Exxon Valdez Oil Spill
Restoration Project Final Report

Status of Harlequin Ducks in Prince William Sound, Alaska after the *Exxon Valdez* Oil Spill, 1995-1997

Restoration Project 97427
Final Report

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Status of Harlequin Ducks in Prince William Sound, Alaska after the *Exxon Valdez* Oil Spill: 1995-1997

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Study History: Restoration Project 97427 concludes harlequin duck (*Histrionicus histrionicus*) studies initiated in 1991 by the Alaska Department of Fish and Game with Bird Study Number 11 (Assessment of Injury to Sea Ducks from Hydrocarbon Uptake in Prince William Sound and the Kodiak Archipelago, Alaska, Following the *Exxon Valdez* Oil Spill) and Restoration Study Number 71 (Breeding Ecology of Harlequin Ducks in Prince William Sound, Alaska). These earlier studies concluded that the number of harlequin ducks inhabiting oiled 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 subsequent low productivity of ducks that survived or avoided initial exposure. A Masters of Science thesis describing breeding habitat of harlequin ducks was also produced during the course of these initial studies (Crowley, D.W. 1994. Breeding habitat of harlequin ducks in Prince William Sound, Alaska. M. S. Thesis. Oregon St. Univ., Corvallis. 64pp.). Restoration Project (RP) 94427 (Experimental Harlequin Duck Breeding Survey) was initiated in 1994 in response to concerns that post-spill productivity by harlequin ducks in WPWS was 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 unoiled areas in eastern PWS (EPWS). Variation in population structure between locations 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 (Distribution, Abundance and Composition of Harlequin Duck Populations in Prince William Sound, Alaska), 96427 (Distribution, Abundance and Composition of Harlequin Ducks in Prince William Sound, Alaska), and 97427 utilized methods derived from RP 94427. Results from surveys conducted in 1995 (RP 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 study areas, 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 (RP 96427) and 1997 (RP 97427) 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, study areas, and among survey periods. A winter survey conducted in March 1997 (RP 97427) suggests that more harlequin ducks inhabit oiled areas of WPWS during the winter than indicated by spring and fall surveys.

Abstract: We compared numbers of breeding pairs, molt chronology, brood observations, and the age and sex composition to determine whether harlequin duck *(Histrionicus histrionicus)* populations in oiled areas of western Prince William Sound (WPWS) and unoiled areas of eastern Prince William Sound (EPWS), Alaska exhibited 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 large proportion of breeding pairs departed EPWS and WPWS early in the spring, presumably to nest on larger, inland drainages. The few paired females remaining in our study areas, combined with the small number of brood observations in EPWS and the absence of broods in WPWS, suggests that suitable breeding habitat is limiting breeding activity in PWS. We did not detect any major difference in population structure between EPWS and WPWS. This suggests similar breeding propensity, recruitment, breeding success, and survival rates. We detected a decrease in the number of harlequin ducks in WPWS, while no significant change was observed for EPWS. Therefore, we believe the harlequin duck population in oiled areas of WPWS has the potential to recover from the effects of the EVOS, but is still declining.

Key Words: *Exxon Valdez* oil spill, harlequin duck, *Histrionicus histrionicus,* 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. *Format* - 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. *Custodian* - 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 (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 may result in long recovery periods, whereas, abnormally high adult mortality combined with 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 et al. 1998a, 1998b) and productivity (Patten et al. 1998a, 1998b) of harlequin ducks inhabiting oiled areas of WPWS. The high incidence of adult mortality directly following the oil spill coupled with successive years of poor production predisposed harlequin ducks in western Prince William Sound (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 in 1995, 1996 and 1997. The objective of the study is to determine whether the harlequin duck population in WPWS recovered from the effects of the oil spill. Preferably, we would compare pre- and post spill populations of harlequin ducks in WPWS to make this determination, however, few data on harlequin ducks exist prior to the spill. Consequently, we cannot make accurate comparisons with post-spill populations. We compared demographic characteristics of harlequin ducks utilizing areas not affected by the oil spill in eastern Prince William Sound (EPWS) with harlequin ducks in WPWS. The number of breeding pairs, age and sex composition of the population, molt chronology, and number of broods were used 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 study area. Variation between study areas in population structure or growth would indicate dissimilar extrinsic influences acting on harlequin populations.

Our surveys of nearshore transects were conducted simultaneously in EPWS and WPWS during three spring and three fall periods in 1995, 1996, and 1997, and during one winter survey in March 1997. 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 (Patten et al. 1998a) 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 and winter surveys we recorded the number of breeding pairs, and classified males as either sub-adult or adult based on plumage (Rosenberg 1995). 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 study areas 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 study areas 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 study areas 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 study areas 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 compared trends in abundance of harlequin ducks between study areas. To determine whether harlequin ducks in WPWS and EPWS exhibit similar population trends we tested the following null hypotheses:

1. The rate and direction of population change between years is the same for oiled and unoiled survey sites.

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. Although variation in population structure existed between study areas, this was minor compared with seasonal and annual differences.

Total numbers of harlequin ducks declined in early spring as breeding pairs moved from coastal areas to nesting areas along river systems. Breeding birds in both WPWS and EPWS departed for breeding areas successively later in 1996, and 1997, than 1995. Breeding chronology was similar for WPWS and EPWS. A relatively large segment of the breeding population departed our study areas to presumably nest on larger, inland river systems (non-local breeding birds). A small segment of the total breeding population remained on our study areas, suggesting that local breeding birds contributed substantially less to overall production. Compared to WPWS, relatively more pairs departed our EPWS study area, but an absolutely greater number of pairs remained on the coast in EPWS. Sex ratios were skewed towards males during all our surveys indicating that the composition of the female population contributes most to production. Similar proportions of paired females and sex ratios between EPWS and WPWS indicated similar breeding propensities.

The potential productivity of the WPWS breeding population, based on its structure, is similar to the EPWS breeding population. Relatively more non-paired females were present in WPWS than EPWS during each spring survey and the difference increased as the breeding season progressed. This suggests lower breeding propensity for females in WPWS. However, because the number of sub-adult males were equal to or greater than the number of non-paired females, we believe all non-paired females are sexually immature rather than non-breeding adults.

We detected no major differences in recruitment. Similar proportions of sub-adults indicated similar success in past breeding efforts. More information, however, is needed on the movements and distribution of sub-adults. The number of sub-adult males, relative to the total number of breeding pairs is a more accurate measure of recruitment in winter than spring. Winter populations are more stable as pairs and sub-adults have not departed for breeding grounds.

Harlequin numbers began to increase in June when males returned to the coast to molt, 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 beginning in July. The number of females in EPWS began to increase earlier in the season than in WPWS possibly because: 1) local breeders were more abundant in EPWS, and more likely to be observed if they failed or abandoned a breeding attempt, and 2) more females pass through EPWS than WPWS on route to wintering sites located outside of our study areas. 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. Non-breeding females molt earlier than breeding females. 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 remained on streams.

No harlequin broods were observed in WPWS for the third consecutive year. The substantial decrease in the number of breeding pairs during the spring suggests that birds emigrate from PWS to larger, inland breeding streams. We believe the lack of suitable breeding habitat limits breeding by harlequin ducks in PWS overall, but comparably more suitable breeding habitat is available 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.

Differences in molt chronology as a function of breeding success is difficult to interpret. Male harlequin ducks return to the coast to molt earlier than females. We believe that all post-breeding males had returned to WPWS and EPWS by late July and were counted during our fall surveys. The number of post-breeding females, however, steadily increased on our study areas throughout the fall. Consequently, the return rate of females influenced the variation in sex ratios we observed among our fall surveys. Annual variation in sex ratios in WPWS was related to annual fluctuation in the number of males rather than females, as the number of females varied little among years for a particular fall survey period (Fig. 6). In EPWS, annual variation in sex ratios was the result of annual fluctuation among survey periods in the number of both males and females (Fig. 6).

We attribute variation in sex ratios between study areas during the fall to variation in return rates by females. The number of females began to increase earlier in EPWS than WPWS, consequently, sex ratios were skewed substantially more towards males in WPWS during the first fall survey (Fig. 10). We are not certain why females return to the coast earlier in EPWS. We may be detecting breeding females that failed or aborted nesting attempts on nearby streams, or we may be detecting a return of transient females that pass through EPWS on route to molting sites south or west of our EPWS study area. The disparity in sex ratios between locations decreased with each successive fall survey, however, relatively more males were always observed in WPWS (Fig. 10).

We suspect that variation in the proportion of flight capable to flightless females may represent annual and geographic variation in breeding success. More information on the relationship between molt chronology and breeding success is needed before we can adequately interpret this portion of our survey results.

We did not detect any substantial differences in population structure between EPWS and WPWS that would indicate continued exposure to oil. Based on similarities in the composition of the breeding, molting, and wintering population of harlequin ducks in WPWS and EPWS, we believe the population in WPWS has the potential to recover from the effects of the EVOS. However, the harlequin duck population in WPWS declined during the course of our study, while it remained stable in EPWS.

We believe the population decline in WPWS is primarily a result of relatively lower survival rates, rather than lower recruitment. Until abiotic and biotic habitat characteristics are further quantified and compared between oiled and unoiled sites, we believe there is sufficient evidence suggesting that harlequin ducks in WPWS are declining. Lower survival rates among females and evidence for continued exposure to hydrocarbons (Holland-Bartels et al. 1998) supports this conclusion. Long-term population stability depends on high adult survival coupled with a relatively few years of successful reproduction (Goudie et al. 1994). Initial high losses of adults may result in a long recovery period, especially if the initial causes of mortality are still having an effect on survival.

Based on our results and the recovery criteria (Exxon Valdez Oil Spill Trustee Council 1996), harlequin ducks have not recovered from the effects of the *Exxon Valdez* oil spill. A similar population structure in EPWS (unoiled) and WPWS (oiled) indicates that the population in oiled areas of WPWS has the potential to recover from the effects of the EVOS. However, our trend analysis indicates that the population in oiled areas is still declining.

INTRODUCTION

Thousands of marine birds died as a result of direct contact with oil following the *Exxon Valdez* oil spill (EVOS) on 24 March 1989 in Prince William Sound (PWS), Alaska (Piatt et al. 1990, Ecological Consulting, Inc. 1991, Piatt and Ford 1996). Approximately 30,000 marine bird carcasses recovered from beaches and waters of PWS and the Gulf of Alaska following the EVOS were killed by oil pollution (Piatt and Ford 1996). Retrieved carcasses, however, represent a small fraction of total birds killed. Estimates of total mortality are much higher and fall within the extreme range of 100,000-690,000 birds (Piatt and Ford 1996). Sea ducks (Mergini) comprised approximately 25% of all bird carcasses retrieved from PWS (ca. 3,400 total birds), representing the highest mortality of any species group in that region; only second to alcids when the entire geographic range of the EVOS is considered (Piatt et al. 1990).

Harlequin ducks *(Histrionicus histrionicus)* occur year-round in PWS (Isleib and Kessel 1973) and were the most abundant waterfowl species along nearshore transects surveyed prior to the EVOS (Irons et al. 1988). Much of the wintering population departs coastal waters during the breeding season in spring, although a segment of the population remains in PWS throughout the year (Rosenberg et al 1996). The EVOS occurred prior to movements to breeding areas, consequently the entire wintering population in oiled areas were at risk of exposure. One hundred and forty seven harlequin duck carcasses were recovered in PWS following the EVOS (Dr. John Piatt, USGS-BRD pers. comm.). However, the number of carcasses recovered is, at best, a poor indicator of total mortality because of the vast extent of the spill, rapid disappearance rate of oiled carcasses, removal by abundant scavenging species, and relatively few observers in the spill area (Ecological Consulting, Inc. 1991). Through extrapolation, a minimum mortality estimate of 423 harlequins in PWS (Ecological Consulting, Inc. 1991) and 1298 harlequin ducks for the entire EVOS zone is generally recognized (Dr. John Piatt, USGS-BRD pers. comm.).

When on the coast, harlequin ducks utilize intertidal and shallow, subtidal zones exclusively while foraging for invertebrates in PWS (Dzinbal and Jarvis 1982), more so than other sea ducks (Goudie and Ankney 1988). These nearshore habitats were subjected to the most severe and persistent effects of oiling (Highsmith et al. 1996, Short and Babcock 1996). Because of the year-round abundance of harlequin ducks, their nearshore habitat preference, and strong fidelity to molting and wintering areas on coastal waters (Robertson 1997, Holland-Bartels et al. 1998), harlequin ducks were considered more vulnerable to the effects of the EVOS than other sea duck species which feed in deeper waters (Koehl et al. 1982, Sanger and Jones 1982, Vermeer and Bourne 1982). Harlequins were at potentially more risk to continued exposure to petroleum hydrocarbons through their food (Hotchkiss 1991). Consequently, damage assessment studies were designed to measure the extent and severity of injuries to the harlequin duck population caused by the EVOS (Klosiewski and Laing 1994, Patten et al. 1998a, 1998b).

