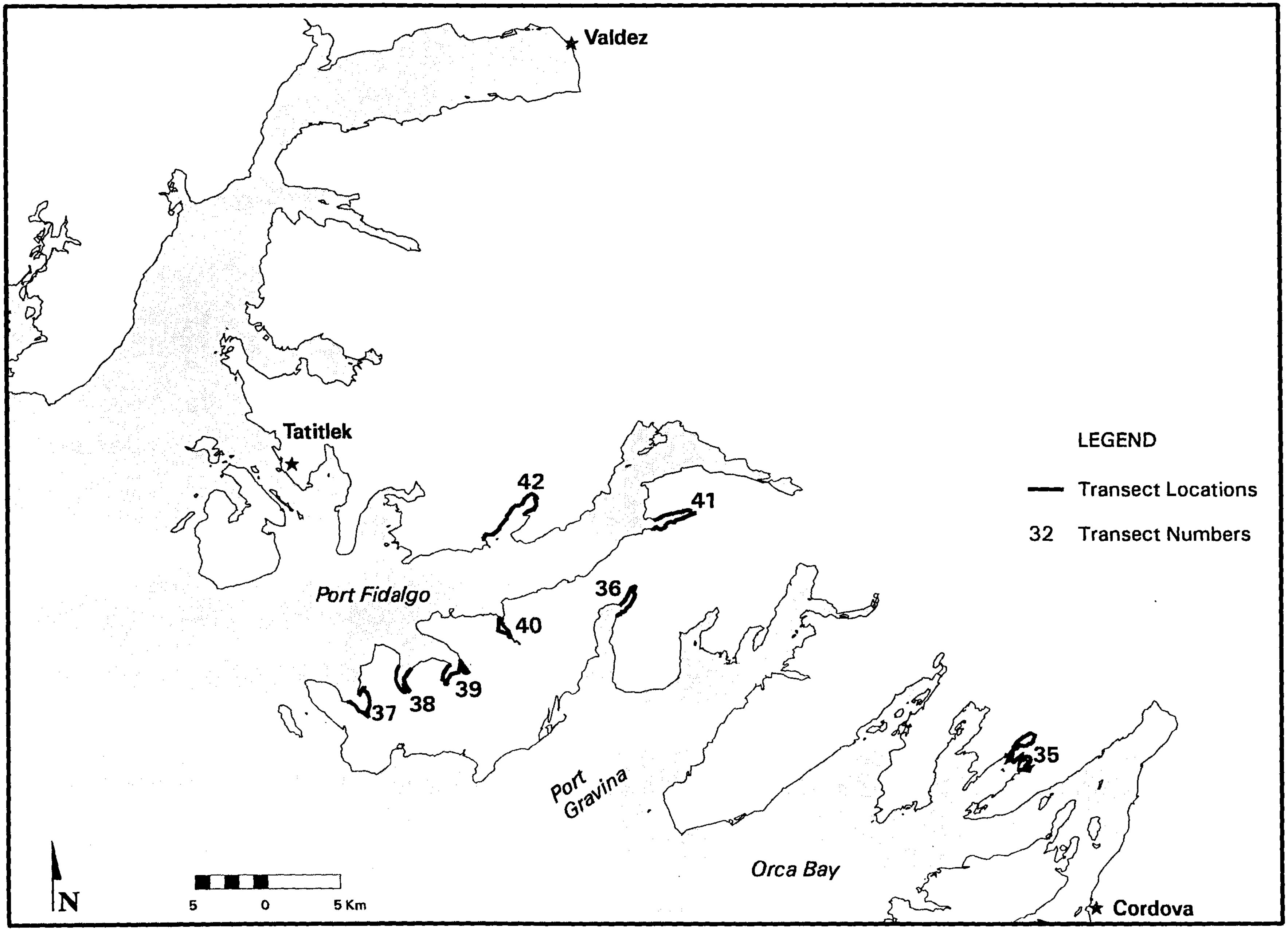


Figure 5. Map of eastern Prince William Sound study area showing the location of transects used during expanded fall surveys in potential brooding rearing areas in 1995 and 1996. Numbers refer to transect numbers listed in tables.

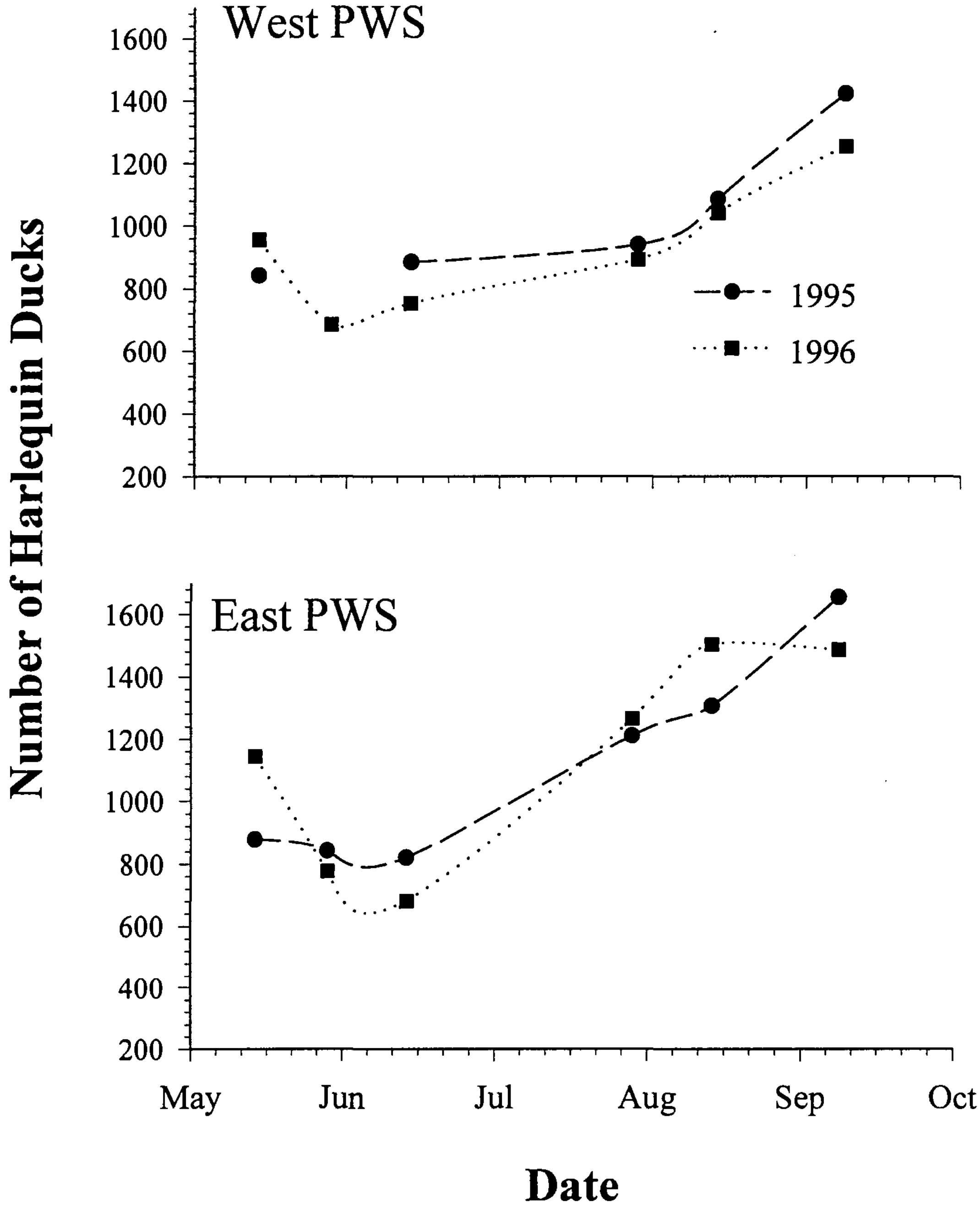


Figure 6. Seasonal variation in the number of harlequin ducks observed on nearshore transects in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995. Only ducks observed on surveys with comparable survey coverage are used.

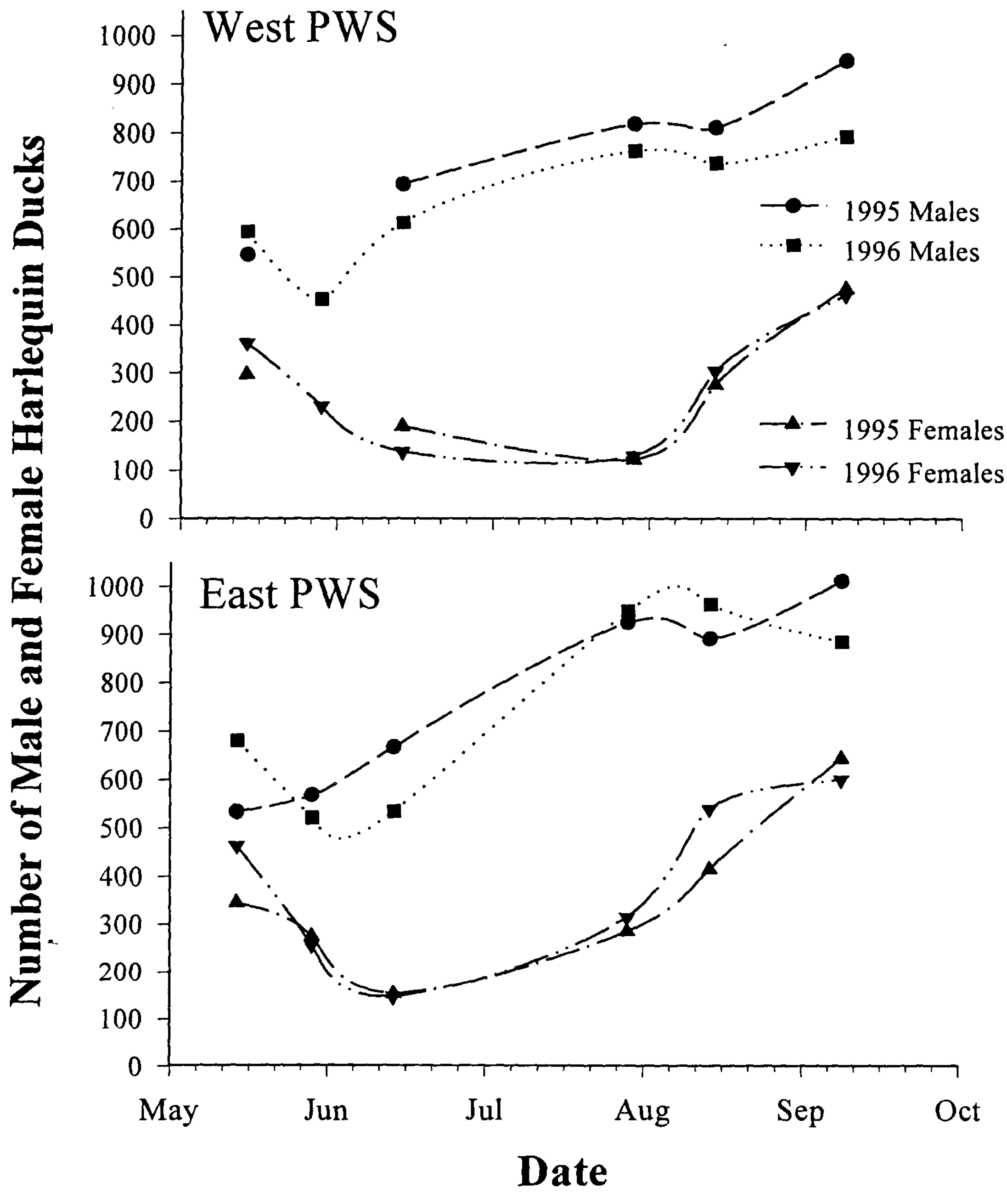


Figure 7. Number of male and female harlequin ducks observed on nearshore transects in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995. Ducks categorized as unknown were partitioned among sex classes according to observed proportions. Only ducks observed on surveys with comparable survey coverage were used.

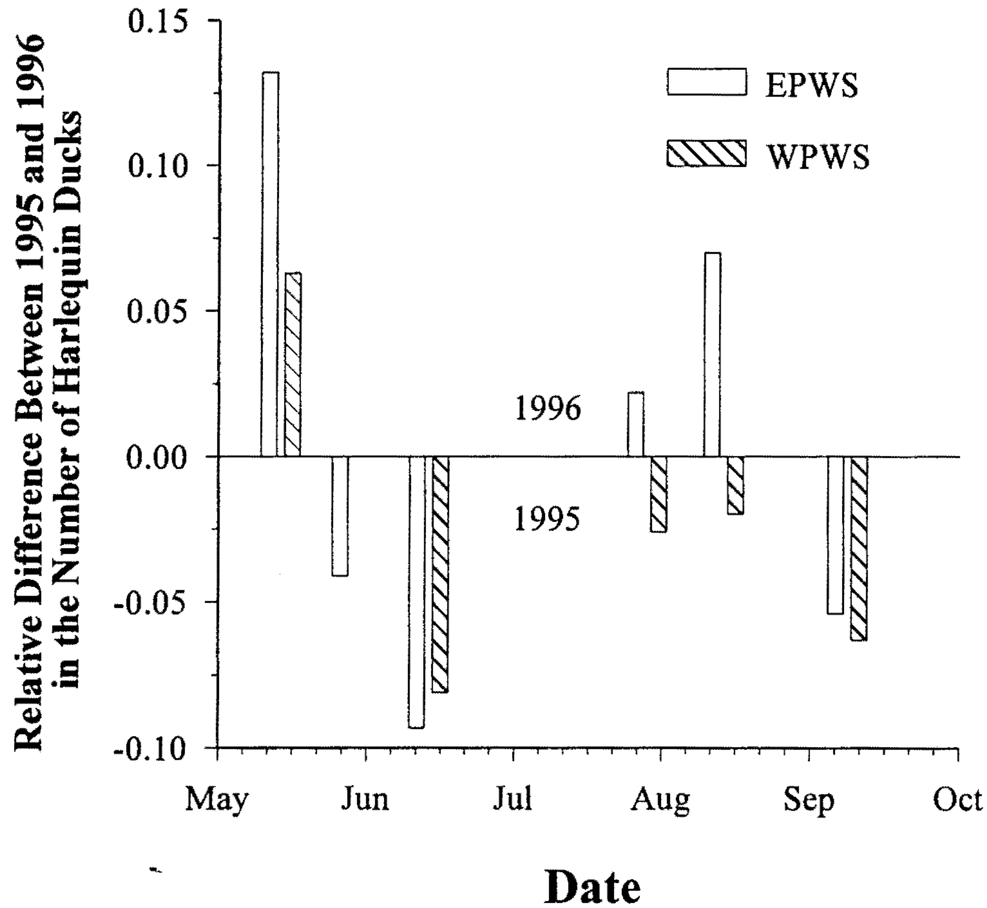


Figure 8. Relative difference between 1995 and 1996 in the number of harlequin ducks observed in western (WPWS) and eastern (EPWS) Prince William Sound Alaska. Annual differences in duck numbers were weighted by total abundance (years combined). Positive values indicate larger numbers of ducks in 1996. Negative values indicate larger numbers of ducks in 1995. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

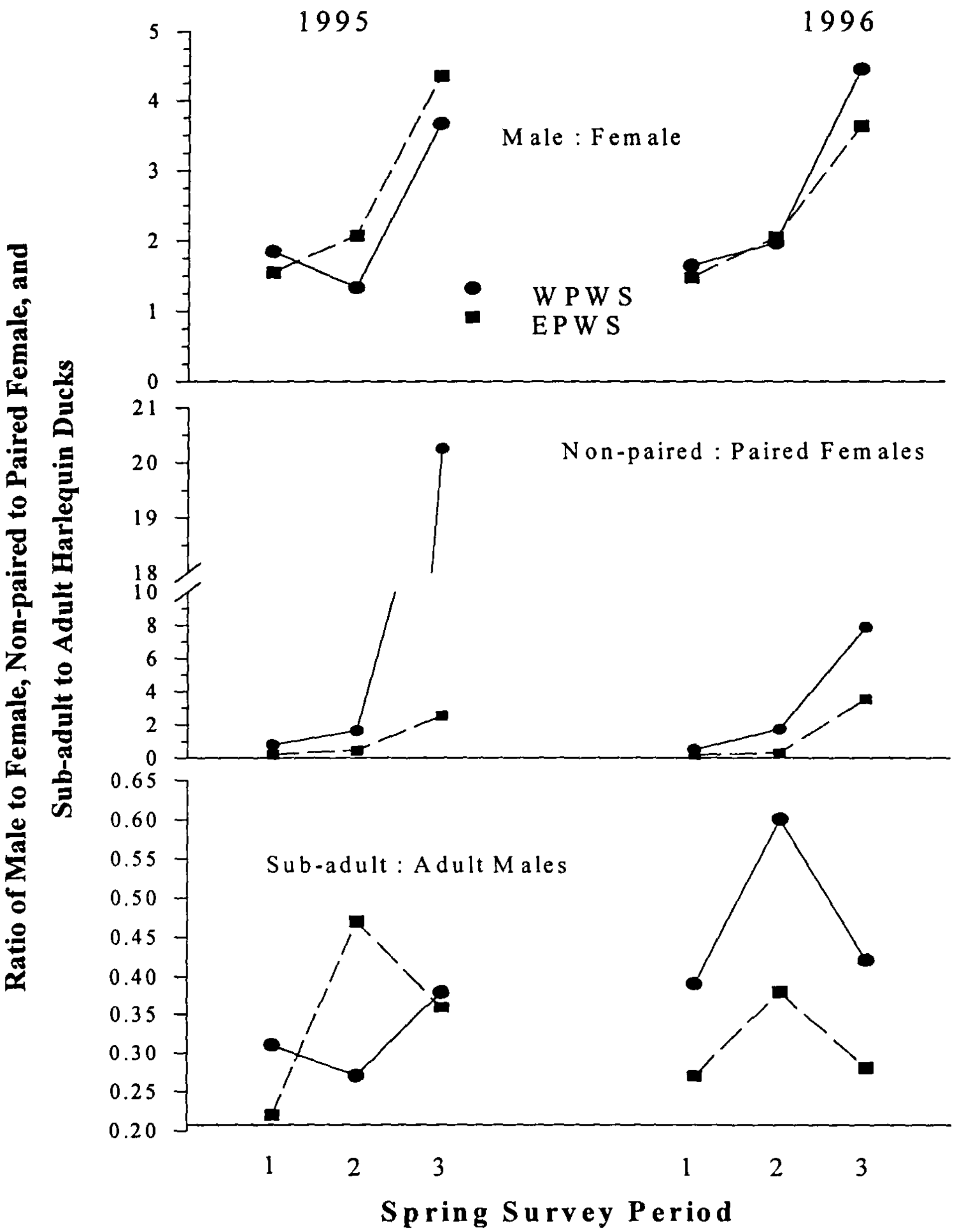


Figure 9. Ratio of male to female, non-paired to paired female, and sub-adult to adult male harlequin ducks in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

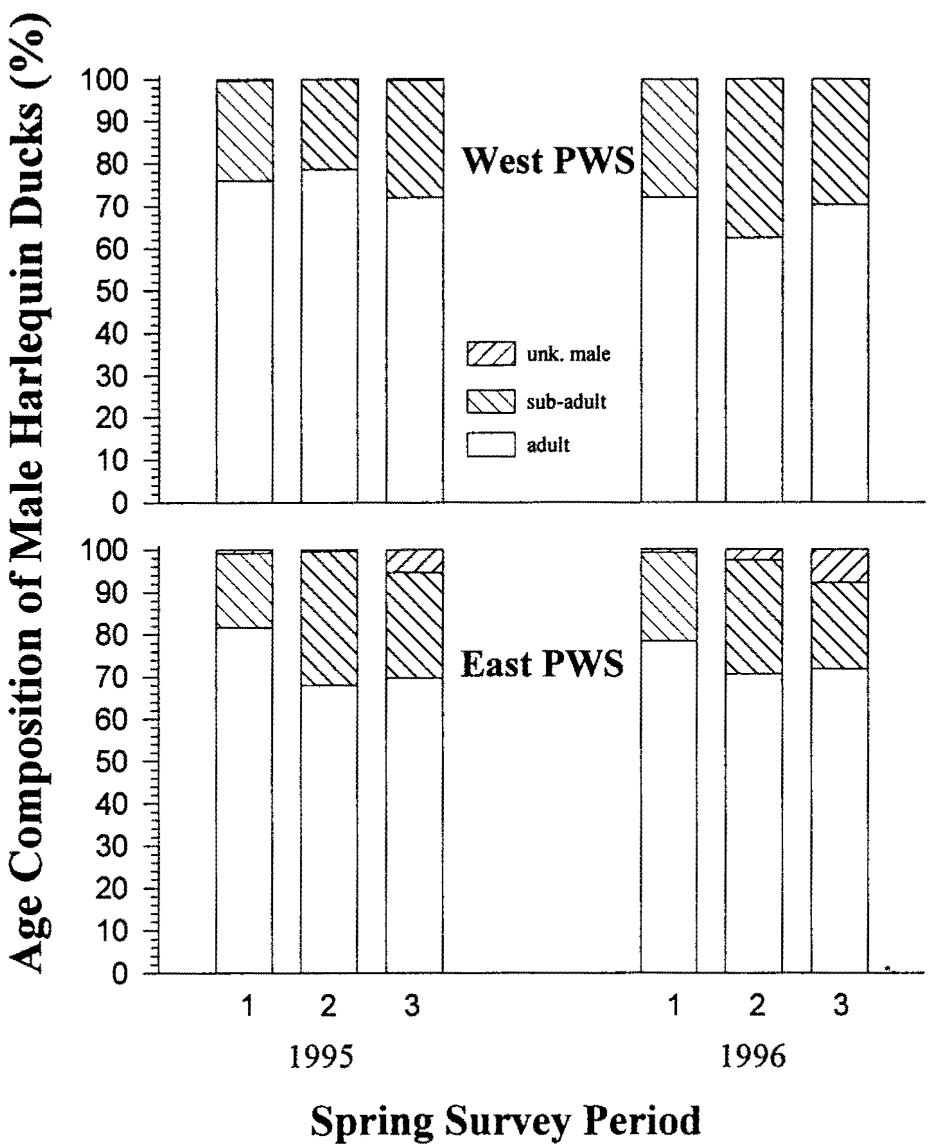


Figure 10. Age composition of male harlequin ducks during the spring in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