Results of small boat (Agler et al. 1995, Agler and Kendall 1997) and aerial (Hotchkiss 1991) surveys of marine bird populations in PWS conducted after the EVOS are equivocal with respect to the effects of oil contamination on the population level of harlequin ducks. Most evidence, however, suggests that harlequin numbers declined significantly, and continued to decline in oiled areas of PWS up to 3 years after the spill (Klosiewski and Laing 1994, Patten et al. 1998a, 1998b), but stopped declining soon afterward (Agler et al. 1995, Day et al. 1995, Murphy et al. 1997). Confounding the interpretation of these results is the: 1) limited and distant (in time) pre-spill data available (see Dwyer et al. 1976, Hogan and Murk 1982, Irons et al. 1988); 2) lack of power to detect trends from few years of post-spill surveys (Klosiewski and Laing 1994, Agler et al. 1994, Agler et al. 1995, Agler and Kendall 1997); (3) potential for birds to immigrate to, or emigrate from oiled areas (Hotchkiss 1991, Klosiewski and Laing 1994); and (4) little knowledge of seasonal variation in population numbers. Additionally, with the exception of Patten et al. (1998a) and Patten et al. (1998b), pre- and post-spill surveys were designed to enumerate all marine bird species, consequently survey methodology may be biased towards a particular species or species group. Also, the accuracy of recording all species may become compromised in areas with large concentrations of birds utilizing a variety of habitats.

Patten et al. (1998a, 1998b) conducted studies designed specifically to investigate the effects of oil contamination on harlequin ducks after the EVOS. These studies reported that harlequin ducks collected in oiled areas in 1989-1990 ingested foods contaminated with oil, and had elevated levels of petroleum metabolites (polynuclear aromatic hydrocarbons) in bile samples (Patten et al 1998a, but see Bence and Burns 1995). Consequently, Patten et al. (1998a) believed that harlequin ducks in oiled areas of PWS were being continuously exposed to oil and exhibited sub-lethal effects of oil contamination. The observation of only 4 harlequin broods during surveys in oiled areas of PWS from 1990 through 1992 provided evidence that sub-lethal effects of oil contamination reduced productivity (Patten et al. 1998a). Harlequin broods were more frequently observed in these oiled areas prior to the spill (Oakley and Kuletz 1979, Patten et al. 1998a), and broods were frequently observed during the same time period in unoiled areas of PWS (Crowley 1996).

Patten et al. (1998a) concluded that productivity by harlequin ducks was impaired by the EVOS and would remain impaired until intertidal communities were no longer contaminated with oil and former breeding sites were recolonized. These conclusions were based on low densities of breeding pairs, lack of breeding activity on coastal streams, and few brood observations. Studies of intertidal communities affected by the EVOS indicate that oil contamination was highest during the first few weeks after the spill followed by a consistent decline (Babcock et al. 1996, Short and Babcock 1996, Hooten and Highsmith 1996). Recovery of invertebrate densities had occurred by the end of 1993 at oiled sites in the lower and middle intertidal zone, but recovery in upper intertidal areas remained incomplete for some taxa (Hooten and Highsmith 1996). On average, total polynuclear aromatic hydrocarbons measured in sediments underlying mussel beds were 50% lower in 1993 than in 1992, but showed little change in protected (from wave action), low-energy areas (Babcock et al. 1996).

Extensive surveys of PWS in 1994 failed to detect harlequin broods in oiled areas (Rosenberg 1995), providing alternative evidence that sub-lethal affects of oil contamination continues to influence harlequin productivity 5 years after the EVOS. Combined with the fact that residual oil still persisted in certain areas of PWS 6 years after the EVOS (Rosenberg pers. observ.) was cause for concern that the harlequin duck population had not yet recovered, and is still at risk of continued exposure to oil.

Relative to dabbling (Anatini) and diving (Aythyini) ducks, sea ducks are considered *K* selected species because: (1) first breeding occurs later than 1 year of age; and (2) their life history is characterized by (a) low rates of annual recruitment, (b) high adult survival, and (c) relatively low and variable breeding propensity (Goudie et al. 1994). Because long-term population stability depends on high adult survival, sea ducks are sensitive to catastrophic causes of mortality such as exposure to oil (Goudie et al. 1994).

A significant decline in numbers resulting from an acute increase in adult mortality would potentially predispose a population of sea ducks to a relatively long recovery period. Mortality through direct contact with oil, however, represents only a fraction of total mortality when continued exposure to oil results in reduced future survival, further lengthening the recovery process. Additionally, sublethal effects of oil pollution may result in lowered productivity when ingestion of contaminated foods, or a reduction in prey abundance resulting from oiling, prevents birds from attaining breeding condition. Extirpation of a sea duck population may occur when continued exposure to oil results in abnormally high levels of adult mortality and long periods without recruitment.

OBJECTIVES

This study was initiated to determine whether the harlequin duck population in oiled areas of PWS recovered from the effects of the EVOS. Previous surveys relied solely on measures of total abundance to make comparisons between harlequin populations in oiled areas of PWS pre- and post EVOS, and between harlequin populations inhabiting oiled and unoiled areas of PWS. We believe, however, that measures of composition and productivity reveals more about the status of a population than total numbers alone, and when combined with annual changes in density, provides a more comprehensive measure for comparison. We hypothesized that the population structure and levels of productivity of harlequin ducks in oiled and unoiled areas of PWS would be similar if the harlequin population in previously oiled areas had recovered from the effects of oil exposure. We used the number of breeding pairs, age and sex composition of the population, chronology of molt and the number of broods as parameters to determine whether harlequin ducks in oiled and unoiled areas of PWS exhibit similar demographic characteristics. We used annual counts of harlequin ducks to compare population trends in each area (oiled vs. unoiled). We hypothesized that population structure or growth in oiled and unoiled areas would be different if dissimilar extrinsic influences acted on harlequin populations. We interpret variation between harlequin populations with respect to geographic and environmental variation between locations, both related and unrelated to the effects of oil pollution.

STUDY AREA AND METHODS

The study was conducted in Prince William Sound (PWS) (ca. 60°30'N, 147°00'W), a marine water body located on the southcentral coast of Alaska (Fig. 1). Prince William Sound is a large estuarine embayment of the northern Gulf of Alaska characterized by fjord-like ports and bays surrounded by steeply rising mountains. Highly irregular in shape, it is approximately 160km east to west and 140km north to south. Tides can exceed 4.5m and water depth can reach 870m in places. Total shoreline (including islands) is approximately 5,000 km. A general description of the physiography, climate, oceanography, and avian habitats of PWS was described by Isleib and Kessel (1973). After running aground on Bligh Reef in northern PWS, oil from the *T/V Exxon Valdez* spread southwest, oiling 563 km of shoreline in PWS before spreading to the Gulf of Alaska (Galt et al. 1991) (Fig. 1).

We surveyed harlequin ducks in areas of WPWS oiled by the EVOS and in areas of EPWS geographically distant from oiled areas (Fig. 1). Study areas were separated by a minimum of approximately 35km. Our shoreline transects were subjectively distributed in each study area, but to maintain a historical perspective for long-term monitoring, transects were established in locations previously surveyed by Patten et al. (1998a). All transects located in the EPWS study area were known to support relatively high densities of harlequin ducks. Relatively high-density areas were selected in WPWS, but some low-density areas were also selected because we believed they might serve as a useful indicator for recovery. 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). Transects varied relative to the extent and amount of oil they received. Some transects were along shorelines that were lightly and sporadically oiled while others were heavily oiled. In EPWS, transects were distributed in selected areas from Shoup Bay in Valdez Arm to Simpson Bay, northwest of Cordova, and included portions of Hinchinbrook Island (Fig. 3). Transects included nearshore habitats and concomitant offshore rocks.

Transects were surveyed simultaneously in EPWS and WPWS during three spring and three fall survey periods at approximately the same time in 1995, 1996, and 1997 (Table 1). On average, each completed survey period lasted approximately eight days in WPWS and seven days in EPWS. Spring surveys were timed to monitor harlequin ducks during the breeding season, while fall surveys coincided with molting and brood rearing. An additional survey was conducted from 13 - 19 March 1997 to monitor the wintering population (winter survey).

Surveys were conducted from open skiffs (ca. 6m long) traveling at 2-10 km/hr within 100 meters of shore at a pace, course, and distance that assured complete coverage of the survey area. This included circling all exposed rocks, and scanning shallow lagoons from shore when boat travel was not possible. Boating distance from shore depended on light, weather, and tide conditions. One full-time observer and an observer/boat operator continuously surveyed nearshore habitats using 10X binoculars. We preferred to observe flocks of resting ducks from a vantage point on shore using a 20X-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) (Appendix A1-A37). During spring and winter surveys, males were classified as adult or sub-adult based on plumage patterns (Rosenberg 1995). Sub-adults require more than one year to reach sexual maturity (Terres 1980). Male harlequin ducks attain adult nuptial plumage in their second-year of life (Cyndi Smith, Banff National Park, unpubl. data, Rosenberg pers. observ.) and can no longer be visually separated from adults. However, they may remain sexually immature. Therefore, we use the term sub-adult to refer to birds still in their first-year of life but in their second calendar year (e.g., hatched in July 1996, and observed in May 1997) unless otherwise noted. Juveniles refer to birds recently fledged and still in their first calendar year of life (e.g., fledged in July 1996, and observed in September 1996). Sub-adult females could not be visually differentiated from adults. When referring to the literature, we indicate the age of sub-adult males and females (calendar year) if reported and pertinent to our discussion.

We subjectively classified an adult male and female as a breeding pair when they were 1) physically closer to each other than either was to the next closest duck when roosting, swimming or in flight; or 2) their behavior suggested that a pair-bond had formed (Inglis et al. 1989, Gowans et al. 1997).

During fall surveys, we recorded the number of flightless and flight-capable harlequin ducks in each flock to compare the chronology of molt between study areas. 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 assess their flight capability and minimize incorrect classification of resting flocks. We could not categorize males to age class during the fall because they were no longer in alternate (breeding) plumage. Broods were identified by the presence of down on ducklings. Ducklings were aged according to Gollop and Marshall (1954). Harlequin ducks that could not be identified by sex were not classified.

Variation in Survey Coverage

Shoreline length (km) of transects 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. We selected more transect locations in EPWS (n=26) than WPWS (n=18) (Table 2), but total shoreline length was greater in WPWS (Table 3). Transect length was variable ranging from 1 to >70 km (Table 2). Average transect length was 16.7 km (SD=19.6) and 10.0 km (SD=7.4) in WPWS and EPWS, respectively. Variation in survey coverage within study areas (mostly in WPWS) existed among years and survey periods because, on occasion, poor weather conditions or a mechanical problem with a boat precluded the completion of some (or portions of) transects (Table 3). An extreme example occurred 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 in WPWS (Table 3). Other variation in survey coverage in WPWS was limited to one transect location (Naked Island = 73.2 km) that could not be surveyed in its entirety during the first spring (23.1 km surveyed) and third fall surveys (42.6 km surveyed) in 1995. In EPWS, one transect (Shoup Bay = 9.5 km) was not surveyed during the third fall survey in 1995 and during the winter survey in 1997. A total of 301.1 km and 249.2 km of shoreline were surveyed in WPWS and EPWS, respectively, during the winter survey.

To increase the likelihood of locating harlequin broods, we expanded our fall survey coverage to include potential brood rearing areas not visited during our standard surveys. The additional survey coverage included mostly stream mouths in sheltered bays where pre- and post-spill (Patten et al. 1998b) observations of harlequin broods were reported. We added seven transect location in WPWS (Fig. 2) and eight in EPWS (Fig. 3), however, some transects were not surveyed during all survey periods because of foul weather (Table 4). In WPWS, shoreline coverage was progressively shortened in 1995 to reduce survey time and effort. One transect was eventually eliminated.