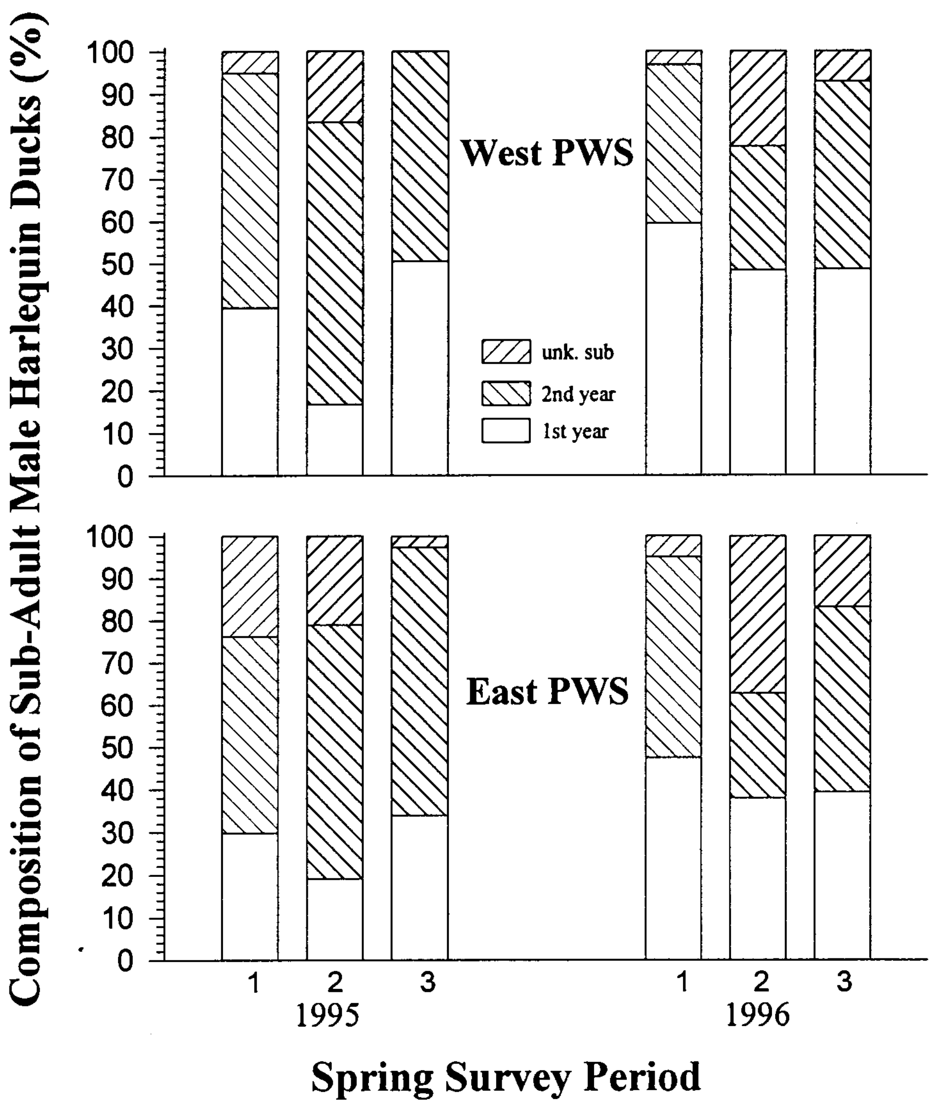


Figure 11. Age composition of sub-adult male harlequin ducks during the spring in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

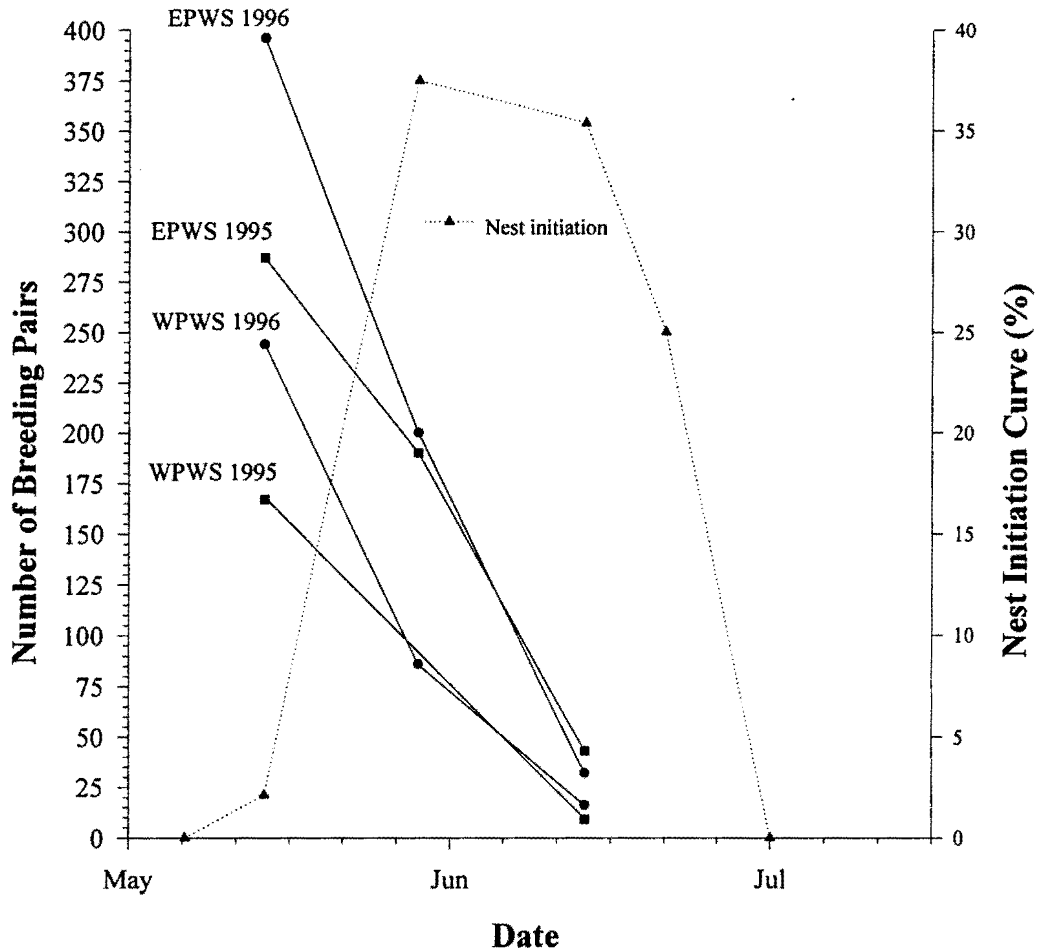


Figure 12. Relationship between the decline in the number of breeding pairs with the progression of nest initiation by harlequin ducks in western (WPWS) and eastern (EPWS) Prince William Sound in 1995 and 1996. Nest initiation curve derived by back-dating from the age of nests and broods observed in EPWS (Crowley 1996). Foul weather precluded the completion of the second spring survey in WPWS in 1995. Unknown birds were partitioned among sex and breeding categories based on observed proportions.

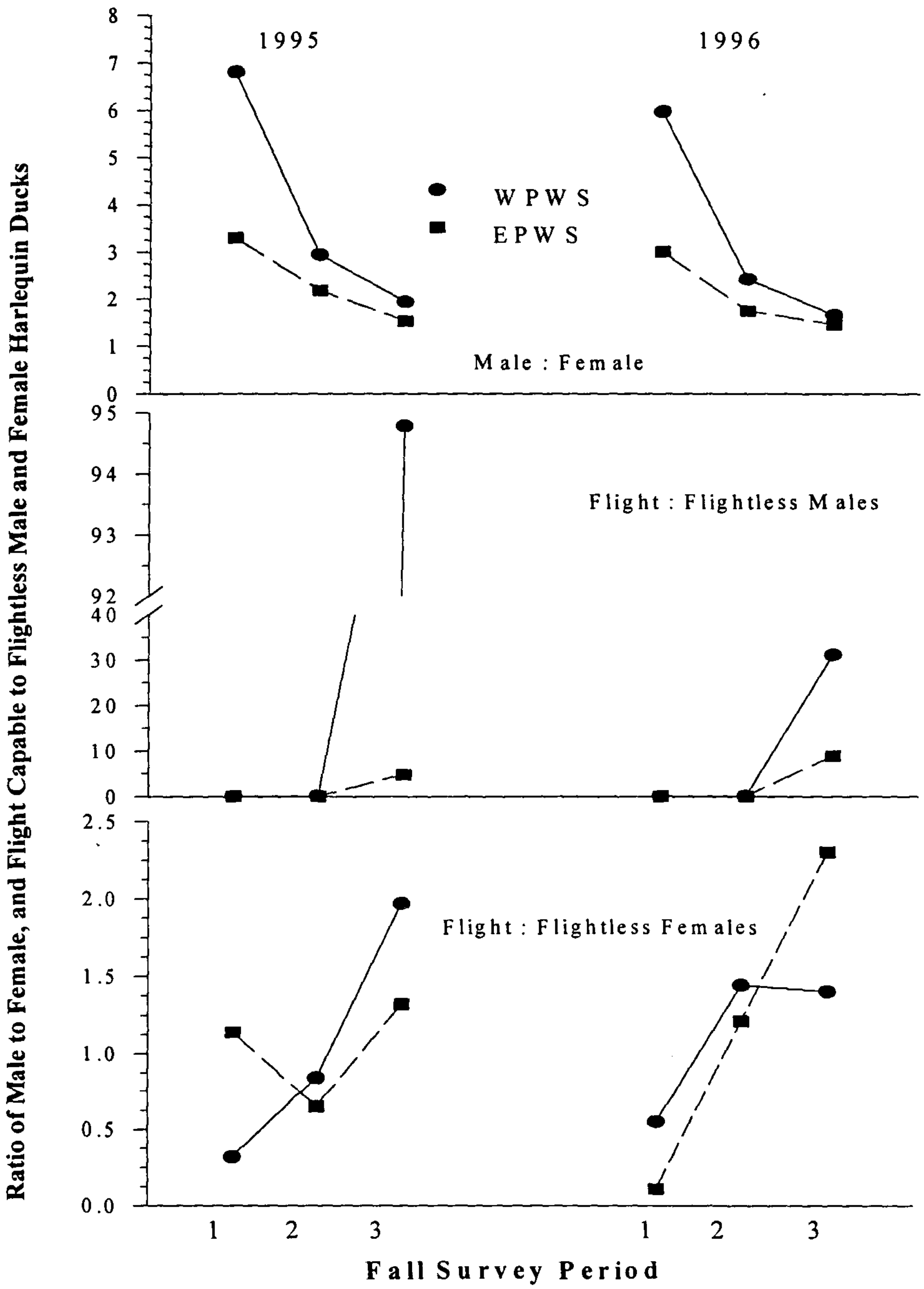


Figure 13. Ratio of male to female and flight-capable to flightless male and female harlequin ducks during the fall in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

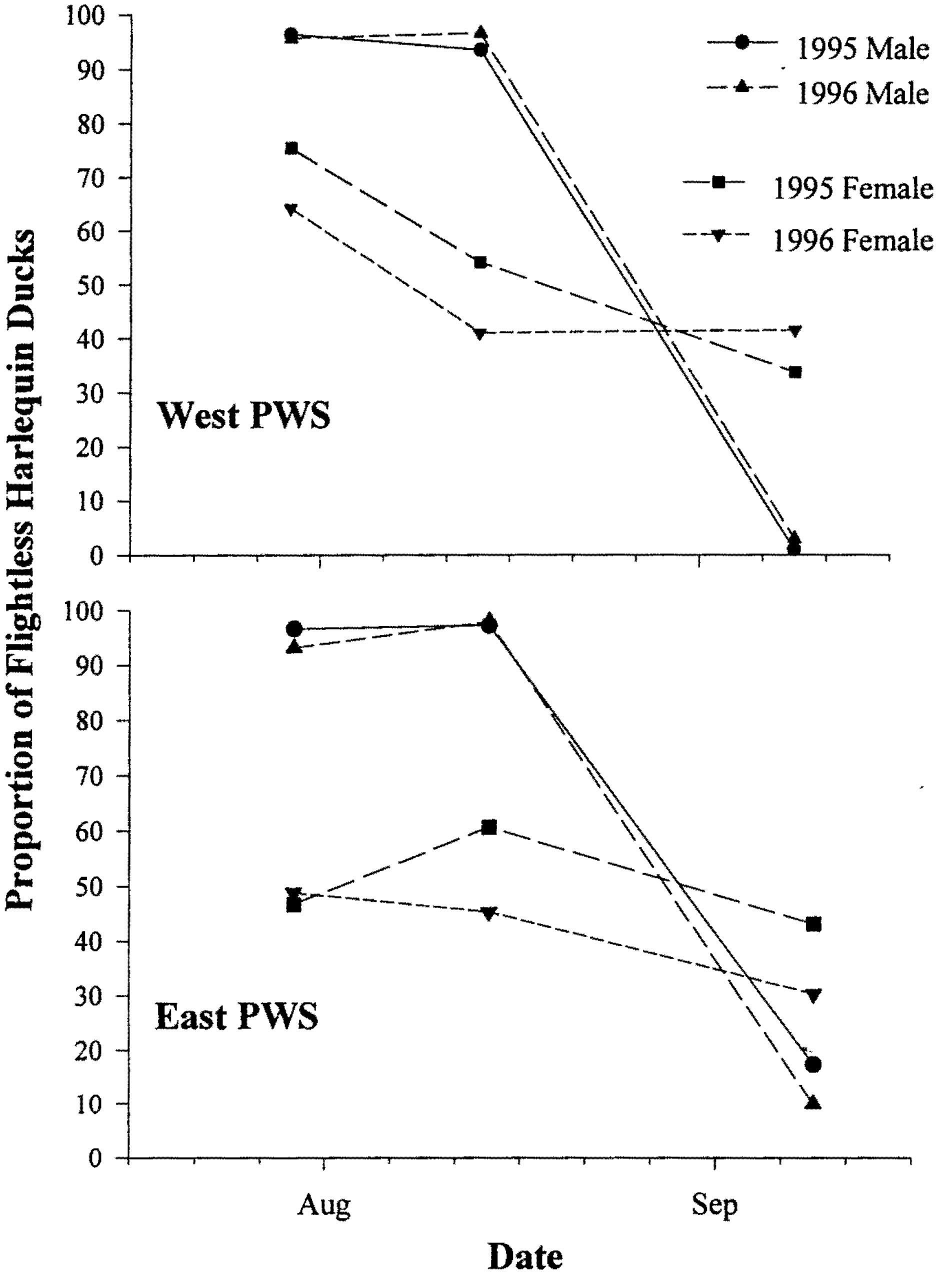


Figure 14. Proportion of flightless harlequin ducks during the fall in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

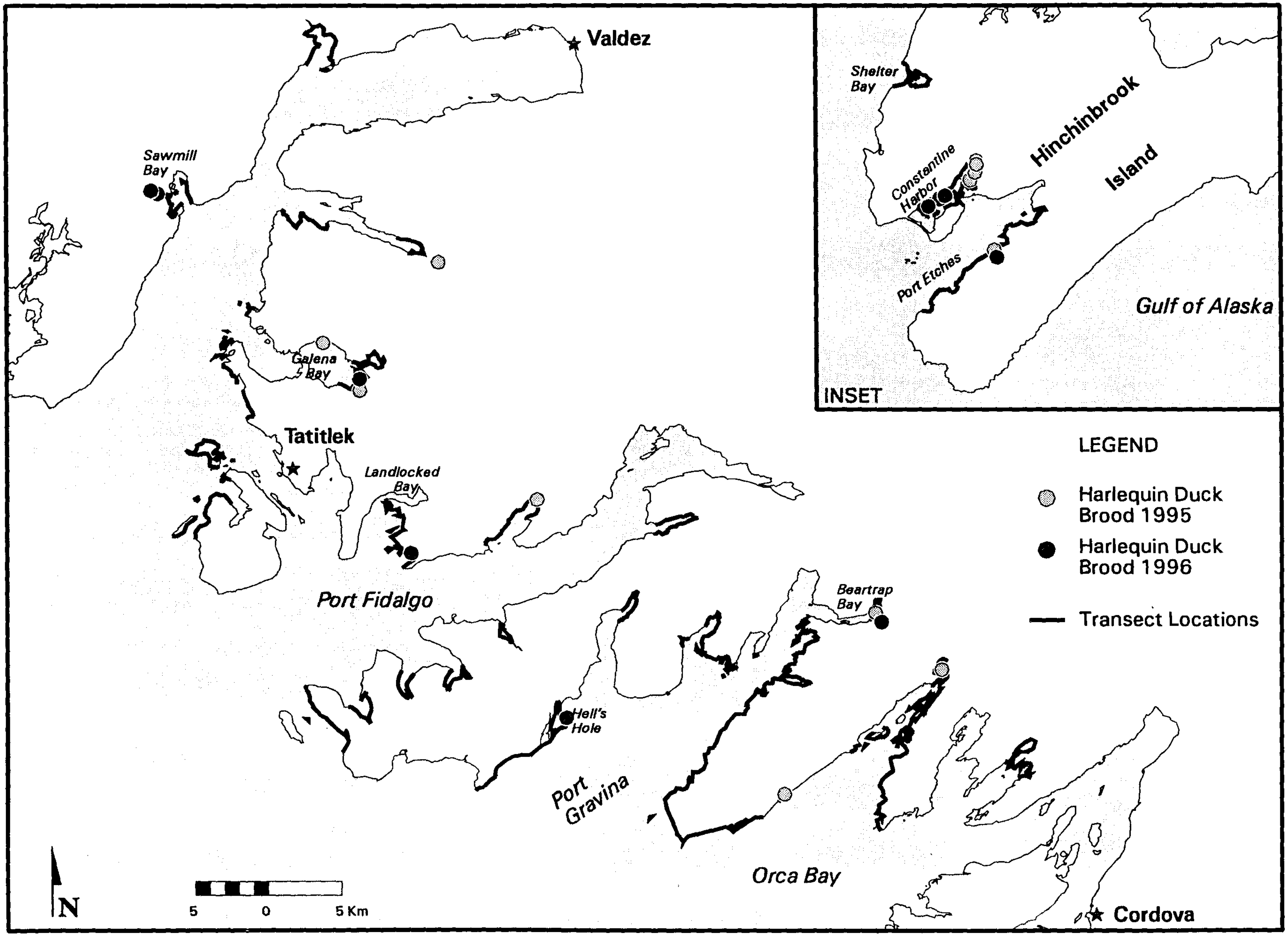


Figure 15. Location of harlequin duck broods observed in eastern Prince William Sound, Alaska in 1995 and 1996.

Difference Between Slopes	0.00	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00
Power @ alpha = .10	0.10	0.11	0.13	0.17	0.23	0.30	0.38	0.46	0.55	0.64	0.72	0.79	0.85	0.89	0.93	0.95
Power @ alpha = .05	0.05	0.06	0.07	0.10	0.14	0.19	0.26	0.33	0.42	0.51	0.60	0.68	0.76	0.82	0.87	0.91

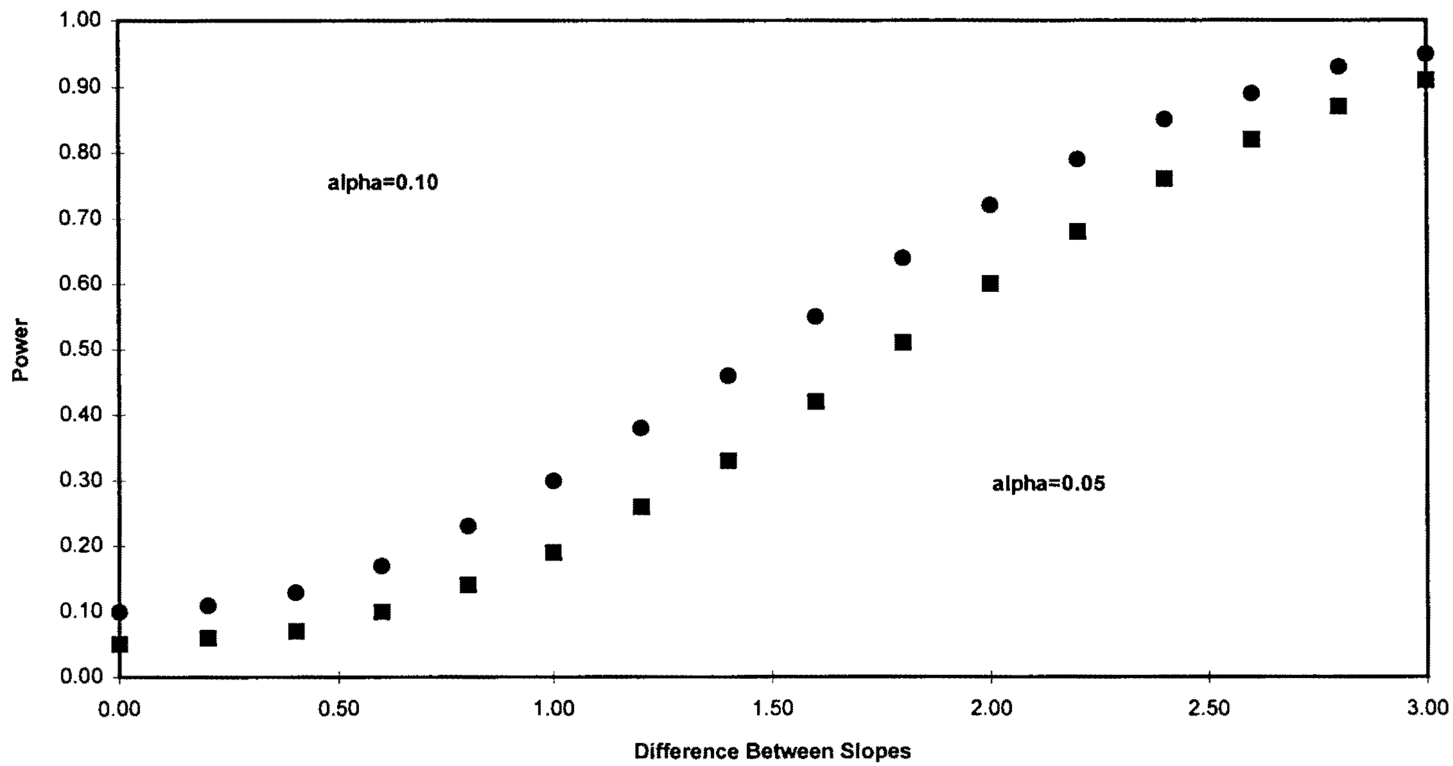


Figure 16. Power to detect differences in rates of change by harlequin populations between western and eastern Prince William Sound, Alaska.

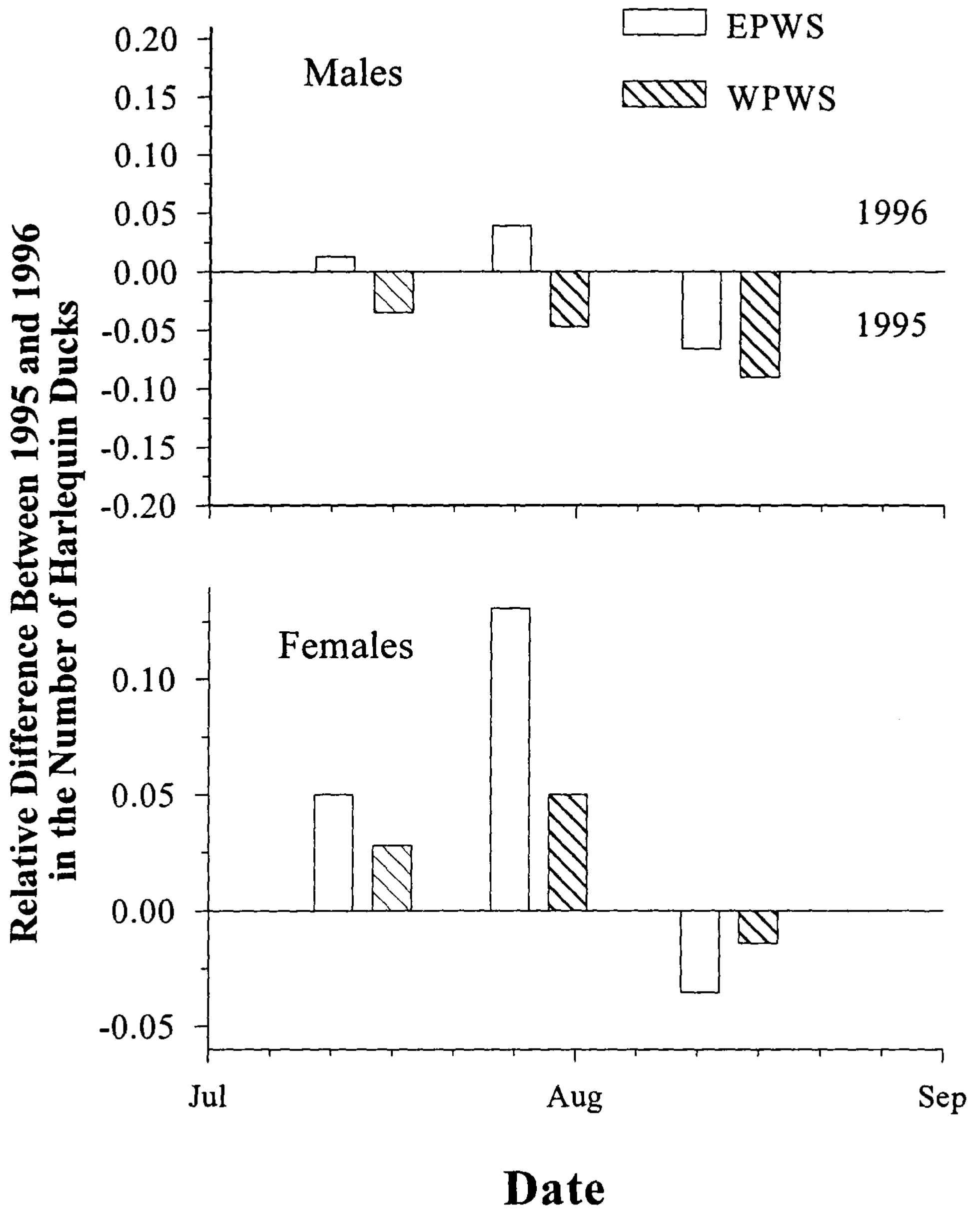


Figure 17. Relative difference between 1995 and 1996 in the number of male and female harlequin ducks during the fall in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska. Annual differences in duck numbers were weighted by total abundance (years combined). Positive values indicate larger numbers of ducks in 1996. Negative values indicate larger numbers of ducks in 1995. Ducks classified as unknown were partitioned according to observed sex ratios.

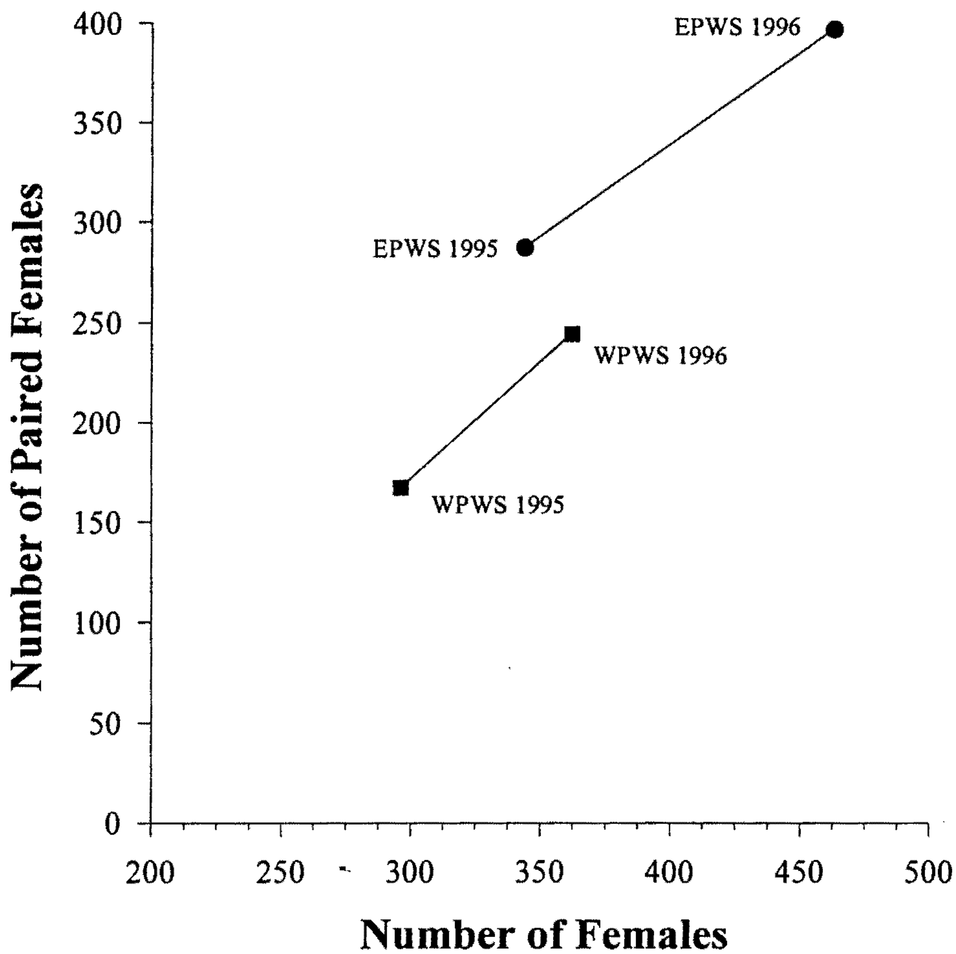


Figure 18. Relationship between the total number of females and the number of paired females counted during the first spring survey in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

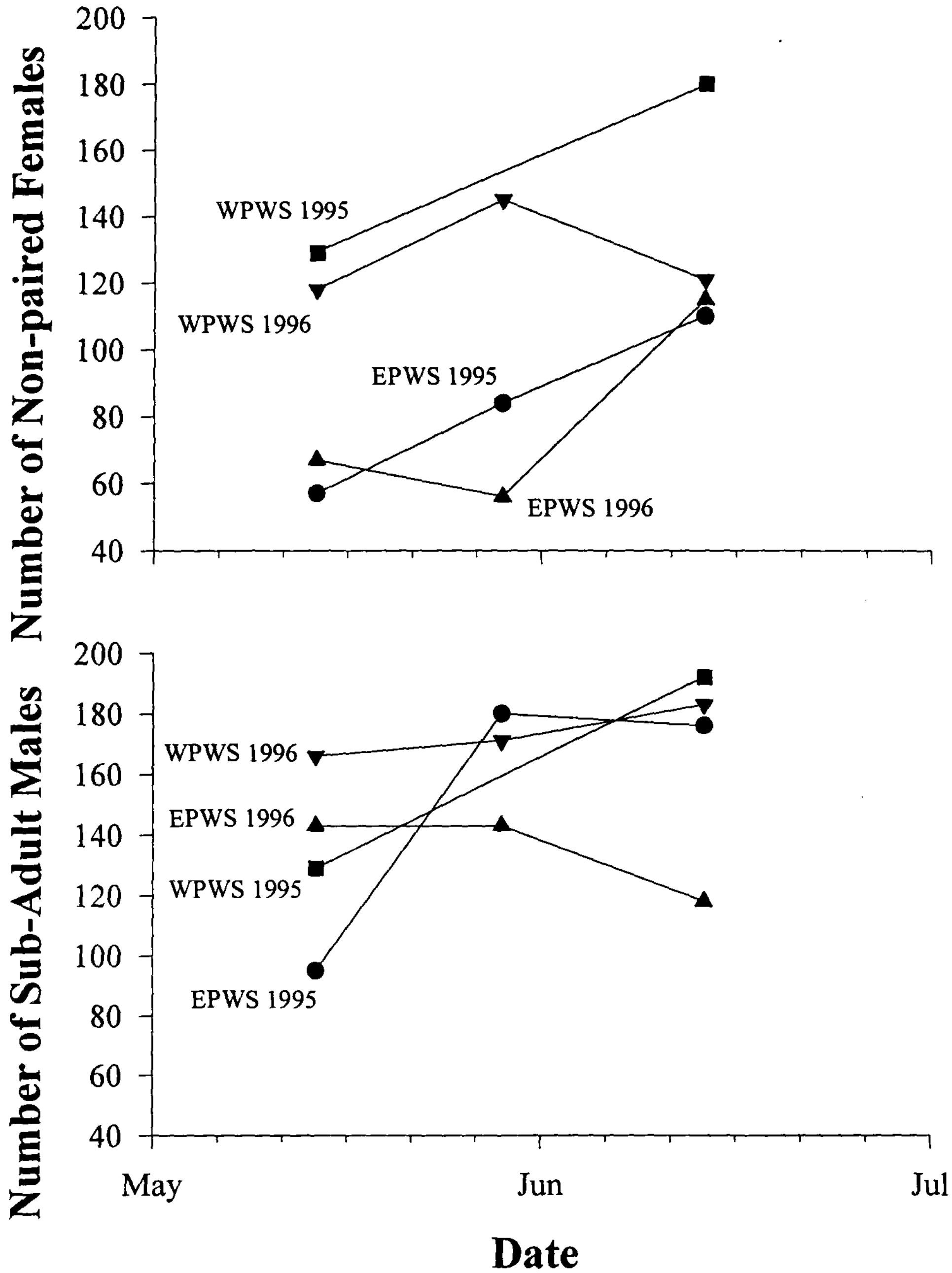


Figure 19. Number of sub-adult male and non-paired female harlequin ducks in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

Appendix A1. Kilometers of shoreline surveyed for harlequin ducks in western Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	10 May-20 May	26 May-27 May[c]	9 June-16 June	25 July-1 Aug.	10 Aug.-18 Aug.	5 Sept.-14 Sept.
Aguliak Island	26	9.02	dns[b]	*	*	*	*
Applegate Island	1	3.96	*	*	5.90	*	*
Bay of Isles	5	44.51	dns	42.82	41.87	42.82	*
Channel Island	7	1.60	dns	*	*	*	*
Clam Island#	20	dns	dns	dns	1.62	*	*
Crafton Island	11	6.82	dns	*	*	*	*
Culross Island	2	33.41	27.46	*	21.45	*	*
Eleanor Island#	27	14.19	dns	*	*	*	*
Falls Bay	4	15.07	dns	*	11.80	15.07	*
Foul Bay	10	11.68	dns	*	*	*	*
Foul Pass	6	5.46	dns	*	*	*	*
Green Island	8	51.52	dns	*	*	*	*
Herring Bay#	12	13.21	dns	15.47	25.68	29.20	30.73
Junction Island	17	2.72	dns	*	*	*	*
Lower Herring Bay#	25	3.26	dns	4.24	25.05	12.06	8.79
Masked Bay	16	6.01	dns	2.76	6.01	7.58	1.8
Mummy Island	18	10.83	10.40	*	10.08	10.40	10.83
Naked Island	9	23.10	dns	73.24	*	*	42.61
New Years Island#	19	dns	dns	dns	2.13	*	*
Squire Island	22	18.77	*	*	20.58	18.77	19.49
Squirrel Island	21	4.46	dns	*	*	*	*
Storey Island	28	2.75	dns	*	*	*	*
Totemoff Creek	15	14.41	dns	*	*	*	*
Total		296.76	60.59	338.82	370.04	364.87	327.87

[a] Transect number refers to Fig.2.

[b] did not survey

[c] Incomplete survey coverage because of poor weather.

* Indicates no change in shoreline length from previous completed survey.

\# Not included in annual and seasonal comparisons.

Appendix A2. Kilometers of shoreline surveyed for harlequin ducks in western Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	8 May- 14 May	24 May- 30 May	11 June- 18 June	23 July- 30 July	8 Aug.- 15 Aug.	5 Sept.- 13 Sept.
Aguliak Island	26	9.02	*	*	*	*	*
Applegate Island	1	5.90	*	*	*	*	*
Bay of Isles	5	41.87	*	*	*	*	*
Channel Island	7	1.60	*	*	*	*	*
Crafton Island	11	6.82	*	*	*	*	*
Culross Island	2	20.98	*	*	*	*	*
Falls Bay	4	15.07	*	*	*	*	*
Foul Bay	10	11.68	*	*	*	*	*
Foul Pass	6	5.46	*	*	*	*	*
Green Island	8	51.52	*	*	*	*	*
Junction Island	17	2.72	*	*	*	*	*
Masked Bay	16	2.62	*	*	*	*	*
Mummy Island	18	10.83	*	*	*	*	*
Naked Island	9	73.24	*	*	*	*	*
Squire Island	22	21.31	*	*	*	*	*
Squirrel Island	21	4.46	*	*	*	*	*
Storey Island	28	2.75	*	*	*	*	*
Totemoff Creek	15	13.21	*	*	*	*	*
Total		301.06	*	*	*	*	*

[a] Transect numbers refer to Fig. 2.

* Indicates no change in shoreline length from previous completed survey.

Appendix A3. Kilometers of shoreline surveyed for harlequin ducks in eastern Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	10 May-17 May	23 May-31 May	10 June-16 June	25 July-30 July	11 Aug.-17 Aug.	6 Sept.-12 Sept.
Beartrap Bay	5	4.84	*	*	*	*	*
Black Creek	27	2.63	*	*	*	*	*
Busby Island (south)	25	6.16	*	*	*	*	*
Busby Island (north)	26	6.18	*	*	*	*	*
Close Island	10	4.75	*	*	*	*	*
Constantine Harbor	19	19.71	*	*	*	*	*
Galena Bay	21	12.63	*	*	*	*	*
Galena Island	29	0.29	*	*	*	*	*
Galena Rocks	30	2.47	*	*	*	*	*
Gravina Island	2	0.61	*	*	*	*	*
Gravina Rocks	1	0.33	*	*	*	*	*
Gull Island	17	0.51	*	*	*	*	*
Hell's Hole	13	6.44	*	*	*	*	*
Jack Bay	22	5.70	*	*	*	*	*
Landlocked Bay	34	13.33	*	*	*	*	*
Olsen Bay	7	14.15	*	*	*	*	*
Parshas Point	6	0.69	*	*	*	*	*
Port Etches	20	17.03	*	*	*	*	*
Port Gravina (SE)	3	16.42	*	*	*	*	*
Port Gravina (NE)	4	20.62	*	*	*	*	*
Porcupine Bay	16	6.85	*	*	*	*	*
Redhead	14	6.99	*	*	*	*	*
Redhead Point	15	1.78	*	*	*	*	*
Reef/Red Sector	24	7.13	*	*	*	*	*
Rocky Point	28	5.79	*	*	*	*	*
Sawmill Bay	31	7.40	*	*	*	*	*
Sheep Bay (east)	9	33.68	*	*	*	*	*
Sheep Bay (SW)	12	8.77	*	*	*	*	*
Sheep Point	8	1.26	*	*	*	*	*
Shelter Bay	18	9.01	*	*	*	*	*

Appendix A3 (cont.)

Shoup Bay	32	9.47	*	*	*	*	dns[b]
Surf Creek	11	0.98	*	*	*	*	*
Vladnoff River	23	3.95	*	*	*	*	*
Total		258.55	*	*	*	*	249.08

[a] Transect number refers to Fig. 3.
[b] did not survey
* Indicates no change from previous completed survey.

Appendix A4. Kilometers of shoreline surveyed for harlequin ducks in eastern Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	9 May-14 May	23 May-27 May	11 June-16 June	24 July-30 July	9 Aug.-17 Aug.	6 Sept.-10 Sept.
Beartrap Bay	5	4.84	*	*	*	*	*
Black Creek	27	2.63	*	*	*	*	*
Busby Island (south)	25	6.16	*	*	*	*	*
Busby Island (north)	26	6.18	*	*	*	*	*
Close Island	10	4.75	*	*	*	*	*
Constantine Harbor	19	19.71	*	*	*	*	*
Galena Bay	21	12.63	*	*	*	*	*
Galena Island	29	0.29	*	*	*	*	*
Galena Rocks	30	2.47	*	*	*	*	*
Gravina Island	2	0.61	*	*	*	*	*
Gravina Rocks	1	0.33	*	*	*	*	*
Gull Island	17	0.51	*	*	*	*	*
Hell's Hole	13	6.44	*	*	*	*	*
Jack Bay	22	5.70	*	*	*	*	*
Landlocked Bay	34	13.33	*	*	*	*	*
Olsen Bay	7	14.15	*	*	*	*	*
Parshas Point	6	0.69	*	*	*	*	*
Port Etches	20	17.03	*	*	*	*	*
Port Gravina (SE)	3	16.42	*	*	*	*	*
Port Gravina (NE)	4	20.62	*	*	*	*	*
Porcupine Bay	16	6.85	*	*	*	*	*
Redhead	14	6.99	*	*	*	*	*
Redhead Point	15	1.78	*	*	*	*	*
Reef/Red Sector	24	7.13	*	*	*	*	*
Rocky Point	28	5.79	*	*	*	*	*
Sawmill Bay	31	7.40	*	*	*	*	*
Sheep Bay (east)	9	33.68	*	*	*	*	*
Sheep Bay (SW)	12	8.77	*	*	*	*	*
Sheep Point	8	1.26	*	*	*	*	*
Shelter Bay	18	9.01	*	*	*	*	*

Appendix A4 (cont.)

Shoup Bay	32	9.47	*	*	*	*	*
Surf Creek	11	0.98	*	*	*	*	*
Vladnoff River	23	3.95	*	*	*	*	*
Total		258.55	*	*	*	*	*

[a] Transect numbers refer to Fig. 3.
[b] did not survey
* Indicates no change from previous completed survey.

Appendix B. Kilometers of shoreline[a] surveyed during expanded fall survey coverage in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

		Fall 1995			Fall 1996		
Transect	No.[b]	Survey 1	Survey 2	Survey 3	Survey 1	Survey 2	Survey 3
WPWS							
Drier Bay	24	14.79	*	*	8.21	*	*
Eshamy Bay	3	45.36	42.55	*	*	*	*
Ewan Bay	14	25.00	14.37	7.04	14.09	*	*
Hidden Bay	29	11.96	*	*	*	*	*
Jackpot Bay	13	27.46	26.09	12.21	27.46	*	*
Johnson Bay	23	17.84	*	16.13	dns	dns	dns
Masked Bay	30	1.69	*	*	*	*	*
Total		144.1	129.29	106.37	105.96	105.96	105.96
EPWS							
Fish Bay	42	7.92	*	dns[c]	7.92	*	*
Irish Cove	40	3.93	*	dns	3.93	*	dns
Simpson Bay	35	12.10	*	*	*	*	*
Snug Corner Cove	37	5.43	*	dns	5.43	*	*
St. Matthew's Bay	36	4.99	*	*	*	*	*
Two Moon Bay (west)	38	5.08	*	dns	5.08	*	*
Two Moon Bay (east)	39	5.85	*	dns	5.85	*	*
Whalen Bay	41	7.36	*	dns	7.36	*	*
Total		52.66	52.66	17.09	52.66	52.66	48.73

[a] Transect lengths not included in survey coverage.
[b] Transect numbers refer to Fig. 4 and Fig. 5.
[c] did not survey
* Indicates no change in shoreline length from previous completed survey.

Appendix C. Number of harlequin ducks[a] observed on transects during expanded fall survey coverage in western (WPWS) and eastern (EPWS) Prince William Sound, Alaska in 1995 and 1996.

		Fall 1995			Fall 1996		
Transect	No.[b]	Survey 1	Survey 2	Survey 3	Survey 1	Survey 2	Survey 3
WPWS							
Drier Bay	24	0	18	52	0	12	21
Eshamy Bay	3	1	4	47	6	12	64
Ewan Bay	14	11	15	25	0	0	5
Hidden Bay	29	0	0	0	0	7	12
Jackpot Bay	13	10	3	5	5	17	55
Johnson Bay	23	19	0	0	dns	dns	dns
Masked Bay	30	0	0	0	0	12	0
Total		41	40	129	11	60	157
EPWS							
Fish Bay	42	5	1	dns[c]	4	4	30
Irish Cove	40	0	0	dns	0	0	dns
Simpson Bay	35	3	0	19	3	0	31
Snug Corner Cove	37	0	0	dns	8	0	2
St. Matthew's Bay	36	0	11	33	1	4	19
Two Moon Bay (west)	38	0	3	dns	0	0	5
Two Moon Bay (east)	39	5	8	dns	0	3	21
Whalen Bay	41	1	0	dns	12	8	0
Total		14	23	52	28	19	108

[a] Ducks not included in analysis.

[b] Transect numbers refer to Fig. 4 and Fig. 5.