Statistical Methods

Ratio Analysis

We used a generalized logit model (Agresti 1990) to test for differences between study areas (EPWS and WPWS), among years (1995, 1996 and 1997) and survey periods for the following ratios: (1) male to female harlequin ducks during the spring and fall; (2) adult males to sub-adult males during the spring; (3) non-paired to paired females during the spring; and (4) flightless to flight-capable females and males during the fall. A test of the hypothesis of no interaction between main effects (i.e., study area, year, and survey) was based on a likelihood ratio test (Stokes et al. 1995). Non-significant interaction terms were excluded from the model and a reduced model was used to test for significant study area, year, or survey effects. We used the natural logarithm of ratios to emphasize variation among years, surveys and between locations. Harlequin ducks classified as unknown, ducks counted on transects surveyed only in the fall (Appendix B), and ducks counted during the winter survey were not included in the ratio analysis. We did not adjust our counts of harlequin ducks to compensate for variation in survey coverage among years and survey periods for our ratio analysis because we used relative measures of abundance. Variation in ratios resulting from the inclusion of data from an incomplete survey in WPWS (second spring survey) in 1995 is specifically discussed when we believe the reduced sample size influenced our analysis.

Trend Analysis

We used the number of harlequin ducks counted during fall surveys to compare trends in abundance between study areas. We analyzed our data in a hierarchical fashion at three spatial scales: (1) transect, (2) region, and (3) study area using simple linear regression. To estimate the rate of change among years for WPWS and EPWS at the "transect" level, we regressed density of harlequin ducks against year to generate a slope and variance for each transect during each fall survey period ($n = 3$), separately. A mean slope for each study area was then calculated by weighting the slopes for each transect by the total number of ducks counted during the survey period in all years combined. At the intermediate spatial scale ("region"), we combined transects that were in close proximity to each other (Table 2), and were for the most part, geographically distant from other regions. At the broadest spatial scale ("study area"), we summed the number of harlequin ducks for each study area during each survey period, separately.

A two-sample t-test was used to test for differences in the rate of change in duck density between WPWS and EPWS at each spatial scale. We then calculated our power to detect differences in slopes between locations. We did not use harlequin ducks counted on transects surveyed only during the fall in our trend analysis. We did not use data for the Shoup Bay transect in EPWS during the third fall survey because harlequin ducks were not observed there.

Absolute Measures

When illustrating annual and seasonal variation in the number and composition of harlequin ducks, we adjusted our counts in WPWS to include only those birds located in areas of comparable survey coverage, thereby adjusting for annual and seasonal differences in survey effort. It was unnecessary to adjust counts in EPWS. The number of harlequin ducks classified as unknown varied among our surveys. To avoid erroneous interpretation when comparing the absolute abundance of specific components of the population, we partitioned unknown birds among the appropriate age, sex, flight, and breeding categories based on observed proportions.

RESULTS

Harlequin Duck Abundance and Distribution

We could not compare total counts of harlequin ducks between WPWS and EPWS because survey effort varied between study areas (Table 3). Density comparisons may also be inappropriate because transect locations were arbitrarily selected and harlequin ducks, for the most part, utilized particular segments of transects (e.g., emergent rock, rocky point) with a high degree of regularity regardless of survey period, creating a patchy rather than uniform distribution throughout PWS (Appendix A1-A37). We believe we were less likely to survey areas with little or no harlequin use in EPWS. Seasonal and annual trends in abundance and composition, however, can be compared between WPWS and EPWS because our surveys were conducted simultaneously in both study areas (spring and fall surveys), or when population numbers were thought to be stable (winter survey).

During the spring (Table 5) and fall (Table 6), we counted more harlequin ducks in EPWS than WPWS, except during the third spring survey in 1995 and 1996. Conversely, we counted more harlequin ducks during the winter survey in WPWS (Table 7). The number of harlequin ducks varied among and within transects among survey periods in WPWS (Table 8) and EPWS (Table 9). Harlequin ducks were observed during at least one survey period on all transects surveyed, however, ducks were frequently absent on the Masked Bay transect in WPWS (Fig. 2) and the Black Creek transect in EPWS (Fig. 3). For all surveys and years combined, harlequin ducks were absent on 6% (19/328 transects) of transects surveyed in WPWS and 10% (47/492 transects) in EPWS. Transects which consistently supported a large proportion of the total number of harlequin ducks in WPWS included Green Island, Foul Bay, Bay of Isles, Channel Island, and Falls Bay (Table 8, Fig. 2). Green Island and nearby Channel Island, combined, accounted for 42%, 32% and 31% of the total ducks counted in WPWS in 1995, 1996 and 1997, respectively. In EPWS, a large proportion of the total number of harlequin ducks were observed on the Port Gravina (SE), Sheep Bay (east), Olsen Bay and Hell's Hole transects (Table 9, Fig. 3).

General Pattern of Seasonal Movements

The number and composition of harlequin ducks in WPWS (Table 5) and EPWS (Table 6) varied among survey periods because of seasonal movements by ducks into and out of the study area. The total number of harlequin ducks in both study areas declined in May, and continued through mid-June in EPWS regardless of year, whereas, an increase in numbers was observed during this period in WPWS (Fig. 4). In both WPWS and EPWS, the initial decline in the total number of harlequin ducks can be attributed to a decline throughout the spring in the number of breeding pairs (Fig. 5). The decline in breeding pairs was accompanied by a decline in the total number of females, however, the total number of males declined in May, but then increased in June (Fig. 6).

During the approximate one-month period between our last spring survey (mid-June) and our first fall survey (late July) the number of male harlequin ducks increased substantially in both study areas (Fig. 6). Females returned to the coast later than males, and progressively increased throughout the fall (Fig. 6). Except for EPWS in 1996, the greatest number of harlequin ducks recorded during the breeding and molting seasons occurred during the last fall survey (Fig. 4).

In March 1997, the number of male and female harlequin ducks in WPWS increased over counts recorded in September 1996, while numbers decreased in EPWS (Fig. 7). Between our March 1997 survey and our first spring survey in May 1997, total counts of harlequin ducks declined in WPWS while they increased in EPWS (Fig. 7).

Variation Among Spring Surveys

Total Abundance of Harlequin Ducks

Except for WPWS in 1995, we counted the most harlequin ducks in the spring during the first survey (Table 5). We counted progressively more harlequin ducks during the first spring survey in 1996 and 1997 than in 1995 in both study areas (Fig. 4) even though surveys began at approximately the same time in each year (Table 1). When adjusted for comparable survey effort, harlequin counts during the first spring survey were 30% and 72% higher in 1996 and 1997, respectively, than in 1995 in EPWS, and 13% and 40% higher in WPWS. Conversely, we counted progressively fewer harlequin ducks during the third spring survey in 1996 and 1997 than in 1995 in both study areas (Fig. 4). Harlequin counts during the third spring survey in 1995 were 20% and 28% higher than in 1996 and 1997, respectively, in EPWS and 19% and 77% higher in WPWS. Overall, counts of harlequin ducks were more variable in EPWS during the first spring survey (coefficient of variation = 26.9%) than the second (C.V. = 11.1%) and third spring survey (C.V. = 13.3%). In WPWS, for the 2 complete survey periods, counts of harlequin ducks were more variable during the third (C.V. = 27.5%) than first spring survey (C.V. = 17.2%).

Sex Ratios

In our model of sex ratios for harlequin ducks in the spring, main effects (study area, year and survey) and interaction terms (all two-way and three-way interactions of the main effects) were significant and could not be excluded (Table 10). Sex ratios were skewed towards males during each spring survey in both WPWS and EPWS (Fig. 8). The smallest male:female ratio for completed surveys occurred during the first survey (range: 1.5:1 - 1.8:1), and the largest ratio occurred during the third survey (range: 3.6:1 - 8.9:1) (Table 11). Differences between WPWS and EPWS in sex ratios varied among survey periods and years (Table 10). Relatively more males were observed in WPWS than EPWS during the first spring survey in all years of the study, the largest and smallest difference between study areas occurring in 1995 and 1997, respectively (Fig. 8). Relatively more males were observed in WPWS during all surveys in 1997 with the relative difference between study areas increasing with each successive survey period (Fig. 8). Sex ratios were more variable in WPWS than EPWS with the greatest difference among years occurring during the third spring survey (Fig. 8).

Non-breeding (non-paired) and breeding (paired) females

Ratios of non-paired to paired female harlequin ducks were best explained by a saturated (full) model (Table 10). A non-significant year*survey and study area*survey interactions were retained in the model because of a significant year*study area*survey term (Table 10). The proportion of non-paired females progressively increased with each successive survey period in WPWS and EPWS (Fig. 8). More non-paired than paired females were counted in WPWS during the second and third spring surveys in 1995 and 1996 and during the third spring survey in 1997 (Fig. 8). In EPWS, the number of non-paired females was larger than paired females during the third spring survey in all years (Fig. 8).

The number of paired female harlequin ducks declined in WPWS and EPWS from May through June with the progression of nest initiation (Fig. 5). During our third spring survey we observed no more than 12 paired females in WPWS and 41 in EPWS (Table 5). Except for the second and third spring surveys in 1997, more non-paired females were observed in WPWS, while more paired females were observed in EPWS (Fig. 5).

For the number of non-paired females, the difference between study areas was variable with respect to survey period and year (Fig. 8). No apparent trend was observed in WPWS, while a slight increasing trend was observed in EPWS (Fig. 5). The largest proportion of non-paired females was observed in WPWS during the third survey in 1995 (20.3:1) and the smallest proportion was observed in EPWS during the first spring survey in 1997 (0.1:1) (Table 11). Among year variation in the number of non-paired females in WPWS was lowest during the first spring survey (C.V. = 11.8%) and highest during the third survey (C.V. = 57.9%) for the 2 years of complete survey coverage. In EPWS the largest annual variation in the number of non-paired females occurred during the second (C.V. = 31.1%) rather than the first (C.V. = 20.9%) or third (C.V. = 8.7%) survey.

Male Age Composition

The ratio of adult to sub-adult males was best explained by a full model where main effects and interaction terms could not be excluded (Table 10). A non-significant study area effect and year*survey and study area*survey interactions were retained in the model because of the significant year*study area*survey term (Table 10).

Adult males always outnumbered sub-adult males during our spring surveys, however, sub-adult males were frequently observed in both WPWS and EPWS (Fig. 9). During most spring surveys the ratio of adult to sub-adult males was greater in EPWS than WPWS (Table 11, Fig. 8). In two out of three years (1995 and 1996) more sub-adult males were counted in WPWS than EPWS (Fig. 9). In general, the greatest relative difference between adult and sub-adult males occurred during the first spring survey, declined during the second survey and then increased during the third survey (Fig. 8, Table 11).

Variation Among Fall Surveys

Total Abundance of Harlequin Ducks

Except for EPWS in 1996, the number of harlequin ducks progressively increased during our fall surveys (Fig. 4, Table 6). Annual variation in total counts among survey periods was less variable during the fall than spring. The coefficient of variation for harlequin counts increased slightly from 7.7% during the first fall survey to 9.2% during the third fall survey in WPWS, and from 5.1% to 8.3% in EPWS.

Sex Ratios

In our model of sex ratios during the fall survey period the year*study area*survey interaction was not significant ($p = 0.887$) and was excluded from the model. A non-significant year*study area interaction (Table 10) was retained in the model because excluding this term resulted in a poorer fit of the data (prob. for maximum likelihood ratio = 0.605 vs. 0.887).

Sex ratios were skewed towards males during all fall survey periods in both study areas (Fig. 10, Table 11). The largest male:female ratio occurred during the first survey (range: 7.9:1 - 3.0:1), and the smallest ratio occurred during the third survey (range: 1.5:1 - 2.0:1) for both locations (Table 11). Relatively more males were observed in WPWS than EPWS during all fall surveys, but the difference between locations decreased with each successive survey period (Fig. 10, Table 11).

Molt Chronology

Male harlequin ducks exhibited a more synchronous and earlier molting period than did females (Fig. 10). In our model of the ratio of flight capable to flightless males, main effects and interaction terms could not be excluded (Table 10). A non-significant year effect was retained in the model because of the significant year*survey and year*study area*survey interaction (Table 10). During the first and second fall surveys most males were flightless (> 97% in WPWS and EPWS), while during the third fall survey, most males were flight capable (> 95% in WPWS and > 82% in EPWS).

In our model of the ratio of flight capable to flightless females, main effects and interaction terms were significant and could not be excluded (Table 10). The proportion of flight capable females was always greater in EPWS during the first fall survey while it was always greater in WPWS during the second fall survey (Fig. 10). During the third fall survey, the proportion of flight capable females was greater in WPWS in two of three years. The greatest variation between study areas occurred during the first and third survey periods, except for 1997 when ratios during the third fall survey were relatively similar (Fig. 10).