[c] did not survey

Appendix D1. Number of harlequin ducks observed during boat surveys of nearshore transects in western Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	10 May- 20 May	26 May- 27 May[c]	9 June- 16 June	25 July- 1 Aug.	10 Aug.- 18 Aug.	5 Sept.- 14 Sept.
Aguliak Island	26	35	dns[b]	43	8	20	8
Applegate Island	1	67	21	40	10	24	12
Bay of Isles	5	38	dns	24	10	59	77
Channel Island	7	16	dns	59	88	86	29
Clam Island#	20	dns	dns	dns	0	6	0
Crafton Island	11	68	dns	88	33	46	122
Culross Island	2	57	9	31	48	45	137
Eleanor Island#	27	12	dns	0	0	0	0
Falls Bay	4	74	dns	12	28	52	140
Foul Bay	10	89	dns	76	61	77	164
Foul Pass	6	22	dns	41	21	27	24
Green Island	8	242	dns	329	517	484	323
Herring Bay#	12	12	dns	0	8	5	24
Junction Island	17	12	dns	8	2	3	10
Lower Herring Bay#	25	1	dns	0	4	27	16
Masked Bay	16	5	dns	0	0	16	11
Mummy Island	18	26	13	21	11	10	8
Naked Island	9	2	dns	16	0	16	124
New Years Island#	19	dns	dns	dns	0	2	0
Squire Island	22	32	6	0	15	41	6
Squirrel Island	21	7	dns	0	21	11	85
Storey Island	28	4	dns	11	0	30	3
Totemoff Creek	15	46	dns	85	65	33	91
Total		867	49	884	950	120	1414

[a] Transect number refers to Fig. 2.
[b] did not survey
[c] Incomplete survey coverage because of foul weather.
Not included in annual and seasonal comparisons.

Appendix D2. Number of harlequin ducks observed during boat surveys of nearshore transects in western Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	8 May-14 May	24 May-30 May	11 June-18 June	23 July-30 July	8 Aug.-15 Aug.	5 Sept.-13 Sept.
Aguliak Island	26	20	51	15	29	16	11
Applegate Island	1	45	19	3	17	28	35
Bay of Isles	5	74	121	201	62	60	92
Channel Island	7	36	21	158	101	103	27
Crafton Island	11	96	50	36	75	57	2
Culross Island	2	48	18	3	49	66	110
Falls Bay	4	66	3	21	22	52	216
Foul Bay	10	140	71	30	79	139	103
Foul Pass	6	0	9	0	23	23	14
Green Island	8	253	160	85	234	253	368
Junction Island	17	25	35	40	24	22	2
Masked Bay	16	0	0	0	21	11	2
Mummy Island	18	17	1	6	23	33	5
Naked Island	9	85(21)	53	14	23	42	125(104)
Squire Island	22	39	15	26	30	39	15
Squirrel Island	21	35	11	25	7	12	68
Storey Island	28	0	2	22	38	25	11
Totemoff Creek	15	33	45	60	34	48	26
Total		1012	685	745	891	1029	1232

[a] Transect numbers refer to Fig. 2.
[b] did not survey
Numbers in parentheses indicate numbers of ducks used in annual comparisons because of annual variation in survey coverage (see Appendix A). Transects with annual variation in survey coverage but no change in harlequin numbers indicates that 0 ducks were observed in the increased survey area.

Appendix D3. Numbers of harlequin ducks observed during boat surveys of nearshore transects in eastern Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	10 May-17 May	23 May-31 May	10 June-16 June	25 July-30 July	11 Aug.-17 Aug.	6 Sept.-12 Sept.
Beartrap Bay	5	10	11	6	4	6	7
Black Creek	27	0	0	0	0	0	63
Busby Island (south)	25	25	21	9	35	24	35
Busby Island (north)	26	24	11	0	36	41	37
Close Island	10	8	22	15	34	42	73
Constantine Harbor	19	33	37	41	5	11	38
Galena Bay	21	36	20	12	4	11	7
Galena Island	29	6	0	0	9	21	0
Galena Rocks	30	20	10	12	50	20	40
Gravina Island	2	7	6	0	45	75	0
Gravina Rocks	1	2	5	75	2	0	0
Gull Island	17	14	20	81	63	31	21
Hell's Hole	13	130	168	66	99	125	55
Jack Bay	22	31	16	21	7	10	25
Landlocked Bay	34	27	25	7	45	71	88
Olsen Bay	7	14	41	93	100	113	180
Parshas Point	6	2	0	1	0	0	15
Port Etches	20	13	58	28	96	75	156
Port Gravina (SE)	3	69	57	163	110	104	210
Port Gravina (NE)	4	43	13	3	26	57	82
Porcupine Bay	16	24	33	24	29	64	79
Redhead	14	29	50	0	61	6	4
Redhead Point	15	7	2	0	6	19	12
Reef/Red Sector	24	11	11	1	20	77	74
Rocky Point	28	43	11	0	24	23	42
Sawmill Bay	31	16	28	18	10	8	8
Sheep Bay (east)	9	44	26	102	108	113	149
Sheep Bay (SW)	12	38	19	0	39	39	68
Sheep Point	8	52	22	0	42	46	31
Shelter Bay	18	44	29	38	80	48	11
Shoup Bay	32	32	60	0	0	0	dns[b]

Appendix D3. (cont.)

Surf Creek	11	17	3	0	17	25	44
Vladnoff River	23	7	8	4	4	0	0
Total		878	843	820	1210	1305	1654

[a] Transect numbers refer to Fig. 3.
[b] did not survey

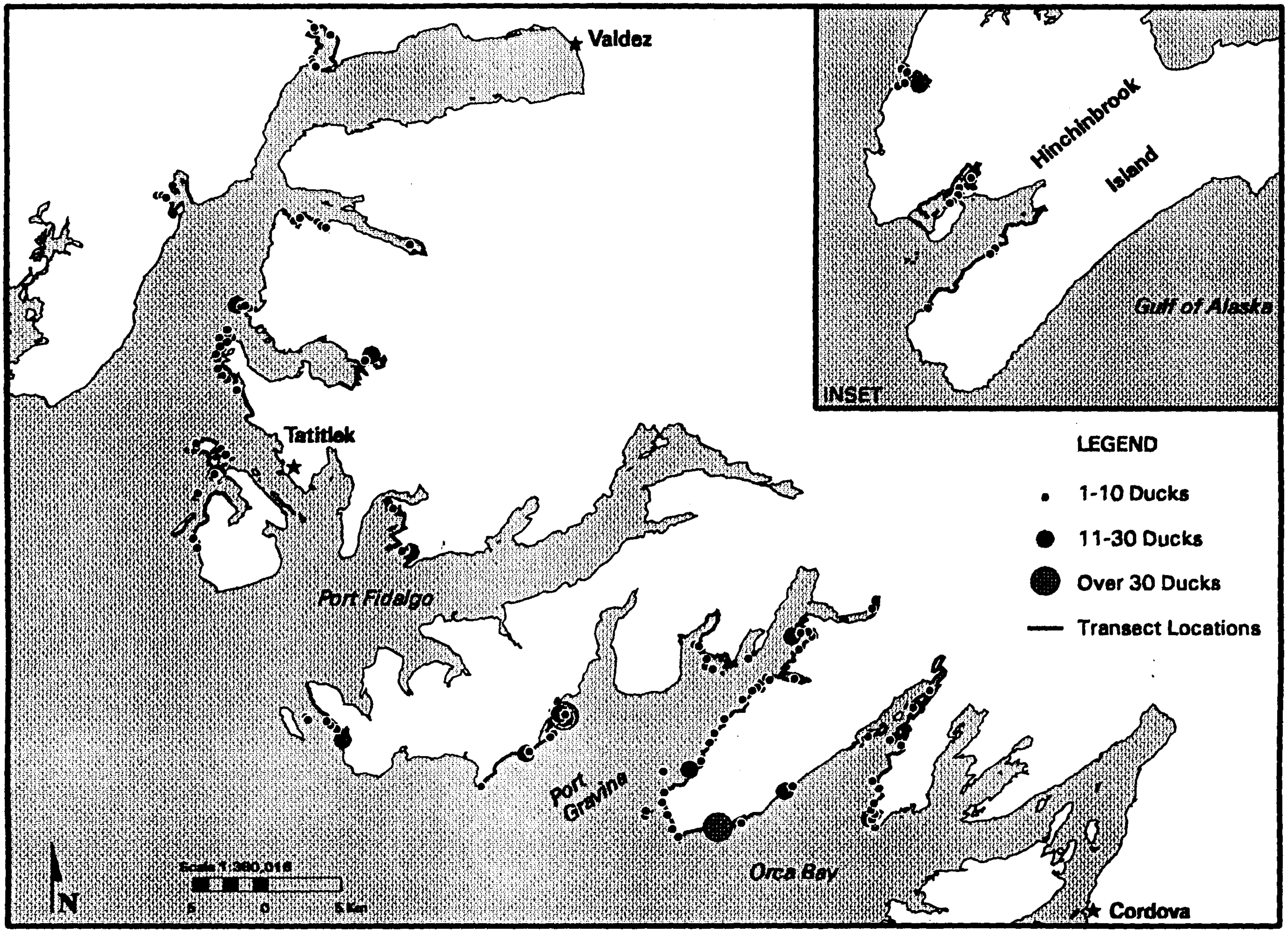
Appendix D4. Numbers of harlequin ducks observed during boat surveys of nearshore transects in eastern Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.[a]	9 May-14 May	23 May-27 May	11 June-16 June	24 July-30 July	9 Aug.-17 Aug.	6 Sept.-10 Sept.
Beartrap Bay	5	7	5	6	0	24	0
Black Creek	27	0	0	0	0	0	15
Busby Island (south)	25	21	10	21	18	23	48
Busby Island (north)	26	51	10	0	40	46	68
Close Island	10	17	17	11	29	53	67
Constantine Harbor	19	35	60	52	22	7	47
Galena Bay	21	35	41	4	7	4	17
Galena Island	29	3	0	0	13	4	4
Galena Rocks	30	38	6	20	39	51	23
Gravina Island	2	28	0	16	22	32	32
Gravina Rocks	1	16	2	10	10	6	4
Gull Island	17	45	17	11	46	62	3
Hell's Hole	13	81	94	89	41	72	22
Jack Bay	22	26	19	9	5	15	17
Landlocked Bay	34	24	4	3	60	68	60
Olsen Bay	7	63	70	73	152	143	182
Parshas Point	6	0	5	12	3	0	0
Port Etches	20	51	24	51	62	83	114
Port Gravina (SE)	3	48	50	36	111	148	138
Port Gravina (NE)	4	30	29	37	46	58	48
Porcupine Bay	16	21	72	52	70	67	56
Redhead	14	66	32	0	53	16	33
Redhead Point	15	21	5	0	25	44	25
Reef/Red Sector	24	36	18	1	67	101	61
Rocky Point	28	37	2	1	42	66	35
Sawmill Bay	31	37	21	27	25	5	16
Sheep Bay (east)	9	44	38	50	92	114	205
Sheep Bay (SW)	12	120	7	0	44	56	63
Sheep Point	8	47	38	70	36	62	37
Shelter Bay	18	30	38	16	52	52	6
Shoup Bay	32	47	26	2	2	4	0

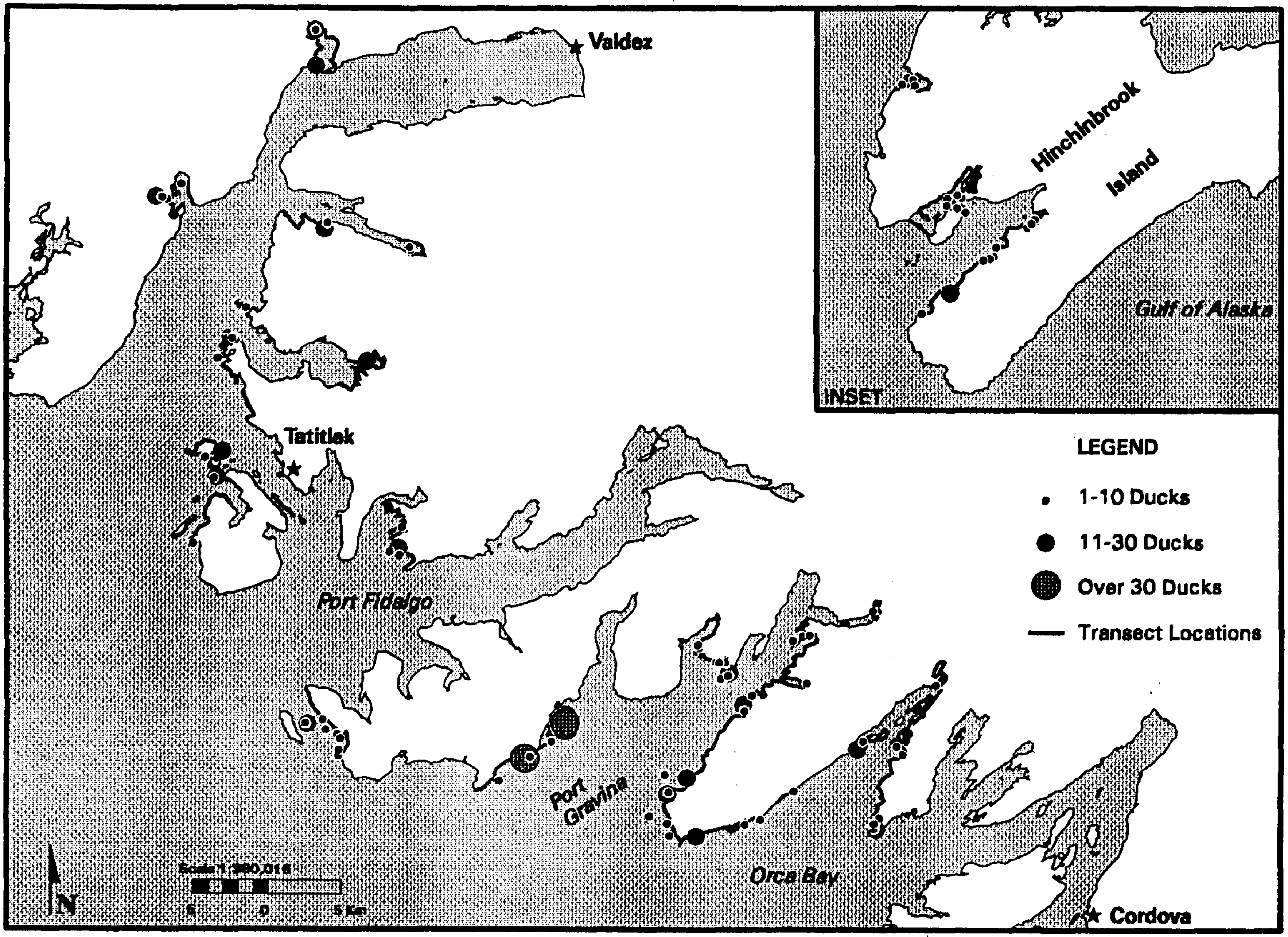
Appendix D4. (cont.)

Surf Creek	11	14	11	1	25	15	22
Vladnoff River	23	5	6	0	5	1	17
Total		1144	777	681	1264	1502	1485

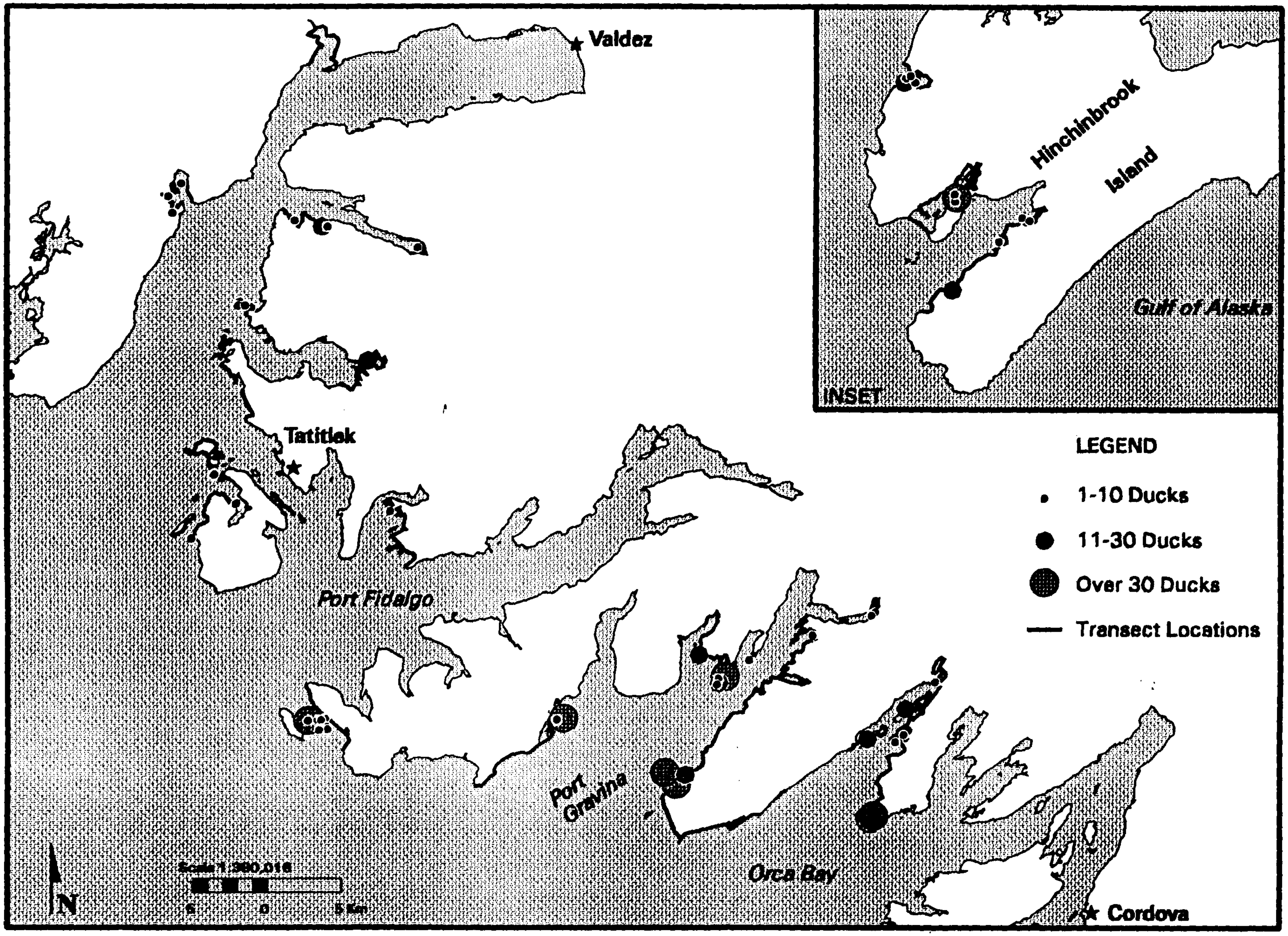
[a] Transect numbers refer to Fig. 3.



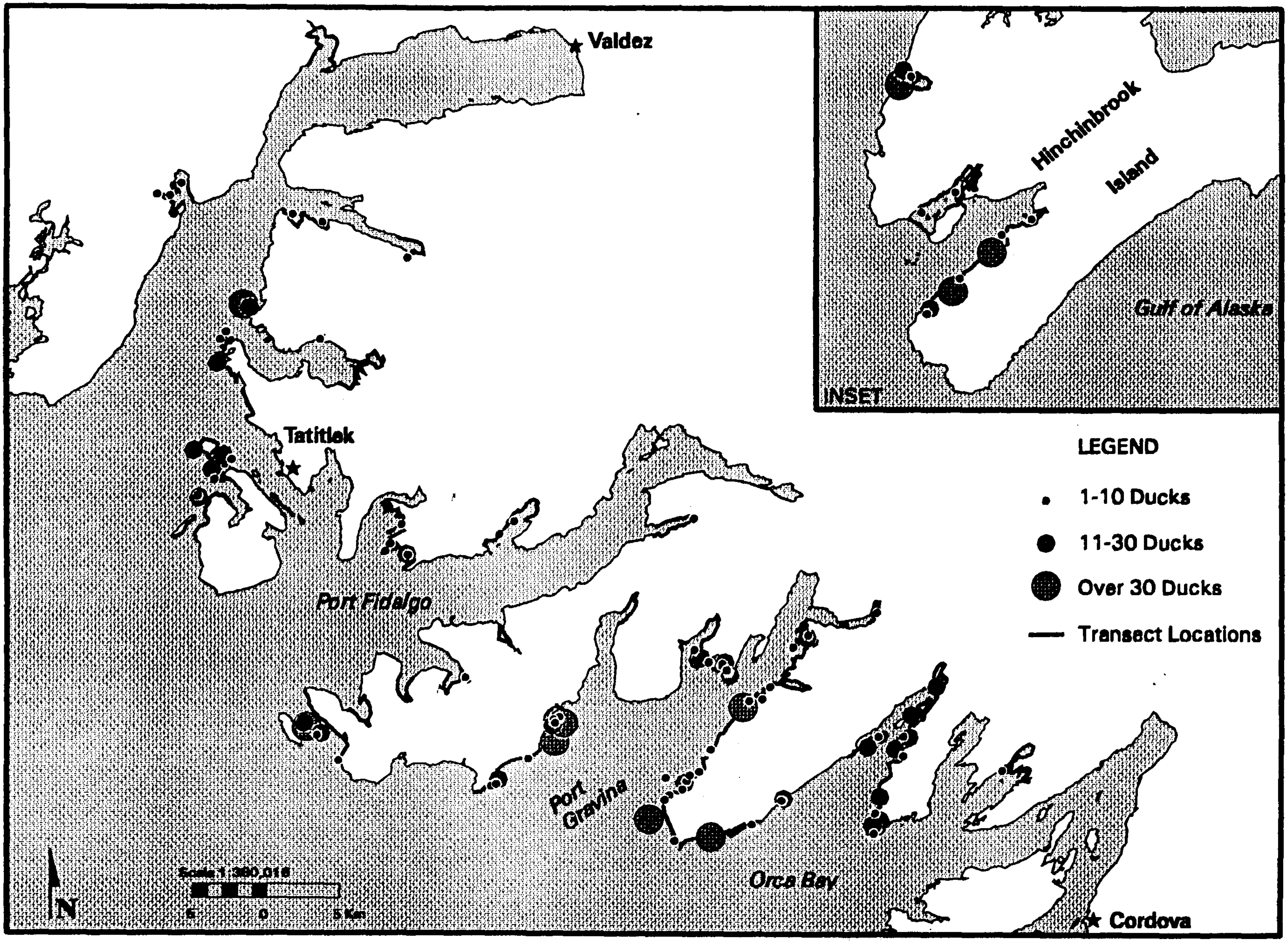
Appendix E1: Location of harlequin ducks observed in eastern Prince William Sound during the first spring survey (10 May-17 May) in 1995.