Brood Observations

Harlequin duck broods were observed only in EPWS (Fig. 11). Ten broods, totaling 26 ducklings (mean = 2.6, SD = 1.35) were observed at seven locations during fall surveys in 1995, 14 broods totaling 54 ducklings (mean = 4.2, SD = 2.36) were observed at nine locations in 1996 and 12 broods totaling 32 ducklings (mean = 2.7, SD = 1.07) were observed at five locations in 1997 (Table 12). We do not know what proportion of broods were observed on more than one survey. All broods were observed at or near the mouth of coastal streams (Fig. 11). Harlequin broods were not observed in WPWS during the three consecutive years of this study nor during surveys conducted in 1994 in the same locations (Rosenberg 1995).

We observed two harlequin broods in Port Nellie Juan (WPWS) outside our study area. An adult female with two flightless young (class IIB) was observed in East Finger Inlet, on August 19, 1995. An adult female with two juveniles (class III) was observed at the creek mouth in West Finger Inlet on August 18, 1997. We observed a female with a brood of two in Hanning Bay, Montague Island in 1994 (Rosenberg 1995). Broods were also observed at Hanning Creek by Patten et al. (1998a) and Grinnel (1910).

Winter Survey

Abundance

The total number of harlequin ducks, the number of adult males, females and sub-adult males, and the number of breeding pairs were greater in WPWS than EPWS during the winter survey (Table 7). This was contrary to what we observed during spring and fall surveys. We counted more ducks during the March 1997 survey in WPWS than we counted during spring or fall surveys in all years (Table 8). Conversely, we counted fewer ducks during the March 1997 survey in EPWS than we counted during fall surveys in EPWS (Table 9). Thus, the number of harlequin ducks increased in WPWS between September 1996 and March 1997, then declined during the period between March 1997 and May 1997 (Fig. 7). In EPWS, the number of harlequin ducks declined during the period between September 1996 and March 1997, then increased between March 1997 and May 1997 (Fig. 7). Numbers of sub-adult males were generally lower during the winter than during spring surveys in both study areas (Tables 5, 7).

Composition

Compared to spring and fall surveys (Table 11), sex ratios were skewed less towards males during the winter in WPWS (1.49:1) and EPWS (1.38:1). Unlike other survey periods (Table 11), the non-paired to paired female ratio during the winter was lower in WPWS (0.41:1) than EPWS (0.56:1). The ratio of adult to sub-adult males was substantially higher during the winter in WPWS (11.3:1) and EPWS (11.4:1) than it was during spring and fall surveys (Table 11).

Trends in Abundance

During the three years of this study, using fall survey data, we calculated a negative rate of change in the number of harlequin ducks in WPWS and a positive rate of change in EPWS regardless of spatial scale (Table 13). A significant trend, however, was only obtained in WPWS ($p = 0.023$) when transects were grouped by "region" (Table 13). When analyzed separately by sex, both males ($p = 0.052$) and females ($p = 0.007$) exhibited significant declines in WPWS, while no trend was observed in EPWS (Table 13). By combining transects into "regions" we reduced the variability associated with small movements by ducks among transects in a centralized area, thereby reducing the variability associated with the weighted mean slope (Table 13). Consequently, we propose that grouping transects at the "region" spatial scale is a better method of analyzing trend data for harlequin ducks in Prince William Sound than at the "transect" or "study area" spatial scale.

We did not detect significant variation in weighted mean slopes between WPWS and EPWS at the transect and study area spatial scale; however, our power to detect differences in trends was low (Table 14). At the region level, trends in the abundance of harlequin ducks was significantly different between WPWS and EPWS when sexes were combined, or analyzed separately (Table 14). At $\alpha = 0.05$, with the observed difference in slopes of 0.394, we would correctly reject the null hypothesis that there is no difference in the rate of change of harlequin populations between WPWS and EPWS 79.4% of the time (Table 14). For males and females, with an observed difference in slopes of 0.729 and 0.264, respectively, we would correctly reject the null hypothesis that there is no difference in the rate of change between locations 67.4% of the time for males and 70.0% of the time for females (Table 14).

DISCUSSION

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

We were surprised when we counted substantially more harlequin ducks in WPWS than EPWS during the winter (Table 7), especially when counts during other survey periods indicate greater abundance of harlequin ducks in EPWS (Tables 5, 6). The inconsistency in results between our fall and winter, and winter and spring surveys introduces new hypotheses for future testing.

Ultimately, our goal was to compare harlequin duck populations in oiled areas of WPWS with unoiled areas of EPWS to determine whether variation exists between populations. Similarity in composition and positive trends in abundance would indicate that the harlequin population in WPWS has recovered from the effects of the EVOS. First, however, before variation between populations can be interpreted with respect to recovery, we must determine whether seasonal (among surveys) and annual (among years) variation observed within populations compares similarly between populations. We utilized data from other studies to aid in the interpretation of our results. However, besides the relative paucity of information on specific aspects of harlequin duck ecology, a large proportion of harlequin duck studies 1) base their conclusions on relatively small sample sizes; 2) are conducted in more temperate latitudes that may not be comparable to Alaska (site specific differences); and 3) differ from our study in spatial scale, timing (seasonally), and objectives. Consequently, some results of our study are difficult to interpret based on comparisons with other studies. Nevertheless, we attempted to consider all plausible explanations when discussing variation observed in harlequin populations in PWS, whether seasonal, annual, or geographic.

Variation Among Survey Periods

Spring

The harlequin duck population in PWS during spring was comprised of breeding and non-breeding birds, the proportion of which changed dramatically as the spring advanced (Fig. 8). Harlequin ducks throughout their North American range depart coastal wintering areas for inland breeding sites (Bellrose 1980, Harlequin Duck Working Group 1993). Consequently, we usually observed the most ducks during the first survey (Table 5), when the largest proportion of the breeding population was present. The substantial decline we observed in the number of breeding pairs in both WPWS and EPWS (Fig. 5) indicated that a relatively large segment of the breeding population emigrated from the coast, probably to nest on larger, inland river drainages.

We observed few breeding pairs in our study areas during our third spring survey in mid-June (Fig. 5). We believe this indicates a relatively small local population of breeding birds. Once non-local breeding birds leave the study area, local breeding and non-breeding birds comprise a substantially larger proportion of the harlequin population. This explains the increase in non-paired to paired female ratios we observed during the spring (Fig. 8).

We consistently observed more male than female harlequin ducks on our surveys (Fig. 8). Sex ratios skewed toward males are typical for sea ducks (Goudie et al. 1994), and have been reported for numerous harlequin populations on wintering (Fleischner 1983, Zwiefelhofer and Forsell 1989, Campbell et al. 1990, Byrd et al. 1992) and breeding areas (Bengtson 1972, Kuchel 1977, Dzinbal 1982, Inglis et al. 1989, Cassirer and Groves 1992, Smith 1996, Wright and Goudie 1998). Sex ratios were more similar during the first survey than other spring surveys (Fig. 8) because relatively more breeding pairs were present (Fig. 5).

The proportion of males increased as the spring progressed because males returned to the coast much earlier than females. During the period between the first and second survey, the number of harlequin ducks declined because of a net movement of breeding birds out of the study area. Meanwhile, the number of sub-adult males and non-paired females remained relatively constant and the number of adult males gradually increased (Figs. 5, 9). Between the second and third survey, however, the number of females continued to decline (Fig. 6), while the number of adult males increased substantially (Fig. 9). This increase in adult males is attributed to the breakdown of pair bonds on breeding streams and a return to the coast (Dement'ev and Gladkov 1967, Bengtson 1972, Kuchel 1977, Cassirer and Groves 1992, Clarkson 1992, Diamond and Finnegan 1993, Ashley 1994, Smith 1996, Bruner 1997). The early return of post-breeding males to the coast masks the continued decline in paired males, and eventually marks the end of the net movement by harlequin ducks out of our study areas

Relative to adult males, the number of sub-adult males varied substantially less among our spring surveys (Fig. 9), indicating that sub-adult males are less likely to depart our study areas. Sub-adult males are an unusual occurrence on breeding streams in Iceland (Bengtson 1972) and they have not been reported on breeding streams in North America (Kuchel 1977, Wallen 1987, Cassirer and Groves 1992, Clarkson 1992, Ashley 1995, Crowley and Patten 1996, Beth MacCallum pers. comm. Bighorn Environmental Design Ltd., Hinton, Alberta). Consequently, movements by paired adult males to breeding areas in May, and their subsequent return to the coast in June, was largely responsible for the variation we observed in male age ratios among spring surveys (Fig. 8). Non-paired adult males (second-year and older) may also migrate to breeding streams where they are much less abundant than paired males (Kuchel 1977, Smith 1996, McCaffery and Harwood 1996, Wright and Goudie 1998). However, their movements also contribute to the variation we observed in male age ratios.

The continued decline in females we observed is likely the result of late-breeding pairs moving to nesting areas (Kuchel 1977). Our spring surveys did not detect a consistently late decline in non-paired females (Fig. 5), despite reports of non-paired females arriving on breeding streams up to 3-4 weeks later than breeding adults (Perfito and Schirato 1998). Numbers of non-paired females in spring may be confounded by a variety of events, including pair breakdown, immigration and emigration, and some "double-counting" of flying birds.

Fall

Whereas variation in the number and composition of harlequin ducks we observed during the spring is explained mostly by movements of the breeding population out of the study area, variation during the fall is explained by differences between males and females in return rates to the coast.

Numbers of post-breeding males increased substantially between the last spring and first fall survey (Fig. 6). This resulted in a large net increase in the number of harlequin ducks relative to our late spring counts (Fig. 4). Females did not increase in WPWS during this period, but we observed a slight increase in EPWS. This was the first indication of females returning to the coast (Fig. 6).

We observed an earlier return to the coast and a more synchronous molting period by males compared to females (Fig. 10). We believe the entire male population returned to the coast by the time of the first fall survey. Throughout their range, harlequin males depart breeding streams soon after the onset of incubation (early June to early July) and return to the coast (Kuchel 1977, Bruner 1997, Dement'ev and Gladkov 1967, Clarkson 1992, Diamond and Finnegan 1993, Ashley 1994, Cassirer and Groves 1992, Smith 1996). Variation in the timing of return may be a function of distance to the nesting site (Robertson and Cooke 1998). In Alaska, Murie (1963) observed one male in Denali National Park as late as July 24.

The number of male harlequin ducks varied substantially less among our fall surveys than the number of females (Fig. 6). This was another indication that our fall surveys began after all males had returned to the coast. We attribute variation in male numbers between the first and second fall surveys to movements by the few flight-capable males rather than a seasonal change in male numbers. This is because most males (<93%) were flightless, and harlequin ducks exhibit fidelity to molting sites (Robertson 1997, Holland-Bartels et al. 1998). By the third fall survey, most males could fly (>80%) (Fig. 10), increasing the probability of measurement error ("double counting") which may explain the general increase in males at this time (Fig. 6).

The principal factor explaining the increase in harlequin ducks during surveys in August and September was the increasing return of females (Fig. 6). Unlike males, the return of females to the coast (Fig. 6) and their molt chronology (Fig. 10) was variable and may be related to age and breeding success (Bruner 1997, John Ashley, Glacier National Park pers. comm., Cyndi Smith, Banff National Park, pers. comm.). Females that successfully raise young remain on streams the longest, while non-breeders and failed nesters depart streams earlier, although this departure can occur over several weeks duration (Bruner 1997, John Ashley, Glacier National Park pers. comm., Cyndi Smith, Banff National Park, pers. comm.). The average date for the last sighting of non-breeding or unsuccessful females on Idaho streams was July 21 (Cassirer and Groves 1992). A female that was an unsuccessful nester in Alberta returned to the British Columbia coast by August 1.

Females that were successful breeders did not return to the coast before mid-August (Cyndi Smith, Banff National Park, pers. comm.). Some females with broods remained on breeding streams until late-September and in a few cases even early October (Ashley 1994, Dement'ev and Gladkov 1967, Smith 1996, McCaffery 1996, Kessel et al. 1982). Murie (1963) observed a female with a brood in McKinley (Denali) National Park on September 9. Further south in Oregon, all females and young departed breeding streams by late-August (Bruner 1997). The variable ratio of flightless to flight-capable females among the fall surveys (Fig. 10) probably represents differences in molt chronology between breeding and non-breeding females in addition to differences between successful and unsuccessful breeders.

Sex ratios were skewed towards males during each fall survey, but the disparity in sex ratios progressively decreased as more females returned to the coast (Fig. 10). Sex ratios during the third fall survey in September were skewed less towards males than other fall surveys (Table 11) because most post-breeding females had returned to the coast by mid-September. By this time, the proportion of males was only slightly higher (Table 11) than what we observed during the winter (1.49 males:1 female in WPWS and 1.38:1 in EPWS) when populations of harlequin ducks are relatively stable. Consequently, relatively few post-breeding females had not returned to the coast prior to the end of our surveys. Granted, because we cannot distinguish recently fledged males from females while conducting surveys, we may have slightly inflated the number and proportion of females counted during the third fall survey.