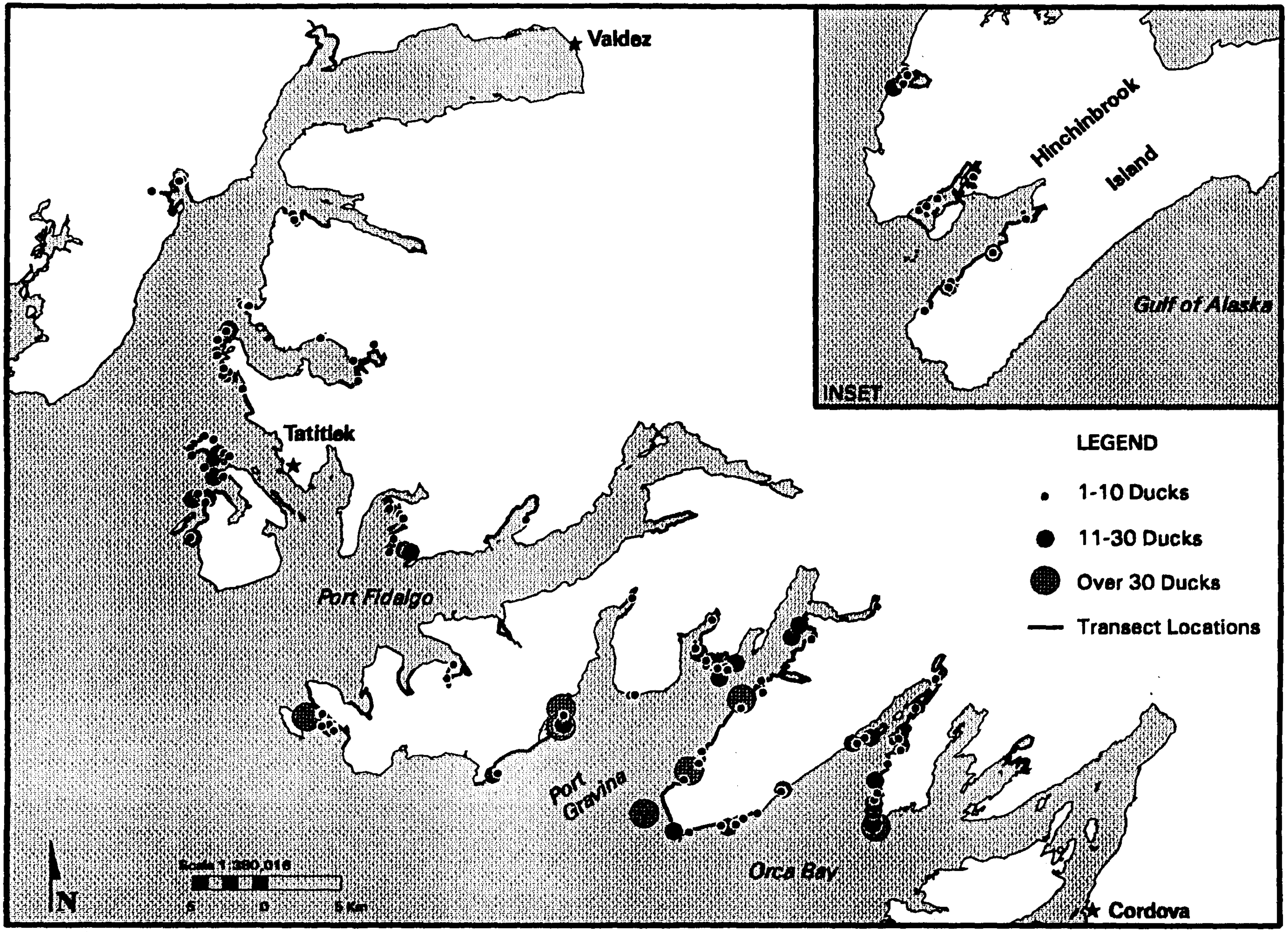
Appendix E2. Location of harlequin ducks observed in eastern Prince William Sound during the second spring survey (23 May-31 May) in 1995.



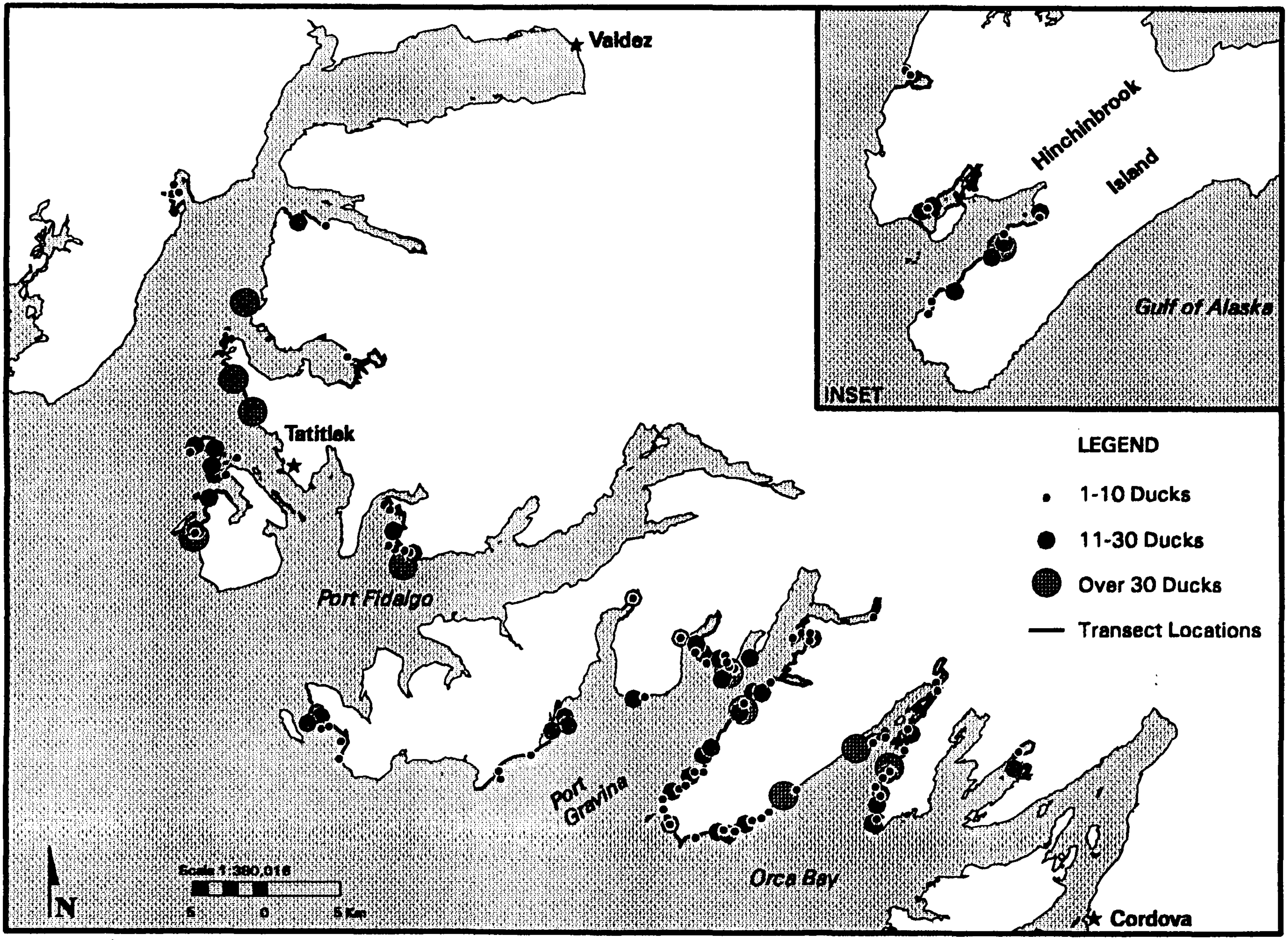
Appendix E3. Location of harlequin ducks observed in eastern Prince William Sound during the third spring survey (10 June-16 June) in 1995.



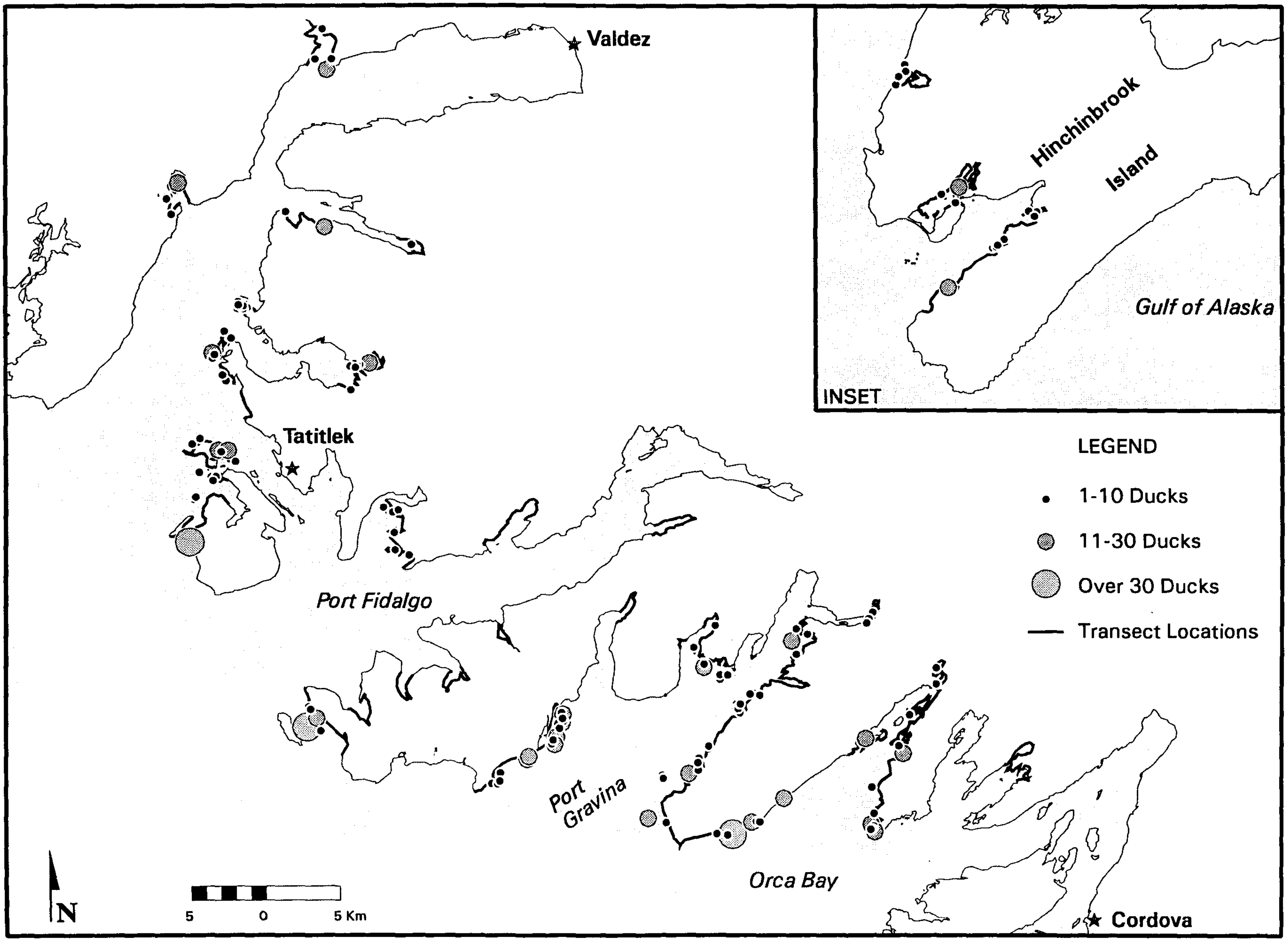
Appendix E4. Location of harlequin ducks observed in eastern Prince William Sound during the first fall survey (25 July-30 July) in 1995.



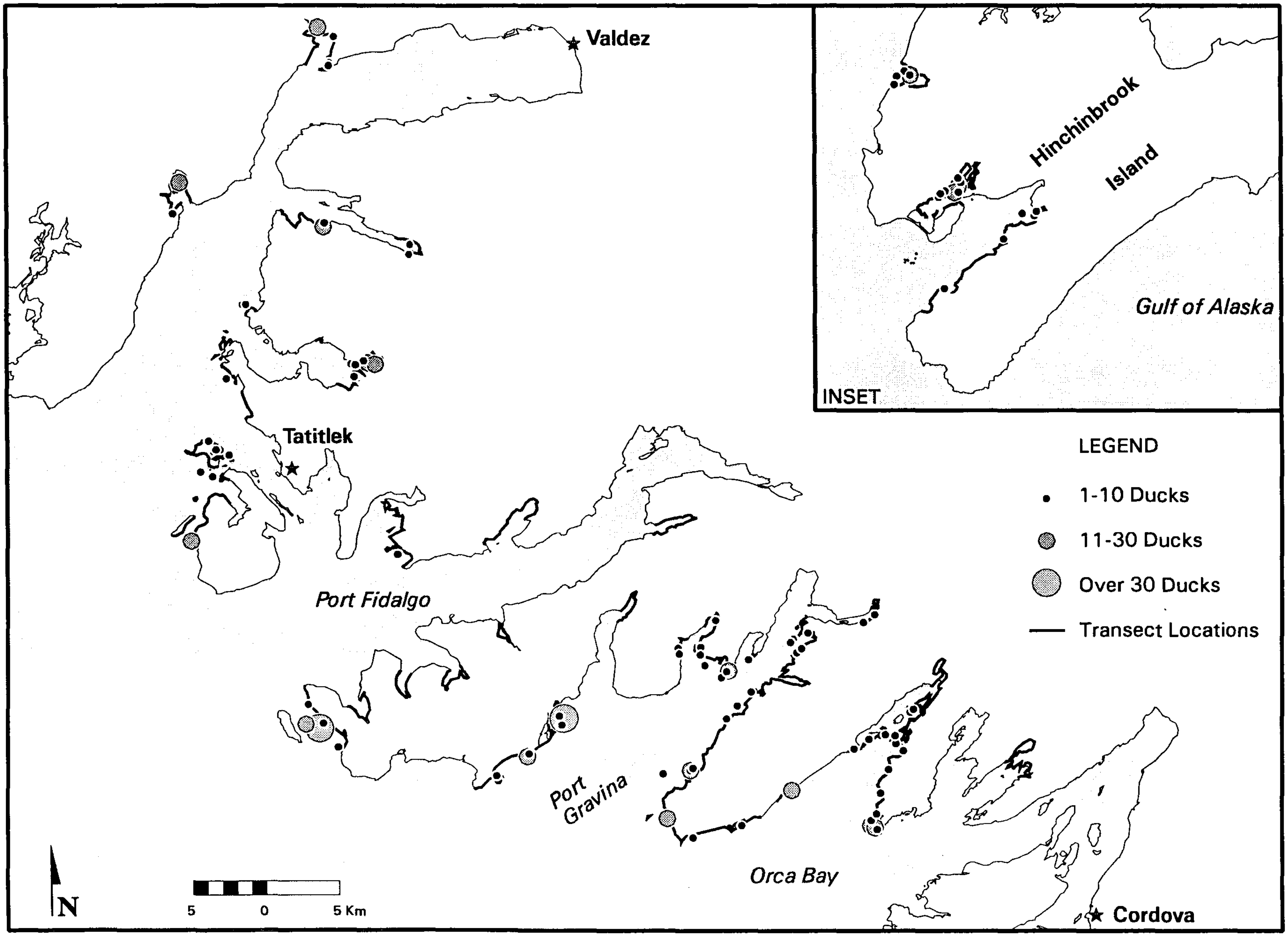
Appendix E5. Location of harlequin ducks observed in eastern Prince William Sound during the second fall survey (11 Aug.-17 Aug.) in 1995.



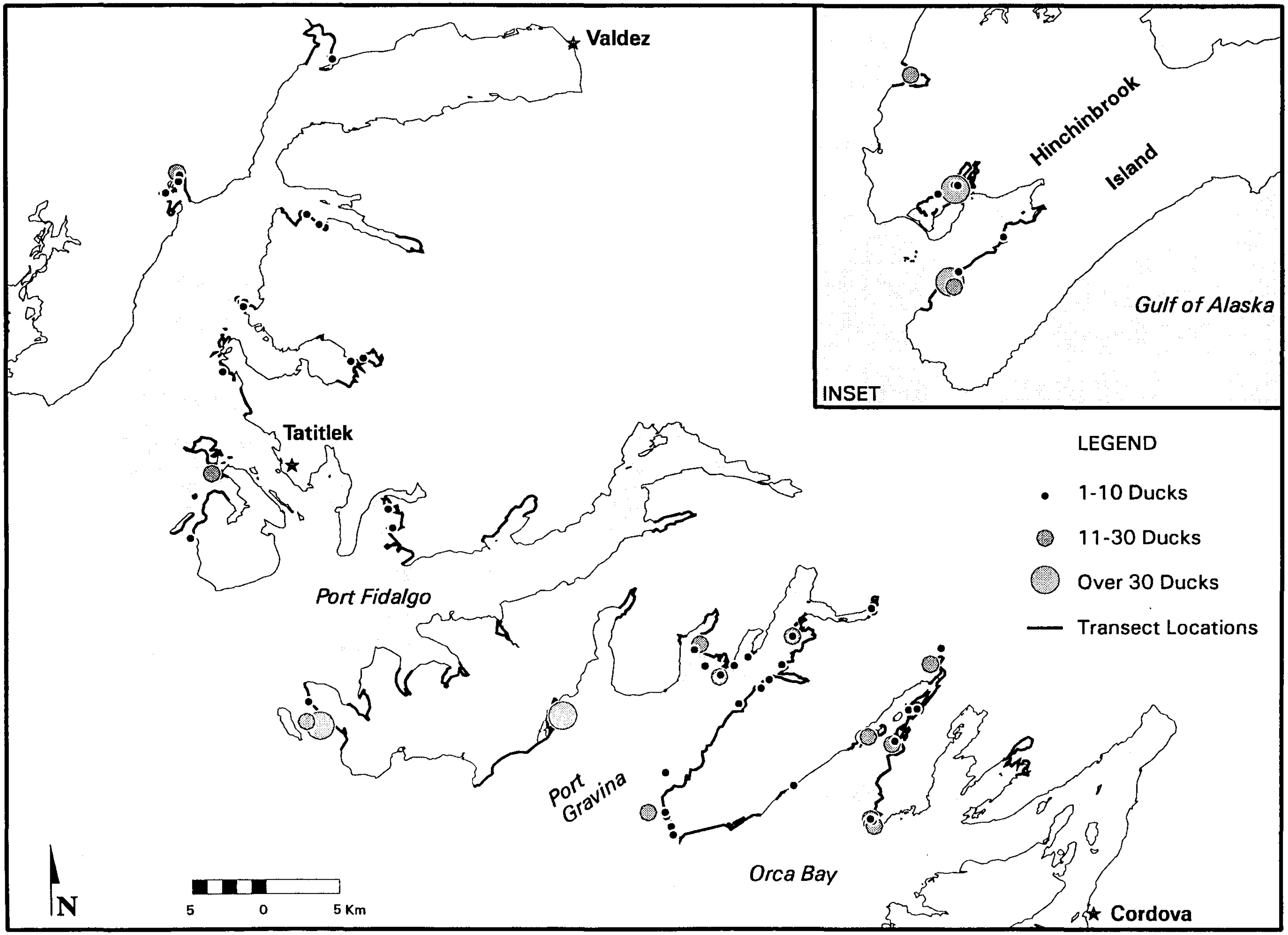
Appendix E6. Location of harlequin ducks observed in eastern Prince William Sound during the third fall survey (6 Sept.-12 Sept.) in 1995.