Variation Among Years

Factors Affecting Counts

Several factors explain annual variation in the number and composition of harlequin ducks we observed in PWS. Because the harlequin population varies seasonally, annual variation in seasonal movements may disguise true differences in abundance and composition. Annual variation in climatic factors such as snowfall and temperature can influence the timing of breeding activity, and consequently the number of ducks we observe during a particular spring survey. Wallen (1987) attributed asynchronous breeding chronology to the timing of snowmelt.

Factors influencing breeding and brood rearing success, such as food availability (Bengtson and Ulfstrand 1971, Gardarsson and Einarsson 1991), depredation, and stream runoff (Kuchel 1977, Genter 1993) probably contribute more to the annual variability we observed during the fall, especially for females. Actual differences between years in abundance and composition, however, are related to variation in productivity, mortality, and rates of immigration and emigration. Although we did not quantify these specific parameters, we can make inferences about their contribution to annual variation observed in the harlequin population.

We realize that measurement error may contribute to variation in our harlequin counts. We believe, however, that because the same observers participated in most surveys, surveys were conducted simultaneously between locations and at the same time each year, transects were thoroughly searched, and precautions were taken to minimize "double counting" of flight-capable birds, any bias in our data resulting from measurement error is minimal and accounted for in our interpretation of the results.

Spring Surveys

Annual variation in the harlequin duck population detected in the spring can be explained by annual variation in breeding chronology and driven by the number and composition of ducks counted during the first survey. The number of ducks varied inversely between the first and third surveys (Fig. 4). In years when breeding activity occurred early (1995), we counted fewer breeding pairs during the first survey, as a relatively larger segment of the breeding population already departed the study area for breeding areas (Fig. 5). Coincident with fewer pairs during the first survey was the greater number of males during the third spring survey (Fig. 6). Thus, in years when pairs departed early for breeding areas, nesting occurred earlier, and males returned to the coast earlier. Conversely, when we counted the greatest number of breeding pairs during the first spring survey (1997), we counted the fewest number of males during the third survey (Fig. 6), indicating a later departure by breeding pairs and later return by post-breeding males.

We attribute annual variation in male to female, non-paired to paired female, and adult to sub-adult male ratios during the spring to be mostly the result of annual variation in breeding chronology rather than actual changes in population structure and abundance. Long-term monitoring is necessary to detect changes in the number and composition of the harlequin population during this period.

Fall Surveys

Fall movements and, consequently, abundance of harlequin ducks is related to their return to the coast. We believe all male harlequin ducks returned to the coast prior to our first fall survey (Fig. 6). We found similar chronologies in male arrival times and molting during the three years of our study, as did Robertson et al. (1997a) in British Columbia. Therefore, for male ducks we can only detect annual variation in breeding chronology during spring surveys.

Facilitating our counts during the first and second fall survey was that the majority of males were flightless (Table 11). Although "year" could not be excluded as a main effect in our model of flightless to flight-capable males, the term was not statistically significant, but kept in the model because of the significant interaction terms (Table 10). Consequently, we believe annual variation in molt chronology to be negligible for males. The return of the entire male population to the coast to predictable molting areas by late July, our ability to obtain an accurate count, and no significant annual variation in molt chronology makes molting males a good indicator of the overall trend in population abundance.

The number of flight-capable females almost always exceeded the number of flightless females during our fall surveys (Table 11). In spite of this, conditions for counting females were more favorable during the fall than the spring. This is because 1) females were often encountered in all female flocks during the fall as opposed to being paired in spring; 2) female groups were less likely to fly long distances after flushing and were more easily identifiable (number/flock) if reencountered; 3) flight-capable females only flew short distances when associated with flightless females; and 4) over 40 percent of females were flightless during each survey (Table 11). Thus, we are confident our counts of female harlequin ducks accurately represent their true abundance.

We observed less annual variation in the number of females than males for a particular survey period even though the number of females progressively increased during the fall (Fig. 6). This was especially true in WPWS where the among-year difference never exceeded 35 females for a given survey (Fig. 6). This suggests little annual variation in return rate, which may indicate little annual variation in breeding success. However, the ratio of flightless to flight-capable females varied among years (Table 10), and due to our survey design, we believe this ratio is a better indicator of annual variation in breeding success. Robertson et al. (1997a) hypothesized that an earlier and more synchronous return to the coast and initiation of molt by females may indicate poor nest success while a later return to the non-breeding grounds and a later molt occurs when nest success is high. While we know little about the true relationship between breeding success and molt chronology for harlequin ducks in PWS, our surveys do allow us to make some comparisons that will require future verification

Although our survey design prevents us from detecting subtle changes in return rates of females because our fall surveys are conducted several weeks apart, the protracted flightless period that occurred in the female population allowed us to detect changes in the ratio of flightless to flight-capable females. Females initiate molt soon after arriving on the non-breeding areas and the minimum flightless period lasts about 21-22 days (Robertson et al. 1997a). Some females were flightless when we began fall surveys in late-July. Our fall surveys were conducted every two to three weeks within an approximately 50-day period. The longest period between surveys was about 18 days (between our second and third fall surveys), making it unlikely that we would observe the same female in a flightless state on each of our last two surveys. Thus, we believe the later molt in 1997 (lower flightless to flight-capable ratio on fall survey three) (Table 11, Fig. 10) indicated better breeding success in that year than in the two prior years.

Variation Between Study Areas

Breeding Chronology

The general pattern of harlequin duck movements to and from breeding areas was similar between WPWS and EPWS (Fig. 4). Breeding chronology did not vary between locations as it did among years, at least for non-local breeding pairs that depart the study area. We believe annual variation in breeding chronology is similar between study areas because the number of breeding pairs in each location declined at similar rates in each year (Fig. 5).

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 indicates that the number of females, rather than males, regulates the abundance of the breeding population as it does for most sea duck species (Goudie et al. 1994). Consequently, a geographic difference in the composition of the female population is a more likely indicator of differences in productivity.

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 study areas. We assume that only paired females will attempt to breed. The proportion of non-paired females increased in both WPWS and EPWS as non-local breeding pairs departed the study area (Fig. 8). The number of non-paired females in WPWS comprised a greater proportion of the female population except for the second spring survey in 1997 (Fig. 8). Differences between study areas became increasingly greater as the season advanced (Table 11). By the end of the third survey, 20.3, 7.4 and 8.8 non-paired females were observed for every paired female in WPWS in 1995, 1996 and 1997 respectively, compared to 2.5, 3.5 and 2.3 in EPWS (Table 11).

Based on the nest initiation curve for coastal breeding females in EPWS (Crowley 1996) (Fig. 5) and radio telemetry studies conducted by Esler (Dan Esler, USGS-BRD pers. comm.), we believe all non-local breeding females left our study areas before the third spring survey in early June. Consequently, the female population during our third survey is comprised of local breeding and non-breeding birds. At this time, we observed more local breeding pairs in EPWS and relatively more non-paired females in WPWS. The number of non-breeding females decreased in each successive year in WPWS as the number of local pairs remained stable. The late-spring WPWS population is composed of relatively fewer breeding females and relatively more non-breeding females compared to EPWS. Little change in numbers of non-breeding females or local pairs was observed in EPWS. Thus, we would expect the amount of local nesting to be similar in each year of our study. This was confirmed by our observations of 10, 12, and 14 broods in EPWS and none in WPWS over the three years of surveys.

We estimated the number of pairs remaining in PWS in late-spring and the number of broods locally produced in fall. However, from our spring surveys we cannot estimate the number of pairs that departed each of our study areas, nor the number of broods they produced. A portion of the breeding population had already left our study areas by the start of our first spring survey. Our spring surveys detected more harlequin ducks (Table 5) and a larger number of breeding pairs (Fig. 5) in EPWS. In contrast, our winter surveys detected more harlequin ducks and a larger number of breeding pairs in WPWS than EPWS at a time when the population is relatively stable. Relatively more non-paired females were observed in EPWS during this period suggesting that the female population is composed of relatively fewer breeding females and relatively more non-paired females compared to WPWS. This disparity between results of our winter and spring surveys leads us to further discussion (see Winter Population).

Juvenile sex ratios are similar on the breeding grounds (Ashley 1998). We would expect the number of sub-adult males and sub-adult females to be similar if they exhibited similar survival and dispersal rates. During the spring, with the exception of the third spring survey in EPWS in 1996, the number of non-paired females was equal to or less than the number of sub-adult males in both study areas, indicating that all non-paired females were sub-adults. Because sub-adult females (first-year and older) have been captured or observed on inland breeding streams (Wallen 1987, Buner 1997, Perfito and Schirato 1998), more commonly than second-year males (Kuchel 1977, Wallen 1987, Cassirer and Groves 1992, Clarkson 1992, Ashley 1995, Crowley and Patten 1996, Beth MacCallum pers. comm. Bighorn Environmental Design Ltd., Hinton, Alberta), we believe dispersal rates vary between sub-adult sex classes. This would account for the smaller numbers of sub-adult females we observed during our spring surveys. All adult females were consequently paired and potential breeders. The limited breeding activity observed by Patten et al. (1998a) in WPWS during the years following the EVOS (1991 and 1992) may be related to: 1) the emigration of most breeding pairs from the coast; and 2) sexual immaturity of females remaining on the coast rather than females not attaining breeding condition.

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. 6). Most males in both study areas were undergoing wing molt during the first and second fall surveys, while most males had regained flight capability by the time of our third survey in both study areas (Fig. 10).

Differences between study areas during the fall were more apparent for females. The number of females consistently increased in EPWS during the period between our third spring survey in June and the first fall survey in late July, while female numbers in WPWS only slightly increased in 1997, but declined in 1995 and 1996 (Fig. 6). Greater proportions of females, however, were flightless in WPWS than EPWS during the first fall survey (Fig. 10). We attribute the relatively greater number of flightless females in WPWS during this period to the composition of the female population during our third spring survey. A greater proportion and absolute number of females were not paired during the third spring survey in WPWS. Consequently, we would expect local non-breeding females to molt earlier than breeding females.

The general decline in WPWS females from our last spring to first fall survey may be a result of dispersal of non-breeding birds. The increase in the number of females in EPWS between the last spring and first fall survey may represent females that never attempted to nest or failed early in their nesting attempts and recently returned to the coast. Some of these females may be on route to other areas of PWS, including our WPWS study area (see Winter Population). Variation between study areas in the proportion of flightless females during the second and third fall survey is less pronounced than on the first fall survey (Fig. 10) and more difficult to interpret.

Winter Population

The winter survey in March 1997 was our only opportunity to quantify the composition and abundance of the pre- and post-breeding population of harlequin ducks in WPWS and EPWS. Winter represents the period of maximum stability in harlequin duck populations. The composition of the EPWS and WPWS populations was similar (Table 7).

We counted more harlequin ducks in WPWS than EPWS (Table 7). This contrasts with our spring (Table 5) and fall (Table 6) surveys when we observed more ducks in EPWS. During the period between our March survey and our first spring survey in 1997 (early May), the number of harlequin ducks increased in EPWS and decreased in WPWS (Fig. 7). We suspect that breeding pairs originating in other locations of PWS (to the south and west), including our WPWS study area, are being counted in EPWS during the spring as they move to breeding areas. These movements, if verified, could explain the west to east displacement reported by Hotchkiss (1991) following the spill. We suspect birds pass through EPWS because it provides easier access via river corridors (e.g., Lowe River, Copper River) through the mountains to inland breeding sites. Few such corridors exist in other parts of PWS. That only two out of over 500 harlequin ducks banded during the molt in WPWS have been observed outside WPWS (both in EPWS) indicates the difficulty in detecting this movement. A paired female was observed in EPWS (Rocky Point, Valdez arm) on 12 May 1997 during our surveys, and a adult male was observed by a U.S. Geological Survey biologist on 17 July 1998, east of the EPWS study area, on a tributary of the lower Copper River (Alaganik Slough).

If a general southwest to northeast movement occurs during the spring, then reverse movements undoubtedly occur after the breeding season. The increase in total ducks in WPWS and the decrease in EPWS that we observed in March relative to our September survey (Fig. 7) suggests that: 1) many birds counted in EPWS during the fall moved from that location after our fall surveys and, 2) many birds moved to wintering areas in WPWS. Because all males had returned to the coast, and most were flightless by the time of our first fall survey, we believe a large proportion of males departed EPWS after the molt, and perhaps some moved to WPWS to winter. Many of the females we counted on our fall surveys probably passed through EPWS prior to molting.

Male harlequin ducks exhibit fidelity to molting sites and females exhibit fidelity to the same location for molting and over-wintering (Holland-Bartels et al. 1998). Nevertheless, a portion of the EPWS population departed that area after we completed our fall surveys. Post-molt migrations by males have been observed (Mittelhauser and McCollough 1993, Robertson et al. 1997b, Robertson et al. 1997c, Smith et al. 1998, Brodeur et al. 1998). Females, in PWS, rarely leave molting sites for different wintering areas (Holland-Bartels et al. 1998). However, PWS residents have reported an interchange of ducks among different parts of PWS (Appendix C). Little is known about the movements of sub-adults in the fall and winter. Regardless, a combination of factors may explain the movements we detected.

More breeding pairs observed in WPWS in winter than spring indicate a larger non-local breeding population exists in WPWS than suggested by our spring surveys. More breeding pairs departed WPWS before our first spring survey than we would have concluded based on the number of harlequin ducks observed during our spring and fall surveys alone. Our ratios of non-paired to paired females, therefore, may not accurately represent the actual composition of the female population during spring because they are not based on the entire breeding population in WPWS, and easterly movements may have inflated the number of breeding pairs in EPWS. Consequently, the true ratio of non-paired to paired females is probably lower in WPWS and higher in EPWS than suggested by our spring surveys.

Unlike spring, during winter we counted substantially more non-paired females than sub-adult males in both WPWS (196 non-paired females and 81 sub-adult males) and EPWS (178 non-paired females and 55 sub-adult males). These numbers are derived by partitioning unclassified birds into each age and sex category based on observed proportions. Pair formation should be nearly complete by our March survey (Fleischner 1983, Gowans et al. 1997, Robertson et al. 1998). These greater numbers of non-paired females indicates that the composition of the winter population differs from spring, and seemingly contradicts our rationale that all non-paired females in spring are sub-adults (first-year). However, our ability to recognize breeding pairs may not be similar for winter and spring surveys. Individual birds comprising a breeding pair may be more closely associated (physically) with each other during the breeding season than they are during winter when foraging rates are higher. Additionally, females breeding for the first time may not establish pair-bonds until April (Robertson et al. 1998). Consequently, our estimate of the number of paired females in winter may be biased low (and non-paired females biased high), and may explain why more non-paired females were observed during the winter than spring in both WPWS (range for all spring surveys: 32-178) and EPWS (range: 43-115).

The number of sub-adult males was lower in both WPWS and EPWS in winter than the following spring. Robertson et al. (1997b) reported an influx of birds, mostly non-paired males, in the spring, prior to departure for the breeding grounds. Lanctot et al. (in prep.) speculated that movements of sub-adults (first-year and older) between populations are responsible for much of the genetic interchange and the subsequent lack of genetic spatial structuring in harlequin populations. We do not know if sub-adult males (first-year and older) are immigrating to our study areas in spring. Little definitive information exists on the movements of sub-adult males. Additional surveys would determine whether this pattern exists in other years.

Productivity and Availability of Breeding Habitat

Detecting harlequin duck broods in PWS has been a major component of monitoring efforts since the EVOS. During the five years immediately following the spill (1989-1993), 14 harlequin duck broods were reported by various trained and untrained personnel in oiled areas of WPWS, leading Patten et al. (1998a, 1998b) to conclude that reproduction by harlequin ducks declined in oiled areas. This conclusion was based on a comparative measure of brood production with EPWS, and reports of broods (Sangster et al. 1978, Isleib and Kessel 1973) and large aggregations of ducklings in WPWS prior to the spill (Oakley and Kuletz 1979). However, no inclusive brood surveys were conducted prior to the spill making comparisons with post-spill surveys difficult. Estimates of expected productivity in WPWS, based on observed nesting and brood rearing activity in EPWS are insubstantial because no comprehensive evaluation exists that compares the availability of suitable breeding habitat between oiled areas in WPWS and non-oiled areas in EPWS. Crowley and Patten (1996) indicated that harlequin ducks nesting on coastal streams in EPWS select streams with a relatively high volume discharge and low gradients. Rosenberg et al. (1996) reported that substantially fewer kilometers of streams in WPWS than EPWS may represent important differences between study areas in the availability of suitable breeding habitat.

For populations of harlequin ducks 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 breeding females undoubtedly contribute more to overall production than do local breeding females. That a relatively small number of breeding pairs remains on our study areas suggests that little suitable nesting or brood rearing habitat is available in PWS. The comparably smaller number of breeding pairs in WPWS indicates that suitable breeding habitat is less available in that region. Few broods have been observed in EPWS on an annual basis since 1991 (Crowley and Patten 1996, this study) (Table 11), and no harlequin broods were observed on our WPWS study area for four consecutive years (Rosenberg 1995, this study). Further, residents of villages in PWS have never observed harlequin broods in coastal habitats (Appendix C). This indicates to us that productivity by coastal nesting harlequin ducks in PWS is low and supports our hypothesis that suitable breeding habitat is limited.

The difference between pre- and post-EVOS observations of harlequin broods in WPWS was the primary evidence that linked oil exposure with reduced productivity of harlequin ducks (Patten et al. 1998a, 1998b). We reevaluated pre-spill observations of broods in WPWS because of concerns about their reliability, and the subsequent interpretation by Patten et al. (1998a, 1998b). Observations of harlequin broods by Isleib (Isleib and Kessel 1973) cannot be used for comparative purposes because dates, locations, number, or age of ducklings is not reported. Sangster et al. (1978) reported a brood of nine in Outside Bay and three 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 two groups around an offshore rock along the coast of Eleanor Island. Holbrook (pers. comm. in Patten et al. 1998a) reported a brood on Otter Creek, Knight Island in 1982.

For our surveys of Naked Island and portions of Storey Island, the total number of harlequin ducks counted in July (range = 0-61) and in August (range = 46-67) fell within the range of ducks observed by Sangster et al. (1978) and Oakley and Kuletz (1979) during these time periods. The majority of harlequin ducks, however, observed prior to the spill (Sangster et al. 1978, Oakley and Kuletz 1979) were reported as ducklings, 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 or juveniles based on their ability to fly, not their plumage or behavior. Consequently, pre-spill estimates of local production by harlequin ducks in WPWS are most likely inflated. Additional evidence that suggests molting flocks were mistakenly classified as ducklings include: 1) Ducklings were not attended by adult females at Naked Island as they were for all our brood observations in EPWS. 2) Brood size was excessively large and more consistent with the size of molting flocks. 3) Aggregations (crèches) of harlequin duck broods have not been observed elsewhere in PWS nor are they reported elsewhere in North America. 4) 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. Zwiefelhofer (1995) reported 12 broods in 1,001 km of shoreline surveyed on Kodiak Island (0.01 broods/km). 5) Most pre-spill brood observations on Naked Island were not associated with the only two, relatively small anadromous streams (ADF&G 1994a, 1994b), while brood observations in EPWS have almost always been associated with anadromous streams (Dzinbal 1982, Crowley and Patten 1996, Rosenberg et al. 1996, this study).

Recruitment and Population Growth

In terms of recruitment, the number of fledged young returning to the coast represents a more meaningful measure of productivity and potential population growth than the number of broods observed on coastal streams alone. Fall surveys end prior to all young returning to the coast and regardless, we are not able to separate young from adult females at this time. Therefore, we use winter and spring surveys to measure recruitment because we can identify sub-adult males in these seasons.

During our first spring surveys, the ratio of sub-adult males and females (assuming 1:1 sex ratio) to breeding pairs was always greater in WPWS than EPWS while the number of breeding pairs was always greater in EPWS (Fig. 5). The later the spring departure by breeding pairs, the less the difference in sub-adult to breeding pair ratios between the two study areas. Thus, 1995 had the greatest difference (1.53:1 in WPWS vs. 0.65:1 in EPWS) and 1997 had the least (0.59:1 in WPWS vs. 0.55:1 in EPWS). During the winter the ratio of sub-adult males and females (assuming 1:1 sex ratio) to breeding pairs was nearly identical in EPWS (110 sub-adults/319 breeding pairs = 0.34 young/breeding pair) and WPWS (162 sub-adults/479 breeding pairs = 0.34 young/breeding pair) even though the number of breeding pairs was greater in WPWS. Thus, for the 1996 breeding season, our winter survey indicated similar recruitment of young occurred in EPWS and WPWS. Conversely, based on our spring surveys, non-local pairs emigrating from WPWS contributed relatively more to annual recruitment in that area than local and non-local pairs did in EPWS. We do not know how to interpret these findings because we know very little about movements of sub-adults. We assumed that juveniles return to molting areas with females (Ashley 1995, Smith 1996), but this may not always occur due to the possibility of brood abandonment (Bengtson 1972, Cassirer and Groves 1992).

We believe the winter survey is a more accurate measure of recruitment due to less movement at this time. Again, how dispersal patterns of sub-adults affects our results remains unknown. Given these constraints, we are hesitant to conclude that recruitment is greater or less for a particular study area based on the number of sub-adults. We did not, however, detect consistent variation in the number of sub-adults between locations that would suggest less recruitment occurred in WPWS.

We compared results of our survey data with the U.S. Fish and Wildlife Service marine bird monitoring surveys conducted in PWS pre- and post-spill (Appendix D). Our trend analysis indicates that numbers of harlequin ducks declined in WPWS, while numbers remained the same in EPWS (Table 13). We detected significant differences in slopes between WPWS and EPWS

($p = 0.007$), and our power to detect differences was high (79.4%), and remained high when males (67.4%) and females (70.0%) were analyzed separately (Table 14). We believe our fall surveys are an appropriate period for detecting annual change in the male population because all males had returned to the coast and most were molting (flightless) during the first and second fall surveys.

We believe the trend we observed in WPWS to be an unbiased estimate for males in oiled areas because all males are at risk of exposure to oil. The negative trend indicated that the population in the oiled area is declining. However, because our winter survey suggested that a westerly movement occurred after our fall surveys, a segment of the male population that molts in EPWS may winter in WPWS, potentially exposing them to oil. Consequently, some males counted on our unoiled study area (EPWS) during the fall may be at risk of exposure to oil during winter. This occurrence would bias the rate of change we observe for males in unoiled EPWS. Therefore, the increasing slope for males in EPWS (Table 13) is probably greater than what we observed if males at risk of exposure could be excluded from the analysis. We assume, however, that survival rates are similar for males whether at risk of exposure to oil only during winter or during fall and winter. Residents of PWS report an interchange of harlequin ducks between EPWS and WPWS and a general decline in most seaduck populations throughout PWS (Appendix C).

For females, we believe fall is not the best period for detecting differences in trends between oiled and unoiled areas because: 1) all females had not returned to the coast; 2) like males, a segment of the female population counted in EPWS during the fall may eventually winter in WPWS; 3) unlike males, an individual female at risk of exposure to oil may be counted in both EPWS and WPWS because some females returning to molt in WPWS probably pass through EPWS; and 4) molt chronology for females is variable among surveys and between years and study areas. Consequently, in EPWS, the probability of counting a female at risk of exposure to oil is variable with respect to survey period and year, thereby creating an unpredictable bias in our data. Nevertheless, as was the case for males, we believe the trend we observed in WPWS to be an unbiased estimate for females in oiled areas because all females are at risk of exposure to oil. The negative trend indicates that the female population in WPWS is declining. We cannot estimate with certainty, however, the trend for females in EPWS. We propose that, given the power of our survey design to detect differences in population trends, surveys conducted during the winter over a minimum of three to five years, would provide the information necessary to compare population trends for females between oiled and unoiled areas in PWS.

The decline in the number of harlequin ducks in WPWS that we observed correlates with results from another study indicating that females wintering in oiled areas experience significantly lower ($p<0.10$) survival rates (76.6%) than do females wintering in unoiled areas (86.6%) (Dan Esler, USGS-BRD, unpub. data). Lower survival rates may be related to the significantly higher ($p<0.01$) EROD (ethoxyresorufin-O-deethylase) enzyme activities (an enzyme indicative of exposure to aromatic hydrocarbons) measured in liver tissues taken from ducks in oiled areas (Dan Esler, USGS-BRD, unpub. data). From this, it is apparent that harlequin ducks in oiled areas (WPWS) are exposed to different extrinsic factors than harlequin ducks in unoiled areas (EPWS). Other than differences in the availability of breeding habitat, we did not evaluate whether habitat characteristics differ between WPWS and EPWS. However, habitats in oiled areas of WPWS and unoiled areas (Montague Island) do not appear to differ with respect to food availability (Holland-Bartels et al. 1998). We believe the population decline we detect in WPWS is a function of lower survival rates, rather than differences in recruitment.