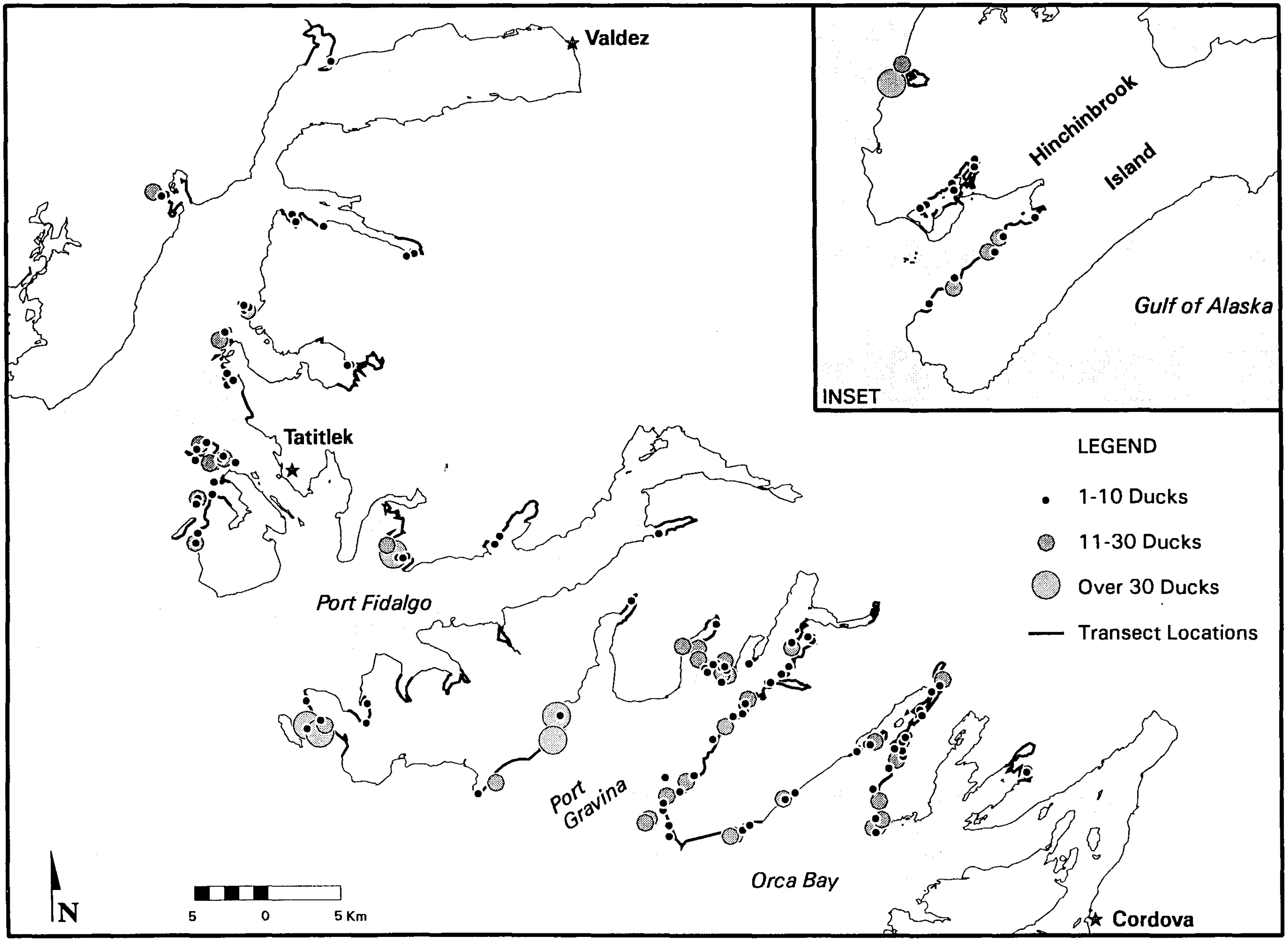
Appendix E7. Location of harlequin ducks observed in eastern Prince William Sound during the first spring survey (9 May-14 May) 1996



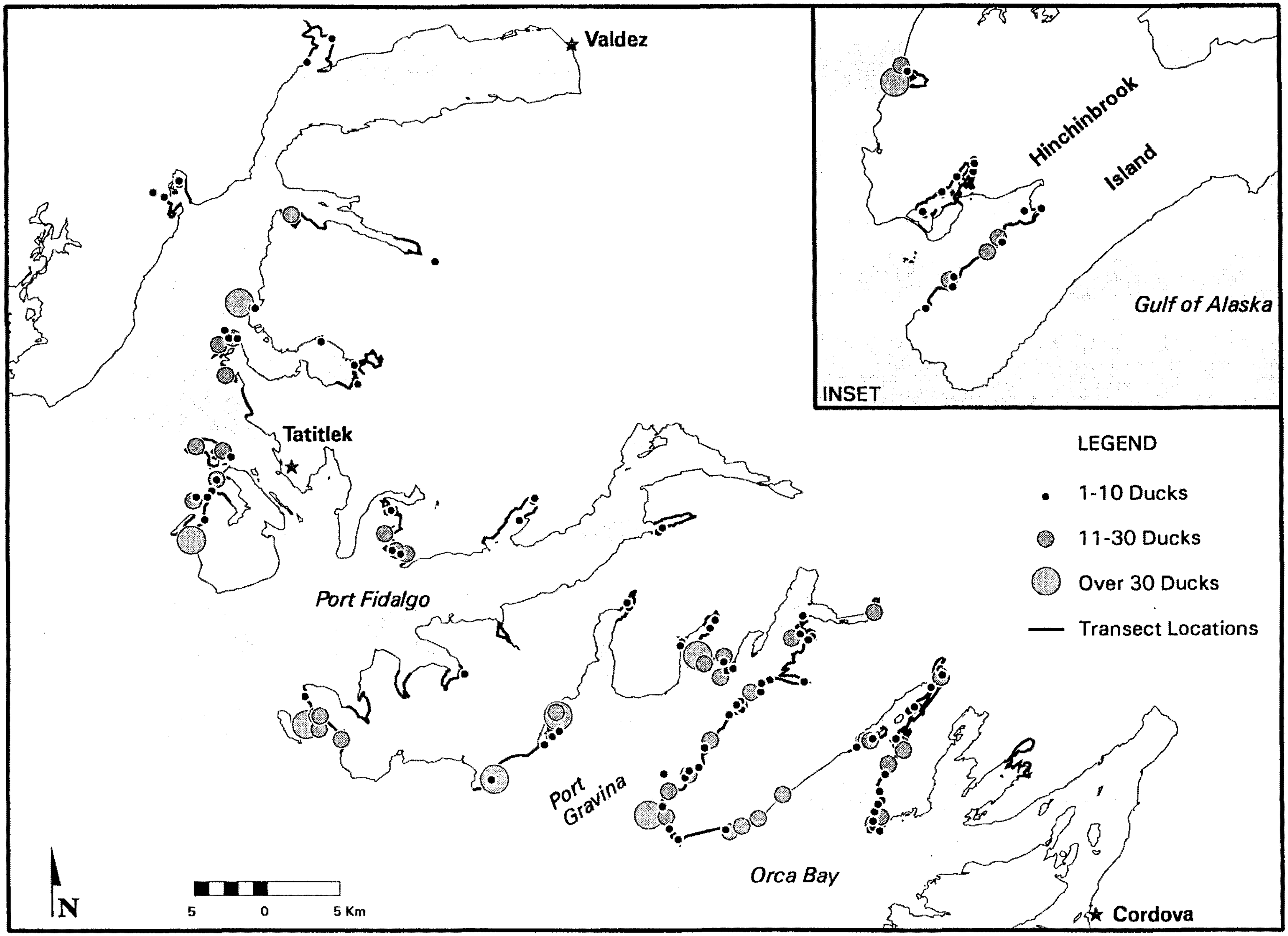
Appendix E8. Location of harlequin ducks observed in eastern Prince William Sound during the second spring survey (23 May-27 May) in 1996.



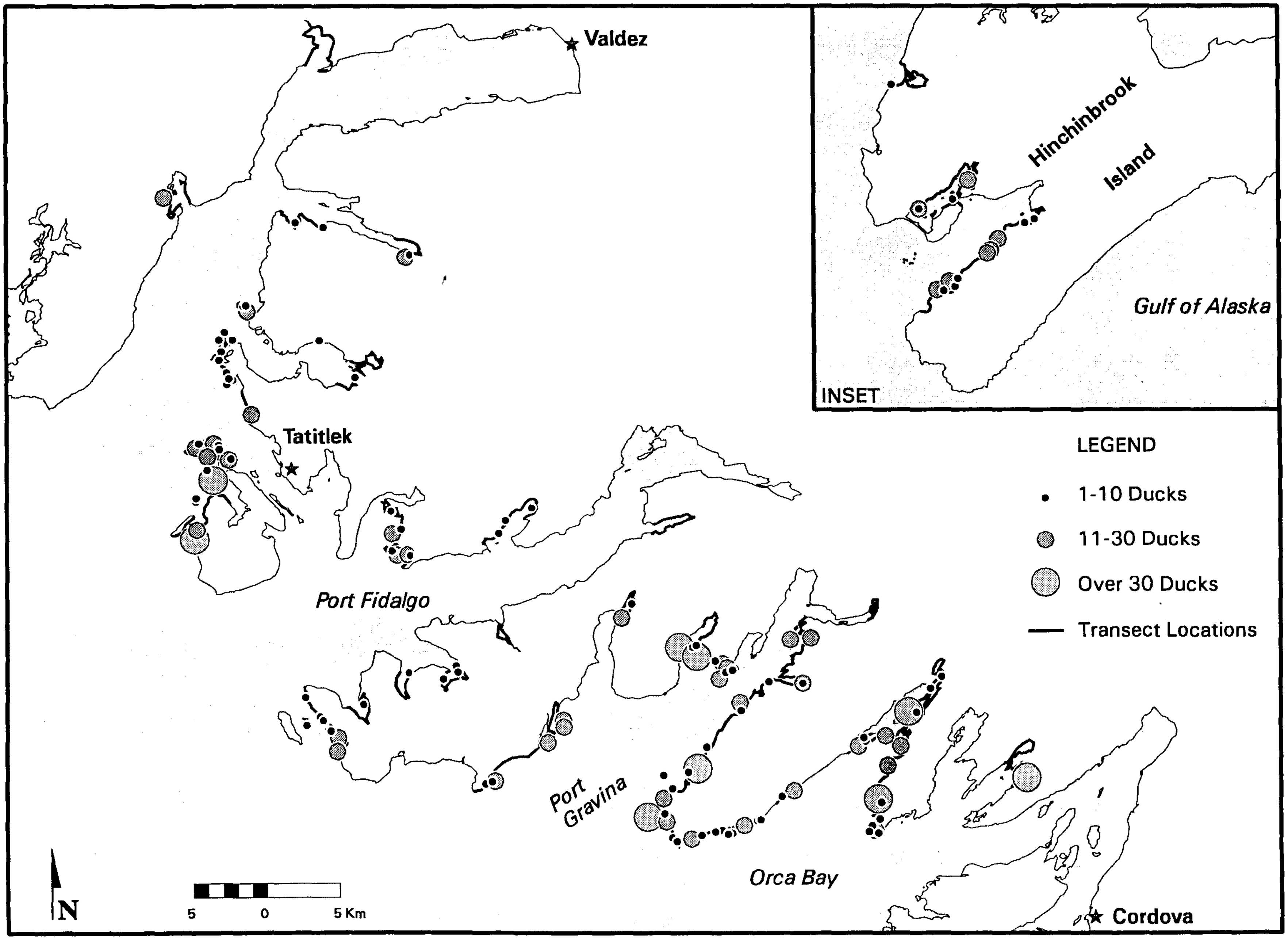
Appendix E9. Location of harlequin ducks observed in eastern Prince William Sound during the third spring survey (11 June-16 June) 1996



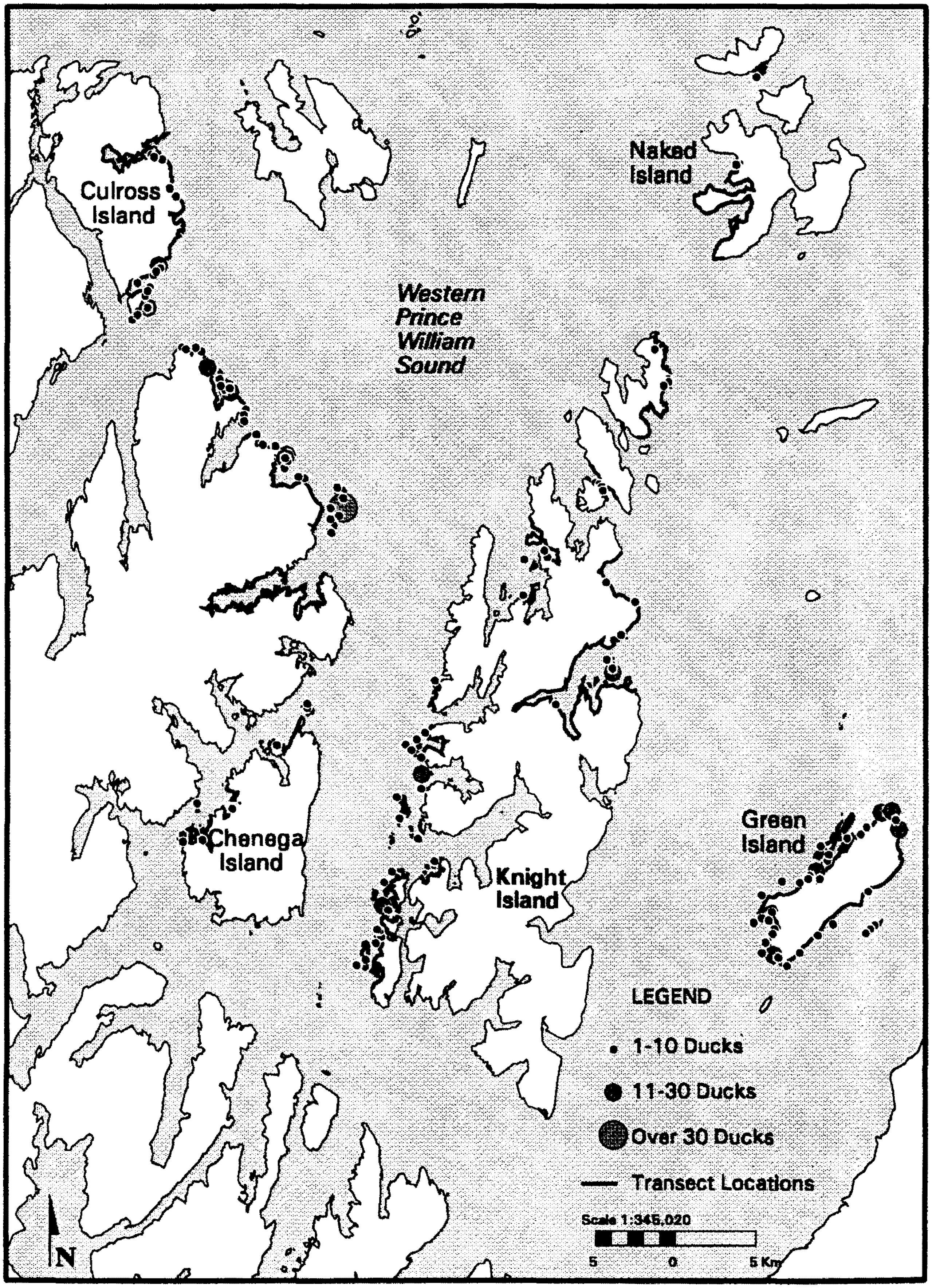
Appendix E10. Location of harlequin ducks observed in eastern Prince William Sound during the first fall survey (24 July-30 July) in 1996.



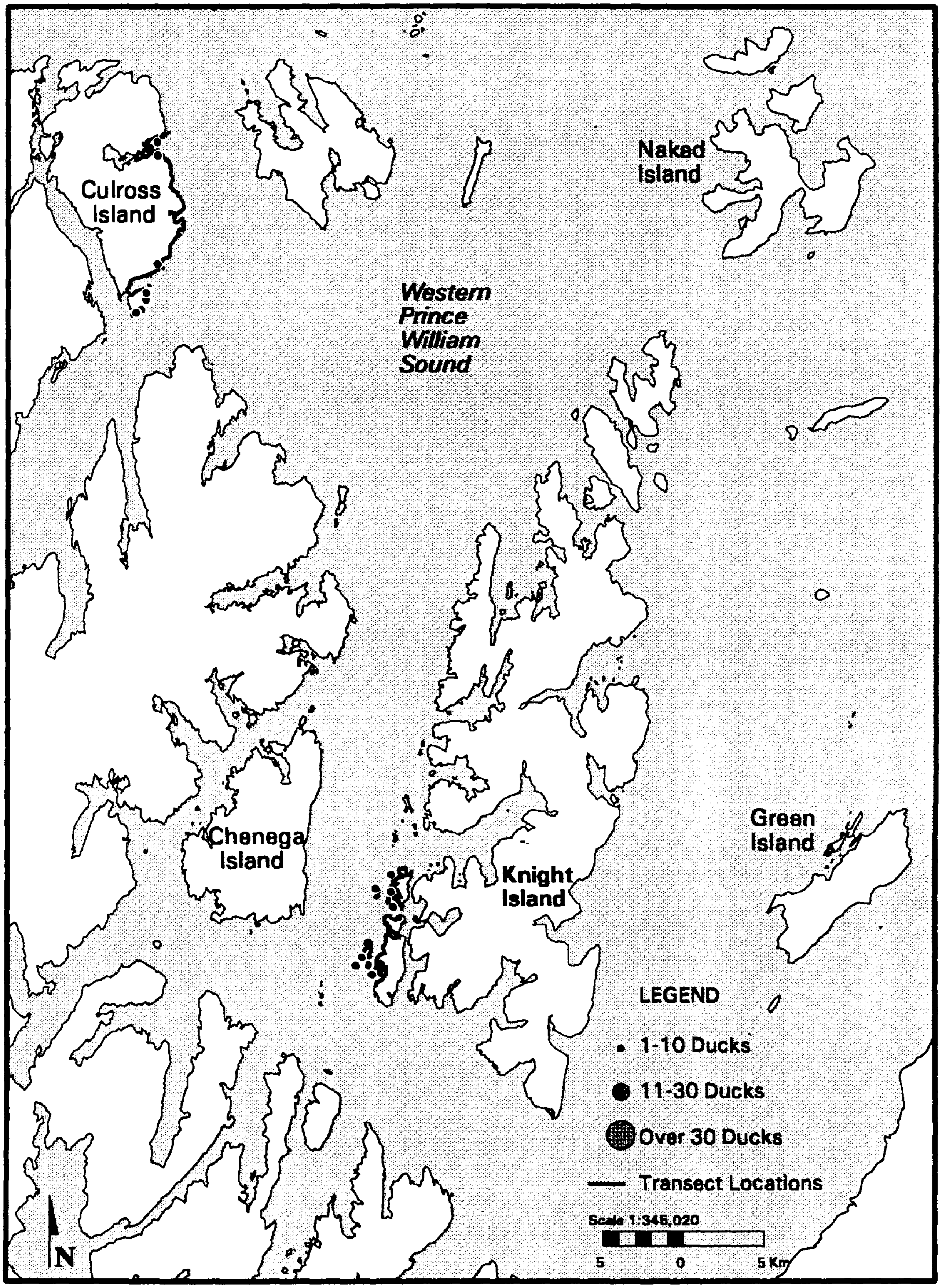
Appendix E11. Location of harlequin ducks observed in eastern Prince William Sound during the second fall survey (9 Aug.-17 Aug.) 996



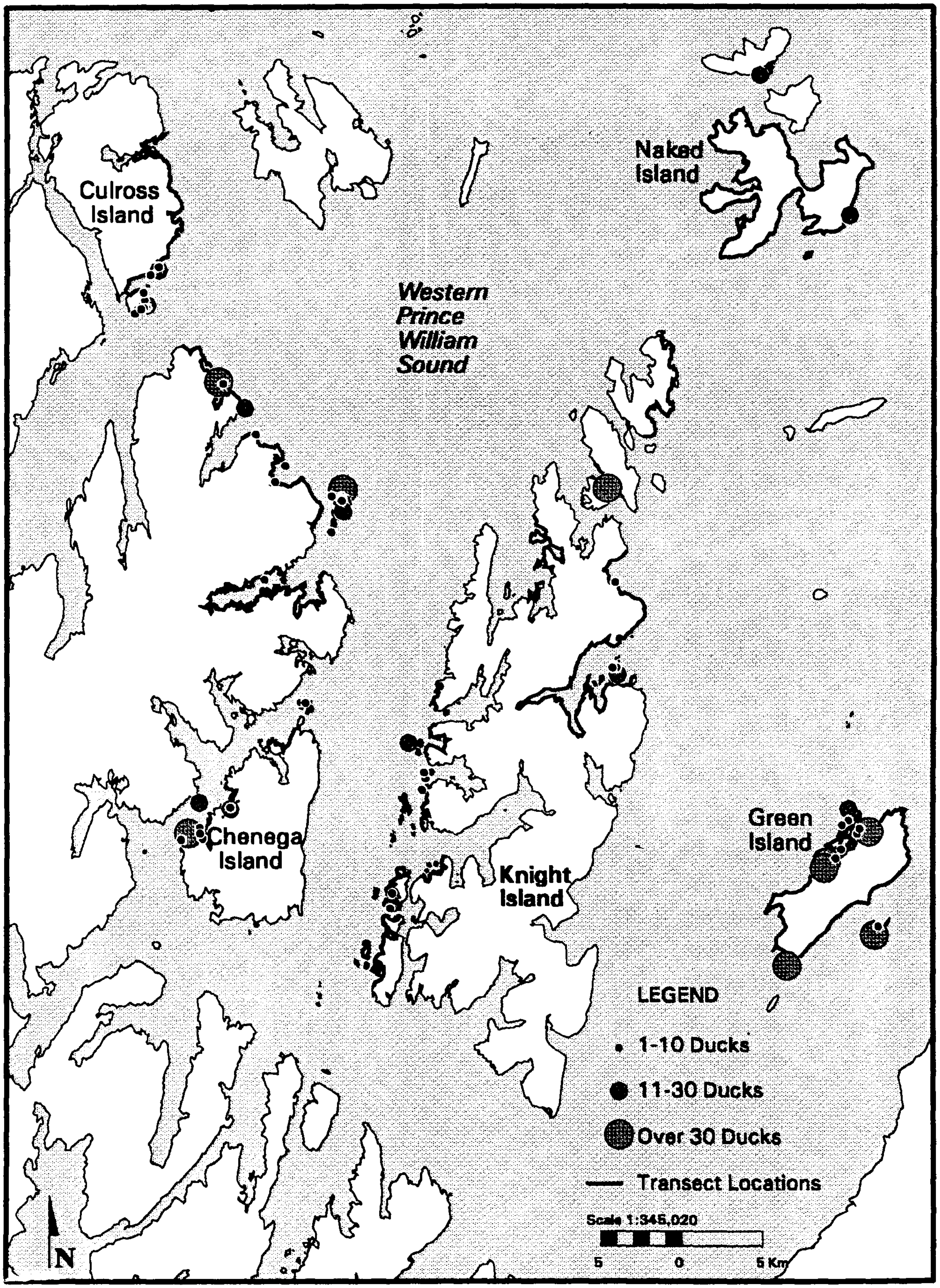
Appendix E12. Location of harlequin ducks observed in eastern Prince William Sound during the third fall survey (6 Sept.-10 Sept.) in 1996.



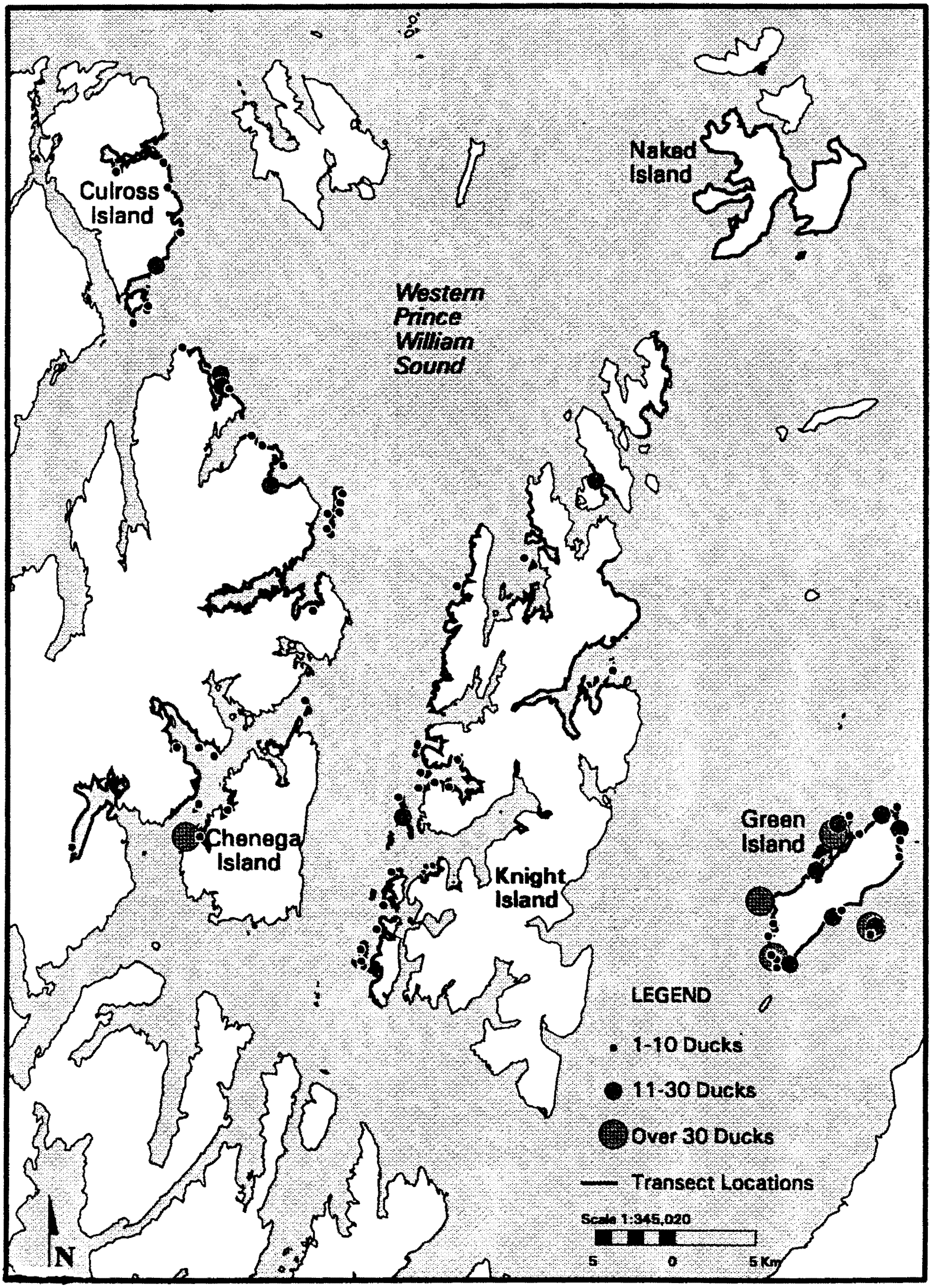
Appendix E13. Location of harlequin ducks observed in western Prince William Sound during the first spring survey (10 May-20 May) in 1995.



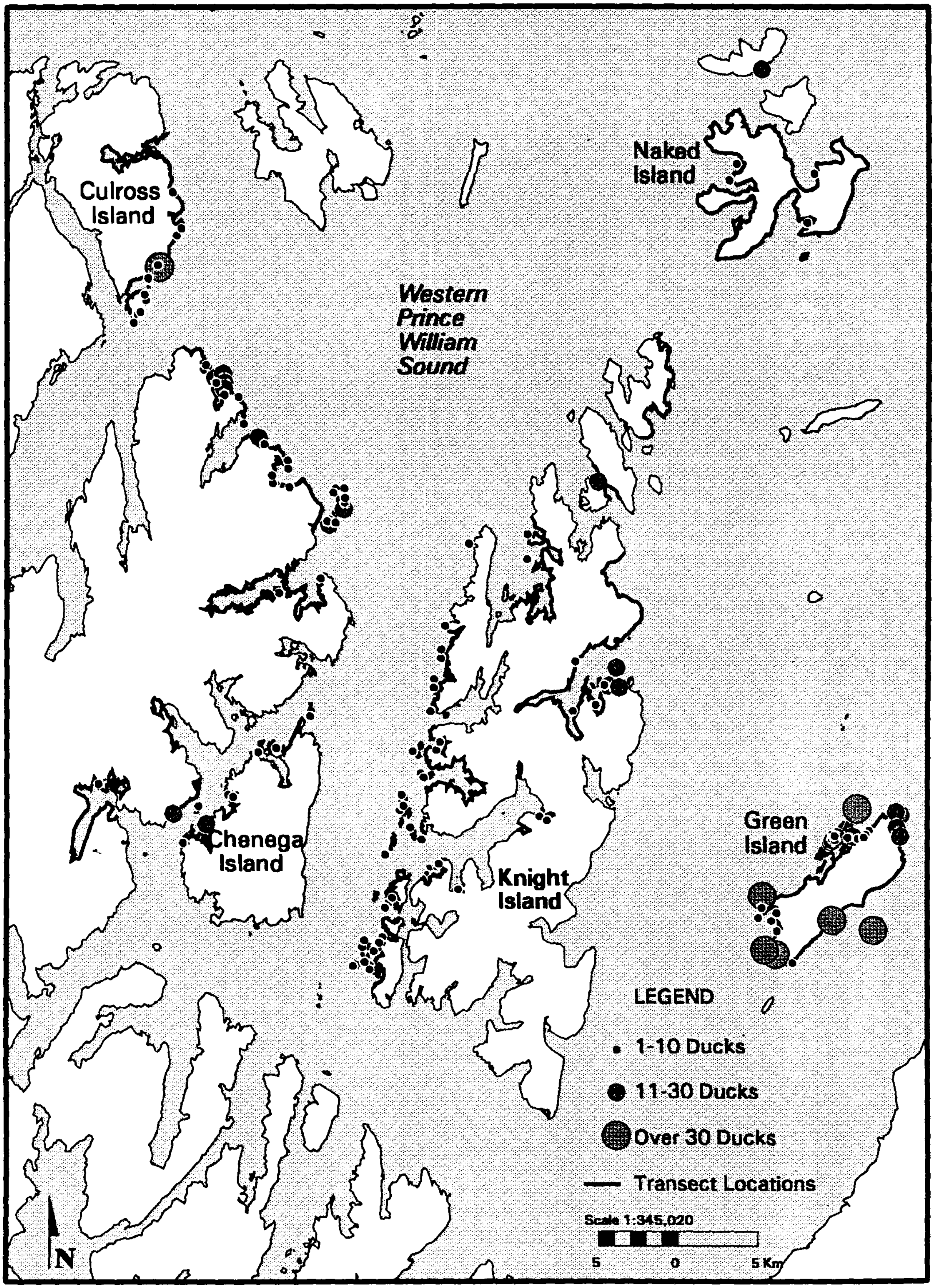
Appendix E14. Location of harlequin ducks observed in western Prince William Sound during the second spring survey (26 May-29 May) in 1995. Survey coverage was not completed because of poor weather.



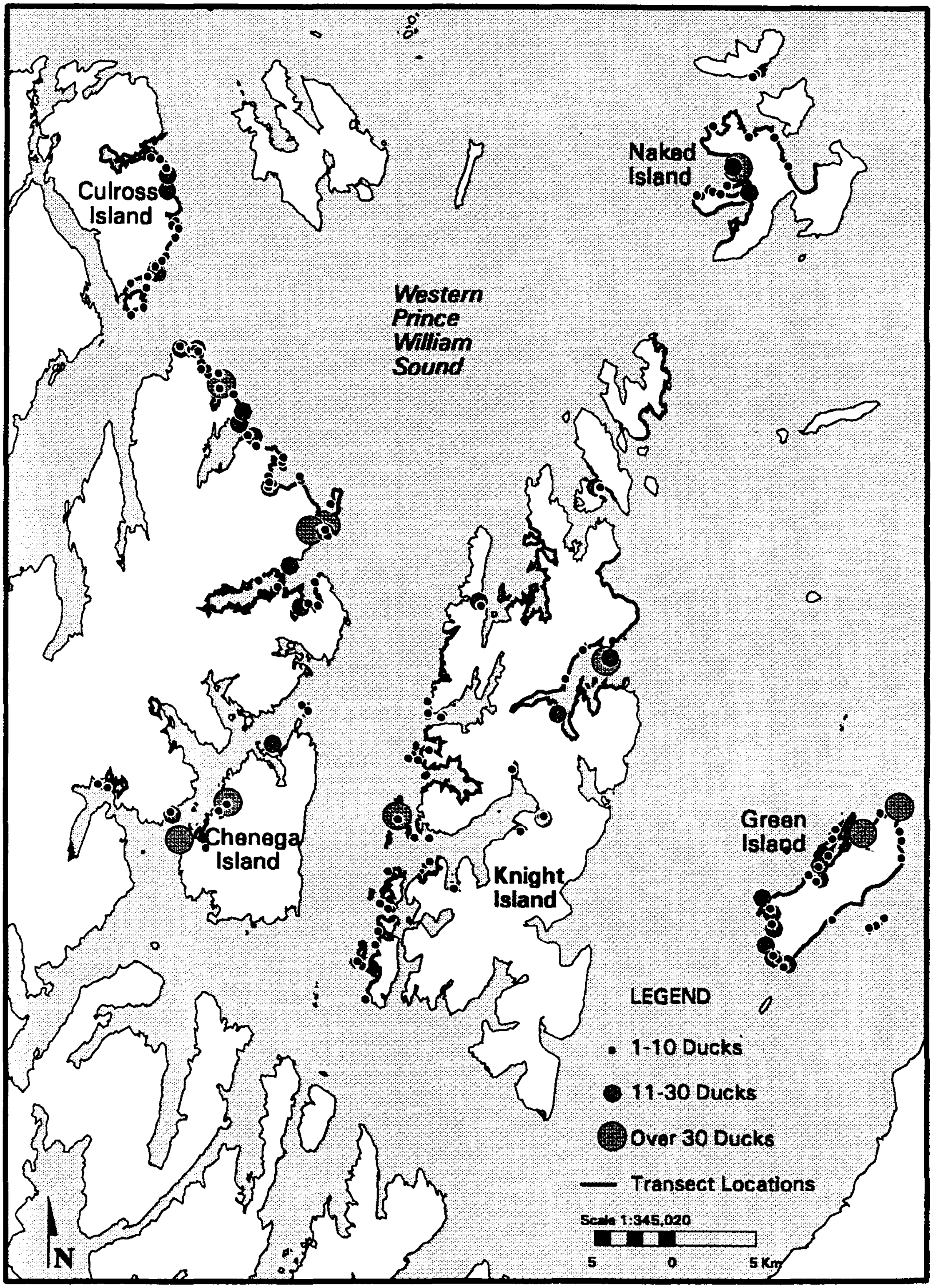
Appendix E15. Location of harlequin ducks observed in western Prince William Sound during the third spring survey (9 June-16 June) in 1995.



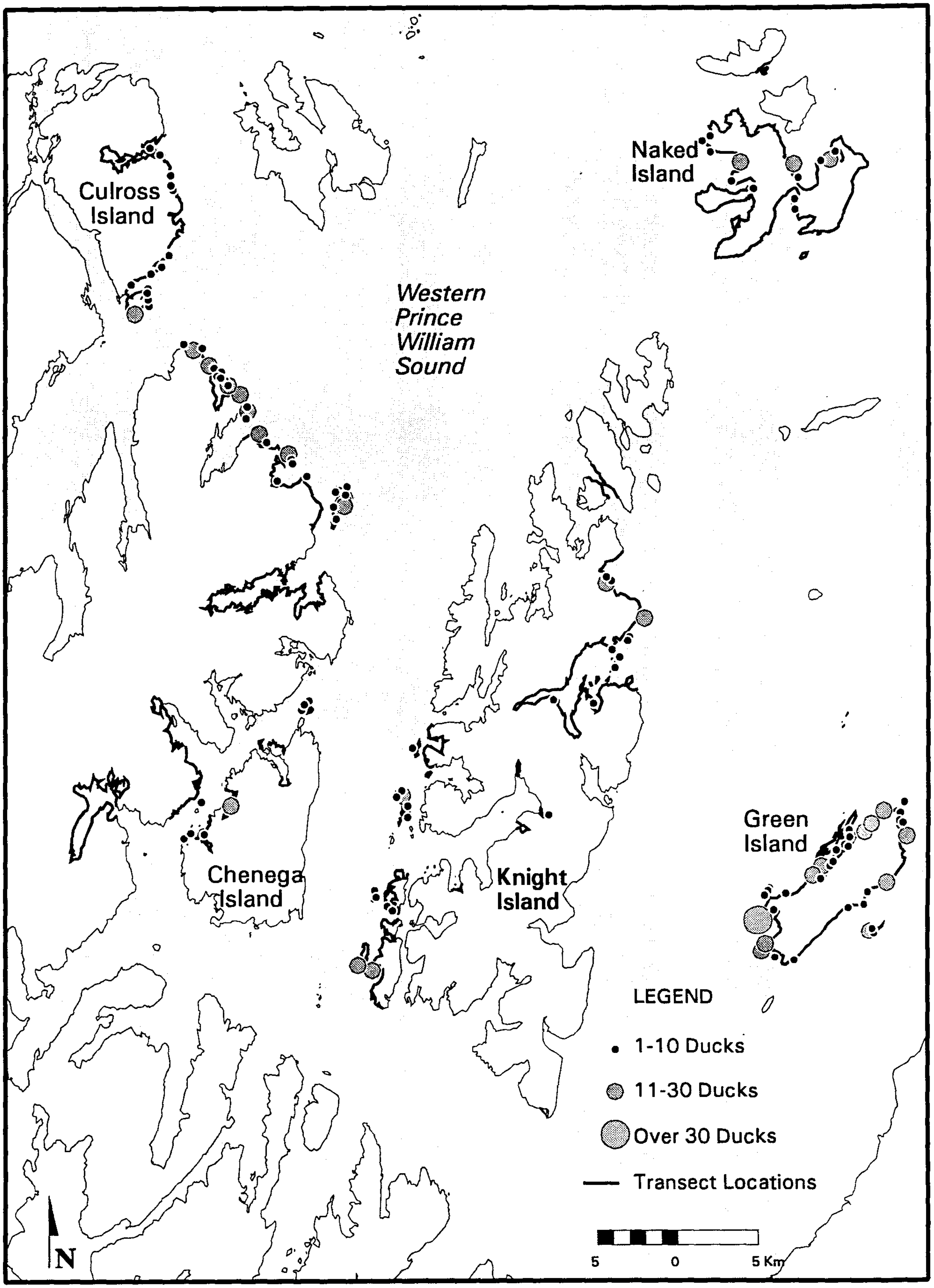
Appendix E16. Location of harlequin ducks observed in western Prince William Sound during the first fall survey (25 July-1 Aug.) in 1995.



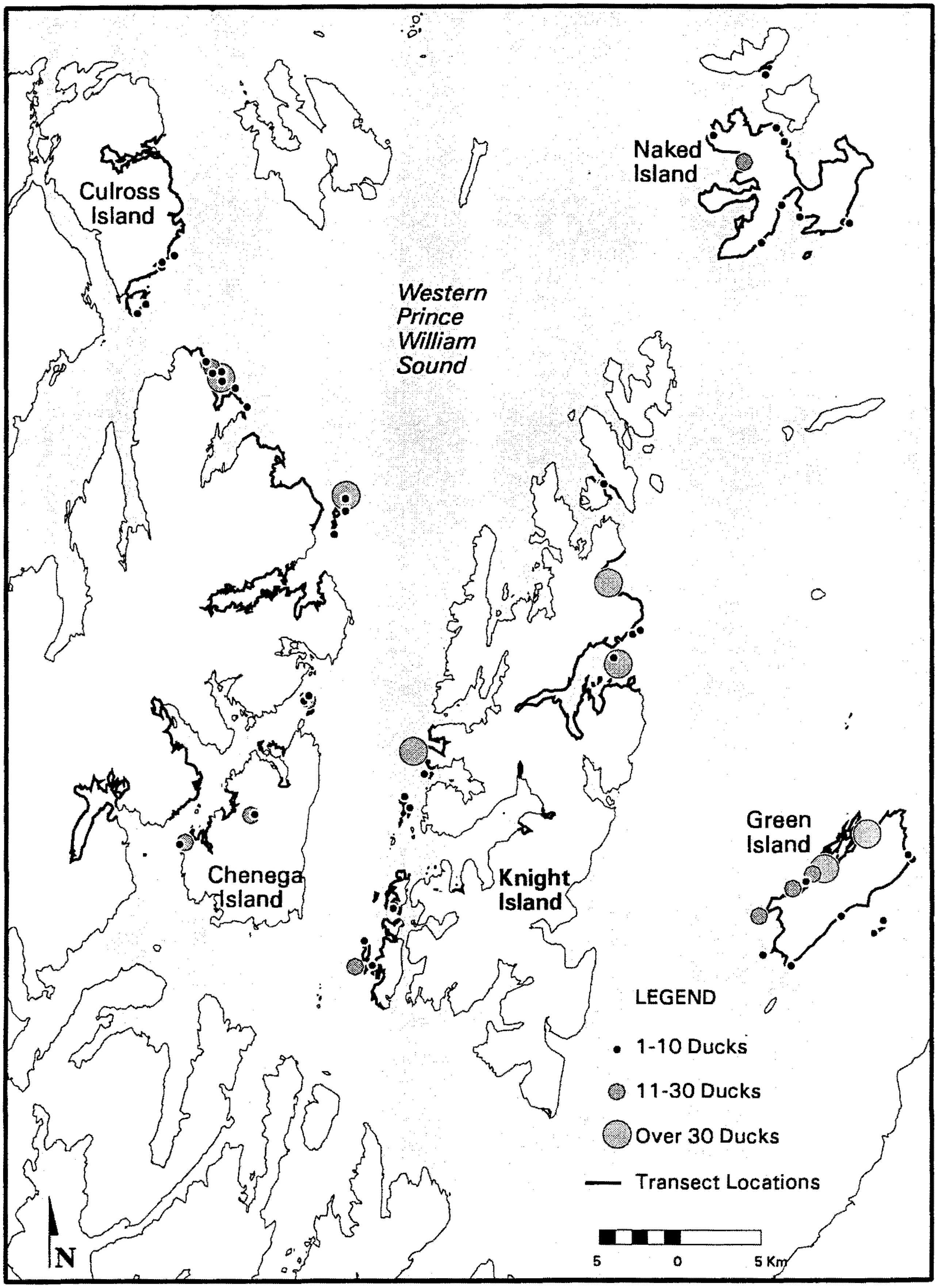
Appendix E17. Location of harlequin ducks observed in western Prince William Sound during the second fall survey (10 Aug.-18 Aug.) in 1995.



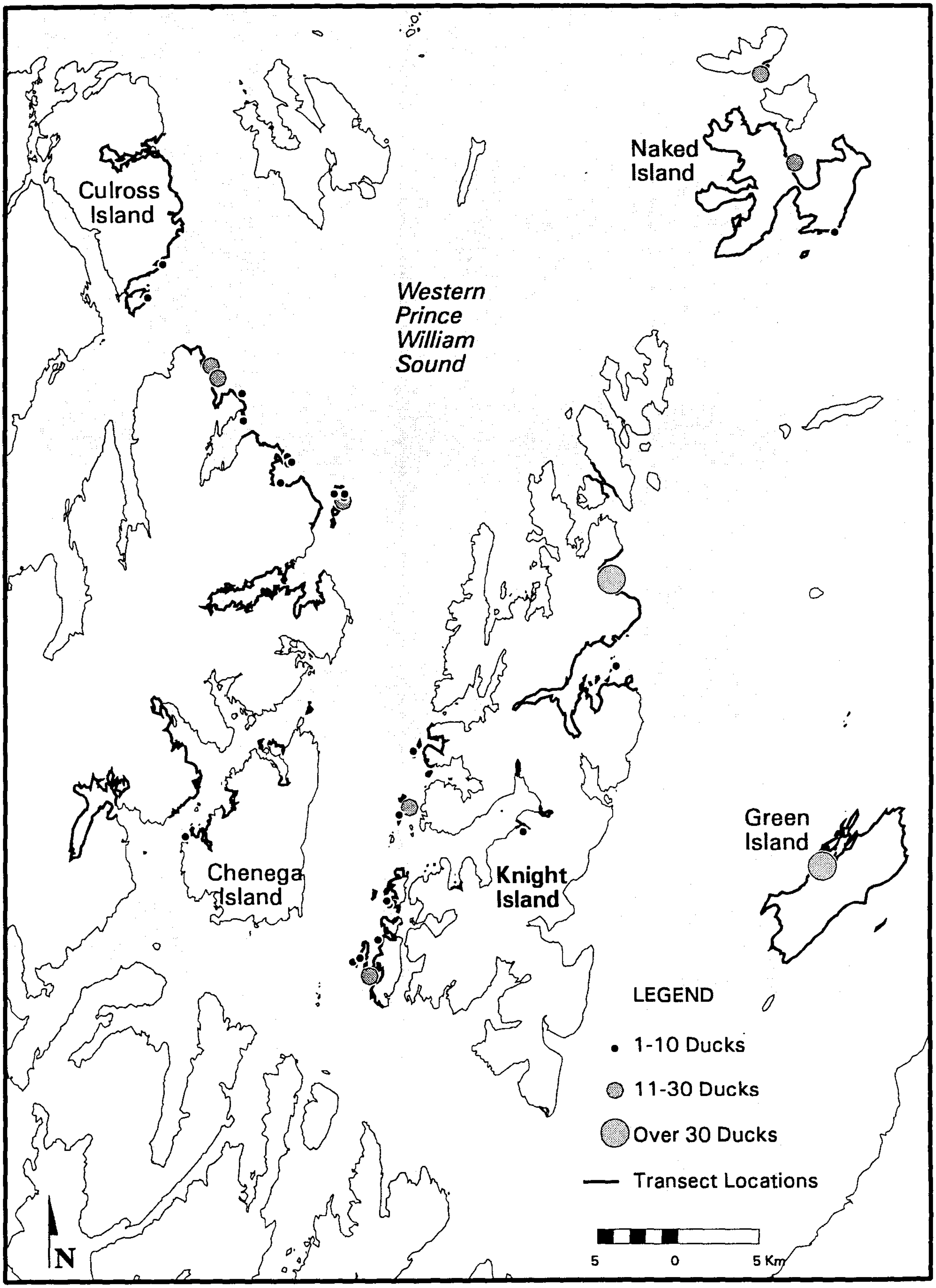
Appendix E18. Location of harlequin ducks observed in western Prince William Sound during the third fall survey (5 Sept.-14 Sept.) in 1995.