CONCLUSIONS

We detected seasonal, annual, and geographic variation in the number and composition of the harlequin duck population inhabiting oiled areas of WPWS and unoiled areas of EPWS. We attribute seasonal variation in the abundance and composition of the harlequin population to movements by ducks into and out of our study areas. Seasonal movements were related to breeding and molting activity and were similar in each study area, resulting in significant variation in population characteristics among our spring and fall surveys. Harlequin populations in WPWS and EPWS also varied annually, primarily as a result of annual variation in breeding chronology.

Both seasonal and annual variation in population characteristics must be considered before geographic variation can be properly interpreted with respect to assessing recovery of harlequin ducks in WPWS. A general lack of information pertaining to harlequin duck ecology limits our ability to interpret certain aspects of our data. Nevertheless, our surveys are unique in that they document population fluctuations of harlequin ducks throughout most of the year on the non-breeding grounds. Because we conducted simultaneous surveys in WPWS and EPWS during the same time periods over three consecutive years, we believe our data provide an important addition to the general understanding of harlequin duck biology.

Breeding chronology was similar for WPWS and EPWS. During the spring, a large proportion of the breeding population departed both WPWS and EPWS as they moved to inland river drainages to nest. In spring, annual variation in the number of breeding pairs (Fig. 5) and adult males (Fig. 9) indicated that the timing of departure to breeding areas varied annually.

We observed no local production in our WPWS study area. The number of local breeding harlequin ducks in both WPWS and EPWS is limited by a lack of suitable breeding habitat, either nesting or brood rearing. The large number of non-local breeding pairs contributes substantially more to productivity than the few breeding pairs that remain on the coast. The few breeding pairs left on our study areas in late spring (local breeding pairs) indicated relatively more harlequin ducks breeding in EPWS than WPWS (Fig. 5) and explained why we observed harlequin broods only in EPWS (Table 12). No harlequin broods were observed in our WPWS study area for four consecutive years (1994-1997) (Rosenberg 1995, this study). This confirms the few brood observations reported by Patten et al. (1998a) in WPWS. Patten et al. (1998a) attributed the lack of production to the effects of oiling because pre-spill, harlequin broods were observed in WPWS. We present evidence suggesting that pre-spill observations of harlequin broods in WPWS were predominantly flocks of molting adults rather than ducklings. Consequently, pre- and post-spill levels of productivity by local breeding pairs in WPWS are comparably low, lending support to our limited breeding habitat hypothesis.

The potential productivity of the WPWS breeding population, based on its structure, is similar to the EPWS breeding population. Population structure during spring varied among surveys, years, and our two study areas (Table 11). Seasonal variation in sex ratios, composition of the female population, and age ratios of males can be explained by the movement of breeding birds out of the study area in May, and the initial return of post-breeding males to the coast in mid-June. Annual variation in these ratios can be explained by annual variation in breeding chronology. Although variation in these parameters exists between study areas, it is minor when compared with seasonal and annual differences.

Similar proportions of paired females and sex ratios between EPWS and WPWS indicate similar breeding propensities and survival rates, although this was not supported by our overall population decline in WPWS. A large proportion of the population formed breeding pairs and departed the study area (as was the case in EPWS), and only slight variation between locations in the proportion of sub-adults indicated no major differences in recruitment.

The number of sub-adult males, relative to the total number of breeding pairs is a more accurate measure of recruitment in winter than spring. Winter populations are more stable and pairs or sub-adults have not departed for breeding grounds. Without more information on movements and distribution of sub-adults we cannot confirm the patterns observed, nor do we know if recruitment is through immigration or sub-adults are direct descendants of our adult population.

Differences in molt chronology as a function of breeding success is difficult to interpret. Male harlequin ducks return to the coast to molt earlier than females. We believe that all post-breeding males had returned to WPWS and EPWS by late July and were counted during our fall surveys. The number of post-breeding females, however, steadily increased on our study areas throughout the fall. Consequently, the return rate of females influenced the variation in sex ratios we observed among our fall surveys. Annual variation in sex ratios in WPWS was related to annual fluctuation in the number of males rather than females, as the number of females varied little among years for a particular fall survey period (Fig. 6). In EPWS, annual variation in sex ratios was the result of annual fluctuation among survey periods in the number of both males and females (Fig. 6).

We attribute variation in sex ratios between study areas during the fall to variation in return rates by females. The number of females began to increase earlier in EPWS than WPWS, consequently, sex ratios were skewed substantially more towards males in WPWS during the first fall survey (Fig. 10). We are not certain why females return to the coast earlier in EPWS. We may be detecting breeding females that failed or aborted nesting attempts on nearby streams, or we may be detecting a return of transient females that pass through EPWS on route to molting sites south or west of our EPWS study area. The disparity in sex ratios between locations decreased with each successive fall survey, however, relatively more males were always observed in WPWS (Fig. 10).

We suspect that variation in the proportion of flight capable to flightless females may represent annual and geographic variation in breeding success. More information on the relationship between molt chronology and breeding success is needed before we can adequately interpret this portion of our survey results.

We did not detect any substantial differences in population structure between EPWS and WPWS that would indicate continued exposure to oil. Based on similarities in the composition of the breeding, molting, and wintering population (only one winter survey) of harlequin ducks in WPWS and EPWS, we believe the population in WPWS has the potential to recover from the effects of the EVOS (see population decline below). The lower densities of harlequin ducks in WPWS during spring and fall is more likely related to differences in sampling a non-uniformly distributed species, and the movements of ducks, wintering in WPWS, through the EPWS study area, rather than the capacity of the habitat to support ducks. A higher density of harlequin ducks in WPWS than EPWS during the winter supports this view.

The harlequin duck population in WPWS declined during the course of our study, while it remained stable in EPWS (Table 13). However, because we believe a segment of the harlequin population counted in EPWS during the fall moved westerly to winter, some ducks counted in EPWS are at risk of being exposed to oil. Consequently, our trend analysis in EPWS, overall, may be biased slightly downwards because it includes some birds that may be exposed to oil. If the males that remain in EPWS that are not at risk of oil exposure could be separated from those at risk of exposure we would expect a higher growth rate. We cannot, however, account for this bias for females in EPWS. Nevertheless, the trend we observed in WPWS, where all ducks are at risk of oil exposure, is an unbiased estimate for males and females. The negative trend indicates that the WPWS population is declining. Winter surveys would eliminate any biases resulting from westerly movements by harlequin ducks after our fall surveys.

We believe the population decline in WPWS is primarily a result of lower survival rates, rather than lower recruitment. Until abiotic and biotic habitat characteristics are further quantified and compared between oiled and unoiled sites, we believe there is sufficient evidence suggesting that harlequin ducks in WPWS are declining. Lower survival rates among females and evidence for continued exposure to hydrocarbons (Holland-Bartels et al. 1998) supports this conclusion. Long-term population stability depends on high adult survival coupled with a relatively few years of successful reproduction (Goudie et al. 1994). Initial high losses of adults may result in a long recovery period, especially if the initial causes of mortality are still having an effect on survival.

Based on our results and the recovery criteria (Exxon Valdez Oil Spill Trustee Council 1996), harlequin ducks have not recovered from the effects of the *Exxon Valdez* oil spill. A similar population structure in EPWS (unoiled) and WPWS (oiled) indicates that the population in oiled areas is in a position to recover but is being prevented by lower survival rates, possibly a result of continued exposure to hydrocarbons.

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Table 1. Dates (month/day) of spring and fall surveys for harlequin ducks conducted in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

		Spring Survey Period			Fall Survey Period		
Study Area	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
WPWS	1997	5/06-5/13	5/22-5/28	6/12-6/18	7/24-7/29	8/11-8/17	9/04-9/11
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
EPWS	1997	5/08-5/14	5/23-5/27	6/12-6/17	7/24-7/29	8/11-8/16	9/05-9/10

[a] Incomplete survey because of foul weather.

Table 2. Transect, region, and study area spatial scales (see Methods) used to compare trends in harlequin ducks observed in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

Study Area	Location	Transect number[a]	Transect length (km)	Region	Study Area	Location	Transect number	Transect length (km)	Region
WPWS	Aguliak Island	26	9.0	7	WPWS	Green Island	8	51.5	4
WPWS	Applegate Island	1	5.9	1	WPWS	Junction Island	17	2.7	3
WPWS	Bay of Isles	5	41.9	6	WPWS	Masked Bay	16	2.6	3
WPWS	Channel Island	7	1.6	4	WPWS	Mummy Island	18	10.8	7
WPWS	Crafton Island	11	6.8	2	WPWS	Naked Island	9	73.2	5
WPWS	Culross Island	2	21.0	1	WPWS	Squire Island	22	21.3	7
WPWS	Falls Bay	4	15.1	2	WPWS	Squirrel Island	21	4.5	7
WPWS	Foul Bay	10	11.7	2	WPWS	Storey Island	28	2.8	5
WPWS	Foul Pass	6	5.5	6	WPWS	Totemoff Creek	15	13.2	3
EPWS	Beartrap Bay	5	4.8	1	EPWS	Port Gravina(SE)	3	17.3	1
EPWS	Black Creek	27	2.6	5	EPWS	Port Gravina(NE)	4	20.6	1
EPWS	Busby Island(south)	25	6.2	5	EPWS	Porcupine Bay	16	7.4	4
EPWS	Busby Island(north)	26	6.2	5	EPWS	Redhead	14	8.8	1
EPWS	Close Island	10	4.8	2	EPWS	Reef/Bligh Islands	24	7.1	5
EPWS	Constantine Harbor	19	19.7	3	EPWS	Rocky Point	28	6.1	5
EPWS	Galena Bay	21	12.6	5	EPWS	Sawmill Bay	31	7.4	5
EPWS	Galena Rocks	30	2.5	5	EPWS	Sheep Bay(east)	9	35.0	2
EPWS	Hell's Hole	13	6.4	1	EPWS	Sheep Bay(SW)	12	8.8	2
EPWS	Jack Bay	22	5.7	5	EPWS	Shelter Bay	18	9.0	3
EPWS	Landlocked Bay	34	13.3	4	EPWS	Shoup Bay	32	9.5	5
EPWS	Olsen Bay	7	14.9	1	EPWS	Surf Creek	11	1.0	2
EPWS	Port Etches	20	17.0	3	EPWS	Vladnoff River	23	4.0	5

[a] Transect numbers referenced in Fig. 2 and Fig. 3.

Table 3. Kilometers of shoreline surveyed for harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

		Spring Survey Period			Fall Survey Period[a]		
Study Area	Year	1	2	3	1	2	3
WPWS	1995	251.0 [b]	59.0 [b]	301.1	*	*	270.5 [b]
WPWS	1996	301.1	*	*	*	*	*
WPWS	1997	301.1	*	*	*	*	*
EPWS	1995	258.7	*	*	*	*	249.2 [b]
EPWS	1996	258.7	*	*	*	*	*
EPWS	1997	258.7	*	*	*	*	*

[a] Does not include shoreline surveyed during expanded fall survey coverage (Table 4).
[b] Incomplete survey because of foul weather.
* Indicates no change from previous survey period.

Table 4. Additional kilometers of shoreline surveyed during expanded fall survey coverage in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

		Fall Survey Period		
Study Area	Year	1	2	3
WPWS	1995	144.2	129.4	106.4
WPWS	1996	106.1	*	*
WPWS	1997	106.1	*	*
EPWS	1995	52.7	*	17.1
EPWS	1996	52.7	*	48.8
EPWS	1997	52.7	*	*

* Indicates no change from previous survey period.

Table 5. Number and composition of harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska used in ratio analysis for spring surveys in 1995, 1996, and 1997.

Study Area	Year	Spring Survey	Adult Males	Sub-adult Males	Unk.[a] Males	Females	Un-classified[b]	Total	Pairs [c]
WPWS	1995	1	384	119	2	274	63	842	155
WPWS	1995	2 [d]	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	431	169	1	360	51	1012	242
WPWS	1996	2	261	157	0	213	54	685	79
WPWS	1996	3	331	139	0	101	174	745	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
WPWS	1997	1	638	107	1	466	30	1242	363
WPWS	1997	2	243	113	0	123	31	510	91
WPWS	1997	3	368	70	0	49	3	490	5
EPWS	1997	1	740	149	0	585	34	1508	542
EPWS	1997	2	475	124	25	291	50	965	190
EPWS	1997	3	372	110	5	135	17	639	41

[a] Age of males unknown.
[b] Not included in ratio analysis.
[c] Included in adult male and female totals.
[d] Negligible survey coverage because of foul weather.