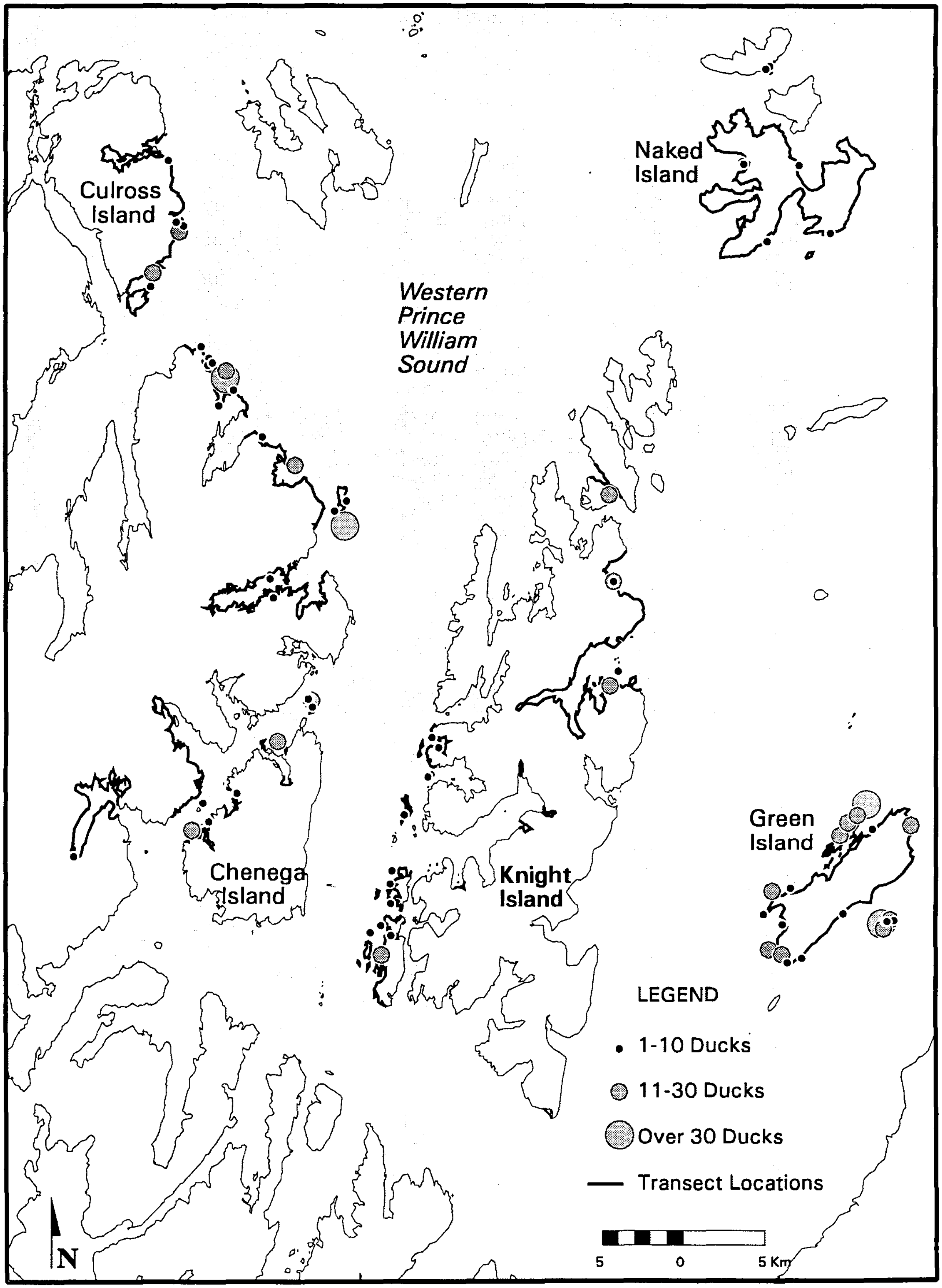
Appendix E19. Location of harlequin ducks observed in western Prince William Sound during the first spring survey (8 May-14 May) in 1996.



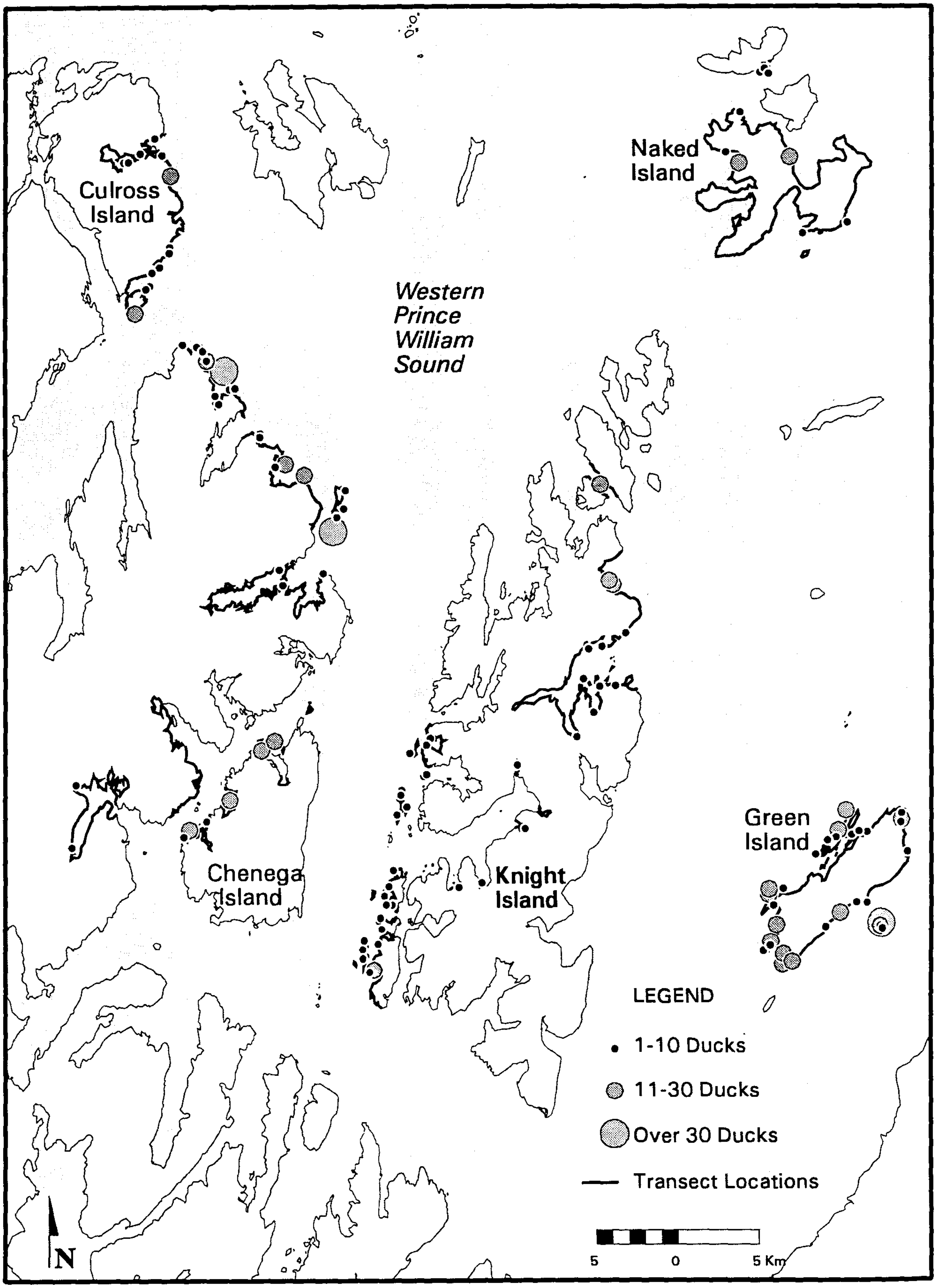
Appendix E20. Location of harlequin ducks observed in western Prince William Sound during the second spring survey (24 May-30 May) in 1996.



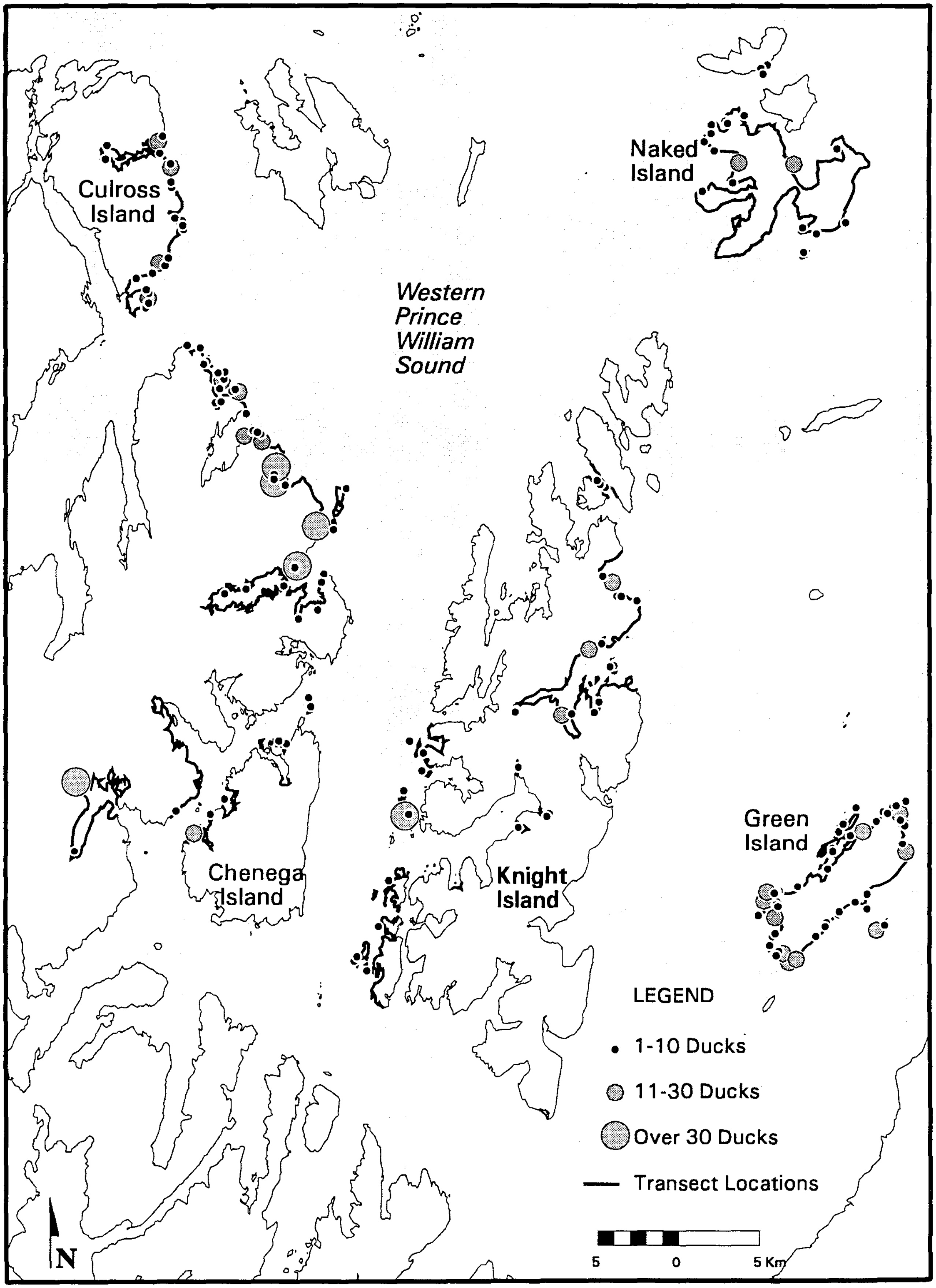
Appendix E21. Location of harlequin ducks observed in western Prince William Sound during the third spring survey (11 June-18 June) in 1996.



Appendix E22. Location of harlequin ducks observed in western Prince William Sound during the first fall survey (23 July-30 July) in 1996.



Appendix E23. Location of harlequin ducks observed in western Prince William Sound during the second fall survey (8 Aug.-15 Aug.) in 1996.



Appendix E24. Location of harlequin ducks observed in western Prince William Sound during the third fall survey (5 Sept.-13 Sept.) in 1996.

Appendix F1. Relative density (ducks/km shoreline) of harlequin ducks along nearshore transects in western Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.	10 May- 20 May	26 May- 27 May[a]	9 June- 16 June	25 July- 1 Aug.	10 Aug.- 18 Aug.	5 Sept.- 14 Sept.
Aguliak Island	26	3.8	dns[b]	4.7	0.8	2.2	0.8
Applegate Island	1	16.9	5.3	10.1	1.7	4.0	2.0
Bay of Isles	5	0.8	dns	0.5	0.2	1.3	1.8
Channel Island	7	10.0	dns	36.8	55.0	53.7	18.1
Clam Island	20	dns	dns	dns	0.0	3.7	0.0
Crafton Island	11	9.9	dns	12.9	4.8	6.7	17.8
Culross Island	2	1.7	0.3	1.1	2.2	2.1	6.4
Eleanor Island	27	0.8	dns	0.0	0.0	0.0	0.0
Falls Bay	4	4.9	dns	0.8	2.3	3.4	9.2
Foul Bay	10	7.6	dns	6.5	5.2	6.5	14.0
Foul Pass	6	4.0	dns	7.5	3.8	4.9	4.4
Green Island	8	4.7	dns	6.3	10.0	9.3	6.2
Herring Bay	12	0.9	dns	0.0	0.3	0.1	0.7
Junction Island	17	4.4	dns	2.9	0.7	1.1	3.6
Lower Herring Bay	25	0.3	dns	0.0	0.1	2.2	1.8
Masked Bay	16	0.8	dns	0.0	0.0	2.1	6.1
Mummy Island	18	2.4	1.2	2.0	1.0	0.9	0.7
Naked Island	9	0.0	dns	0.2	0.0	0.2	2.9
New Years Island	19	dns	dns	dns	0.0	0.9	0.0
Squire Island	22	1.7	0.3	0.0	0.7	2.1	0.3
Squirrel Island	21	1.5	dns	0.0	4.7	2.4	19.0
Storey Island	28	1.4	dns	4.0	0.0	10.9	1.0
Totemoff Creek	15	3.1	dns	5.9	4.5	2.2	6.3

[a] Incomplete survey coverage because of poor weather.

[b] did not survey

Appendix F2. Relative density (ducks/km shoreline) of harlequin ducks along nearshore transects in western Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.	8 May- 14 May	24 May- 30 May[a]	11 June- 18 June	23 July- 30 July	8 Aug.- 15 Aug.	5 Sept.- 13 Sept.
Aguliak Island	26	2.2	5.7	1.7	3.2	1.8	1.2
Applegate Island	1	7.6	3.2	0.5	2.9	4.7	5.9
Bay of Isles	5	1.8	2.9	4.8	1.5	1.4	2.2
Channel Island	7	22.5	13.1	98.8	63.1	64.4	16.9
Crafton Island	11	14.1	7.3	5.3	11.0	8.4	0.3
Culross Island	2	2.3	0.9	0.1	2.3	3.1	5.2
Falls Bay	4	4.4	0.2	1.4	1.5	3.5	14.3
Foul Bay	10	12.0	6.1	2.6	6.8	11.9	8.8
Foul Pass	6	0.0	1.6	0.0	4.2	4.2	2.6
Green Island	8	4.9	3.1	1.6	4.5	4.9	7.1
Junction Island	17	9.2	12.9	14.7	8.8	8.1	0.7
Masked Bay	16	0.0	0.0	0.0	8.0	4.2	0.8
Mummy Island	18	1.6	0.1	0.6	2.1	3.0	0.5
Naked Island	9	1.2	0.7	0.2	0.3	0.6	1.7
Squire Island	22	1.8	0.7	1.2	1.4	1.8	0.7
Squirrel Island	21	7.8	2.5	5.6	1.6	2.7	15.2
Storey Island	28	0.0	0.7	8.0	13.8	9.1	4.0
Totemoff Creek	15	2.5	3.4	4.5	2.6	3.6	2.0

Appendix F3. Relative density (ducks/km shoreline) of harlequin ducks along nearshore transects in eastern Prince William Sound, Alaska in 1995.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.	10 May-17 May	23 May-31 May	10 June-16 June	25 July-30 July	11 Aug.-17 Aug.	6 Sept.-12 Sept.
Beartrap Bay	5	2.0	2.2	1.2	0.8	1.2	1.4
Black Creek	27	0.0	0.0	0.0	0.0	0.0	23.9
Busby Island (south)	25	4.0	3.4	1.4	5.6	3.8	5.6
Busby Island (north)	26	3.8	1.7	0.0	5.8	6.6	5.9
Close Island	10	1.6	4.6	3.1	7.1	8.8	15.3
Constantine Harbor	19	1.6	1.8	2.0	0.2	0.5	1.9
Galena Bay	21	2.8	1.5	0.9	0.3	0.8	0.5
Galena Island	29	20.4	0.0	0.0	30.6	71.4	0.0
Galena Rocks	30	8.1	4.0	4.8	20.2	8.1	16.2
Gravina Island	2	11.4	9.8	0.0	73.8	123.1	0.0
Gravina Rocks	1	6.1	15.3	230.0	6.1	0.0	0.0
Gull Island	17	27.6	39.5	160.0	124.5	61.2	41.5
Hell's Hole	13	20.1	26.0	10.2	15.3	19.4	8.5
Jack Bay	22	5.4	2.8	3.6	1.2	1.7	4.3
Landlocked Bay	34	2.0	1.8	0.5	3.3	5.3	6.6
Olsen Bay	7	0.9	2.9	6.5	7.0	7.9	12.7
Parshas Point	6	2.9	0.0	1.4	0.0	0.0	21.9
Port Etches	20	0.7	3.4	1.6	5.6	4.4	9.1
Port Gravina (SE)	3	4.2	3.4	9.9	6.7	6.3	12.7
Port Gravina (NE)	4	2.0	0.6	0.1	1.2	2.7	3.9
Porcupine Bay	16	3.5	4.8	3.5	4.2	9.3	11.5
Redhead	14	4.1	7.1	0.0	8.7	0.8	0.5
Redhead Point	15	3.9	1.1	0.0	3.3	10.6	6.7
Reef/Red Sector	24	1.5	1.5	0.1	2.8	10.8	10.3
Rocky Point	28	7.4	1.9	0.0	4.1	3.9	7.2
Sawmill Bay	31	2.1	3.7	2.4	1.3	1.0	1.0
Sheep Bay (east)	9	1.3	0.7	3.0	3.2	3.3	4.4
Sheep Bay (SW)	12	4.3	2.1	0.0	4.4	4.4	7.7
Sheep Point	8	41.3	17.4	0.0	33.3	36.5	24.6
Shelter Bay	18	4.8	3.2	4.2	8.8	5.3	1.2
Shoup Bay	32	3.3	6.3	0.0	0.0	0.0	dns[a]

Appendix F3 (cont.)

Surf Creek	11	17.4	3.0	0.0	17.4	25.6	45.1
Vladnoff River	23	1.7	2.0	1.0	1.0	0.0	0.0

[a] did not survey

Appendix F4. Relative density (ducks/km shoreline) of harlequin ducks along nearshore transects in eastern Prince William Sound, Alaska in 1996.

		Spring Survey Dates			Fall Survey Dates		
Transect Location	No.	9 May- 14 May	23 May- 27 May	11 June- 16 June	24 July- 30 July	9 Aug.- 17 Aug.	6 Sept.- 10 Sept.
Beartrap Bay	5	1.5	1.0	1.2	0.0	5.0	0.0
Black Creek	27	0.0	0.0	0.0	0.0	0.0	5.7
Busby Island (south)	25	3.4	1.6	3.4	2.9	3.7	7.8
Busby Island (north)	26	8.3	1.6	0.0	6.5	7.4	11.0
Close Island	10	3.6	3.6	2.3	6.1	11.2	14.1
Constantine Harbor	19	1.8	3.0	2.6	1.1	0.4	2.4
Galena Bay	21	2.8	13.3	0.3	0.6	0.3	1.4
Galena Island	29	10.3	0.0	0.0	44.8	13.8	13.8
Galena Rocks	30	15.4	2.4	8.1	15.8	20.7	9.3
Gravina Island	2	45.9	0.0	26.2	36.1	52.5	52.5
Gravina Rocks	1	48.5	6.1	30.3	30.3	18.2	12.1
Gull Island	17	88.2	33.3	2.0	90.2	121.6	5.9
Hell's Hole	13	12.6	14.6	13.8	6.4	11.2	3.4
Jack Bay	22	4.6	3.3	1.6	0.9	2.6	3.0
Landlocked Bay	34	1.8	0.3	0.2	4.5	5.1	4.5
Olsen Bay	7	4.5	5.0	5.2	10.7	10.1	12.9
Parshas Point	6	0.0	7.3	17.4	4.4	0.0	0.0
Port Etches	20	3.0	1.4	3.0	3.6	4.9	6.7
Port Gravina (SE)	3	2.9	3.1	2.2	6.8	9.0	8.4
Port Gravina (NE)	4	1.5	1.4	1.8	2.2	2.8	2.3
Porcupine Bay	16	3.1	10.5	7.6	10.2	9.8	8.2
Redhead	14	9.4	4.6	0.0	7.6	2.3	4.7
Redhead Point	15	11.8	2.8	0.0	14.0	24.7	14.0
Reef/Red Sector	24	5.0	2.5	0.1	9.4	14.2	8.6
Rocky Point	28	6.4	0.3	0.2	7.3	11.4	6.0
Sawmill Bay	31	5.0	2.8	3.6	3.4	0.7	2.2
Sheep Bay (east)	9	1.3	1.1	1.5	2.7	3.4	6.1
Sheep Bay (SW)	12	13.7	0.8	0.0	5.0	6.4	7.2
Sheep Point	8	37.3	30.2	55.6	28.6	49.2	29.4
Shelter Bay	18	3.3	4.2	1.8	5.8	5.8	0.7
Shoup Bay	32	4.9	2.7	0.2	0.2	0.4	0.0

Appendix F4 (cont.)

Surf Creek	11	14.3	11.2	1.0	25.5	15.3	22.4
Vladnoff River	23	1.3	1.5	0.0	1.3	0.3	4.3