Table 6. Number and composition of harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska used for ratio analysis during fall surveys in 1995, 1996, and 1997.

Study Area	Year	Fall Survey	Number of Harlequin Ducks			
			Males	Females	Unclassified[a]	Total
WPWS	1995	1	809	118	11	938
WPWS	1995	2	800	267	13	1080
WPWS	1995	3	842	422	111	1375
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	727	290	12	1029
WPWS	1996	3	697	419	116	1232
EPWS	1996	1	917	305	42	1264
EPWS	1996	2	924	528	50	1502
EPWS	1996	3	837	574	74	1485
WPWS	1997	1	715	90	3	808
WPWS	1997	2	642	248	29	919
WPWS	1997	3	828	407	36	1271
EPWS	1997	1	1045	286	7	1338
EPWS	1997	2	869	530	15	1414
EPWS	1997	3	964	658	132	1754

[a] Not used in ratio analysis.

Table 7. Number and composition of harlequin ducks observed in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska during winter surveys in March 1997.

	Number of Harlequin Ducks					
	WPWS			EPWS		
	Original Count	Corrected for Unclassified	Percent of total	Original Count	Corrected for Unclassified	Percent of total
Adult Males	892	918	54.7	511	625	52.8
Sub-adult males	79	81	4.8	45	55	4.7
Unknown males[a]	3	4	1.0	5	6	1.0
Females	655	674	40.2	406	497	42.0
Unclassified	48	0[c]	0.0	216	0[c]	0.0
Breeding Pairs[b]	465	478	57.0	261	319	54.0
Total	1677	1677	------	1183	1183	------

[a] Age of males unknown.
[b] Included in adult male and female totals.
[c] Distributed among other categories based on relative percent.

Table 8. Number of harlequin ducks counted on transects surveyed in oiled areas of western Prince William Sound, Alaska in 1995, 1996, and 1997.

	Spring Survey 1			Spring Survey 2			Spring Survey 3			Fall Survey 1			Fall Survey 2			Fall Survey 3			Winter
Transect location	95	96	97	95	96	97	95	96	97	95	96	97	95	96	97	95	96	97	97
Aguliak Island	35	20	29	dns	51	13	43	15	0	8	29	17	20	16	26	8	11	14	37
Applegate Island	67	45	71	21	19	53	40	3	17	10	17	15	24	28	20	12	35	25	40
Bay of Isles	38	74	99	dns	121	52	24	201	44	10	62	46	59	60	49	77	92	111	86
Channel Island	16	36	37	dns	21	39	59	158	85	88	101	109	86	103	92	29	27	62	33
Crafton Island	68	96	100	dns	50	30	88	36	35	33	75	40	46	57	58	123	2	98	79
Culross Island	57	48	76	9	18	24	31	3	0	48	49	50	45	66	38	137	110	81	96
Falls Bay	74	66	126	dns	3	55	12	21	3	28	22	58	52	52	75	140	216	143	154
Foul Bay	89	140	112	dns	71	31	76	30	70	61	79	78	77	139	77	164	103	107	146
Foul Pass	22	0	10	dns	9	27	41	0	5	21	23	17	27	23	18	24	14	12	6
Green Island	242	253	285	dns	160	38	329	85	50	517	234	186	484	253	231	323	368	401	559
Junction Island	12	25	47	dns	35	13	8	40	26	2	24	15	3	22	9	10	2	3	20
Masked Bay	5	0	0	dns	0	0	0	0	5	0	21	17	16	11	16	11	2	3	3
Mummy Island	26	17	20	13	1	0	21	6	27	11	23	31	10	33	26	8	5	1	51
Naked Island	2[a]	85	109	dns	53	67	16	14	4	0	23	12	16	42	31	124[b]	125	51	168
Squire Island	32	39	51	6	15	0	0	26	0	15	30	33	41	39	44	6	15	18	105
Squirrel Island	7	35	29	dns	11	2	0	25	10	21	7	10	11	12	12	85	68	74	59
Storey Island	4	0	4	dns	2	9	11	22	15	0	38	19	30	25	30	3	11	21	6
Totemoff Creek	46	33	37	dns	45	57	85	60	94	65	34	55	33	48	67	91	26	46	29
Total	842	1012	1242	49	685	510	884	745	490	938	891	808	1080	1029	919	1375	1232	1271	1677

dns = did not survey

[a] Only 23.1 km out of 73.2 km surveyed.

[b] Only 42.6 km out of 73.2 km surveyed.

Table 9. Number of harlequin ducks counted on transects surveyed in unoiled areas of eastern Prince William Sound, Alaska in 1995, 1996, and 1997.

	Spring Survey 1			Spring Survey 2			Spring Survey 3			Fall Survey 1			Fall Survey 2			Fall Survey 3			Winter
Transect location	95	96	97	95	96	97	95	96	97	95	96	97	95	96	97	95	96	97	97
Beartrap Bay	10	7	8	11	5	10	6	6	4	4	0	10	6	24	5	7	0	2	0
Black Creek	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	63	15	29	4
Busby Island(south)	25	21	32	21	10	0	9	21	0	35	18	14	24	23	25	35	48	20	44
Busby Island(north)	24	51	45	11	10	0	0	0	0	36	40	48	41	46	51	37	68	112	35
Close Island	8	17	40	22	17	2	15	11	5	34	29	34	42	53	76	73	67	105	107
Constantine Harbor	33	35	51	37	60	45	41	52	17	5	22	22	11	7	24	38	47	6	27
Galena Bay	36	35	28	20	41	28	12	4	8	4	7	5	11	4	4	7	17	4	0
Galena Rocks	20	38	51	10	6	138	12	20	19	50	39	57	20	51	17	40	23	63	0
Hell's Hole	130	81	91	168	94	122	66	89	55	99	41	79	125	72	78	55	22	28	65
Jack Bay	31	26	43	16	19	26	21	9	12	7	5	3	10	15	6	25	17	19	21
Landlocked Bay	27	24	39	25	4	0	7	3	9	45	60	54	71	68	97	88	60	82	42
Olsen Bay	16	63	67	41	75	67	94	85	33	100	155	112	113	143	127	195	182	119	95
Port Etches	13	51	85	58	24	51	28	51	69	96	62	82	75	83	108	156	114	138	55
Port Gravina(SE)	78	92	82	68	52	82	238	62	83	157	143	159	179	186	165	210	174	250	189
Port Gravina(NE)	43	30	43	13	29	70	3	37	40	26	46	41	57	58	60	82	48	101	39
Porcupine Bay	38	66	27	53	89	67	105	63	37	92	116	116	95	129	130	100	59	144	30
Redhead	36	87	138	52	37	2	0	0	6	67	78	59	25	60	31	16	58	74	59
Reef/Bligh Islands	11	36	34	11	18	3	1	1	15	20	67	91	77	101	64	74	61	101	23
Rocky Point	49	40	92	11	2	2	0	1	23	33	55	54	44	70	56	42	39	59	54
Sawmill Bay	16	37	21	28	21	19	18	27	23	10	25	16	8	5	21	8	16	17	0
Sheep Bay(east)	96	91	187	48	76	159	102	120	128	150	128	190	159	176	155	180	242	179	181
Sheep Bay(SW)	38	120	155	19	7	0	0	0	0	39	44	34	39	56	38	68	63	35	55
Shelter Bay	44	30	52	29	38	41	38	16	33	80	52	36	48	52	48	11	6	35	34

Table 9. (cont.)

Shoup Bay	32	47	60	60	26	12	0	2	14	0	2	11	0	4	8	dns	0	0	dns
Surf Creek	17	14	8	3	11	0	0	1	0	17	25	11	25	15	13	44	22	32	24
Vladnoff River	7	5	9	8	6	19	4	0	6	4	5	0	0	1	7	0	17	0	0
Total	878	1144	1508	843	777	965	820	681	639	1210	1264	1338	1305	1502	1414	1654	1485	1754	1183

dns = did not survey

Table 10. Logit analysis used to test for differences in demographic parameters of the harlequin duck population between western and eastern Prince William Sound, Alaska.

Ratio	Survey period	Source	DF	Chi-square	Prob.
Males: Females	Spring	Intercept	1	1218.7	<0.001
		Year	2	16.0	<0.001
		Study Area	1	6.3	0.012
		Survey	2	411.5	<0.001
		Year*Study Area	2	18.7	<0.001
		Year*Survey	4	17.7	0.001
		Study Area*Survey	2	7.7	0.021
		Year*Study Area*Survey	4	25.7	<0.001
Non-paired : Paired females	Spring	Intercept	1	0.6	0.449
		Year	2	23.3	<0.001
		Study Area	1	113.2	<0.001
		Survey	2	523.4	<0.001
		Year*Study Area	2	8.5	0.015
		Year*Survey	4	3.3	0.516
		Study Area*Survey	2	3.1	0.216
		Year*Study Area*Survey	4	42.4	<0.001
Adult : Sub-adult males	Spring	Intercept	1	1115.6	<0.001
		Year	2	48.1	<0.001
		Study Area	1	3.0	0.082
		Survey	2	28.5	<0.001
		Year*Study Area	2	14.6	0.001
		Year*Survey	4	7.6	0.109
		Study Area*Survey	2	2.4	0.305
		Year*Study Area*Survey	4	17.0	0.002
Males : Females	Fall	Intercept	1	3339.9	<0.001
		Year	2	15.0	0.001
		Study Area	1	185.5	<0.001
		Survey	2	617.2	<0.001
		Year*Study Area	2	3.4	0.185
		Year*Survey	4	13.9	0.007
		Study Area*Survey	2	33.8	<0.001

Table 10 (cont.)

Flight : Flightless females	Fall	Intercept	1	14.6	<0.001
		Year	2	29.6	<0.001
		Study Area	1	8.4	0.004
		Survey	2	34.6	<0.001
		Year*Study Area	2	6.1	0.048
		Year*Survey	4	95.6	<0.001
		Study Area*Survey	2	37.7	<0.001
		Year*Study Area*Survey	4	20.7	<0.001
Flight : Flightless males	Fall	Intercept	1	544.1	<0.001
		Year	2	1.6	0.445
		Study Area	1	48.5	<0.001
		Survey	2	3355.4	<0.001
		Year*Study Area	2	29.7	<0.001
		Year*Survey	4	10.0	0.041
		Study Area*Survey	2	33.7	<0.001
		Year*Study Area*Survey	4	32.8	<0.001

Table 11. Ratios of the harlequin duck population in oiled areas of western (WPWS) and unoiled eastern (EPWS) Prince William Sound, Alaska during spring and fall surveys in 1995, 1996, and 1997.

			Ratios					
			Spring surveys			Fall surveys		
Study area	Year	Survey period	Males to females	Non-paired to paired females	Adult to sub-adult males	Males to females	Flight to flightless females	Flight to flightless males
WPWS	1995	1	1.84	0.77	3.23	6.86	0.33	0.05
WPWS	1995	2 [a]	1.33	1.63	3.67	3.00	0.84	0.07
WPWS	1995	3	3.66	20.25	2.60	2.00	1.99	96.29
EPWS	1995	1	1.55	0.20	4.64	3.30	1.12	0.03
EPWS	1995	2	2.07	0.44	2.14	2.18	0.64	0.03
EPWS	1995	3	4.35	2.53	2.80	1.53	1.24	4.66
WPWS	1996	1	1.67	0.49	2.55	5.97	0.56	0.05
WPWS	1996	2	1.96	1.70	1.66	2.51	1.44	0.04
WPWS	1996	3	4.65	7.42	2.38	1.66	1.41	32.60
EPWS	1996	1	1.47	0.17	3.76	3.01	1.19	0.06
EPWS	1996	2	2.04	0.28	2.64	1.75	1.21	0.02
EPWS	1996	3	3.63	3.53	3.54	1.46	2.35	9.20
WPWS	1997	1	1.60	0.28	5.96	7.94	1.21	0.05
WPWS	1997	2	2.89	0.35	2.15	2.59	1.67	0.04
WPWS	1997	3	8.94	8.80	5.26	2.03	1.03	20.45
EPWS	1997	1	1.52	0.08	4.97	3.65	1.70	0.05
EPWS	1997	2	2.14	0.53	3.83	1.64	1.37	0.02
EPWS	1997	3	3.61	2.29	3.38	1.47	0.90	27.24

[a] Negligible survey coverage because of foul weather.

Table 12. Location, date, and composition of harlequin duck broods observed in eastern Prince William Sound, Alaska in 1995, 1996, and 1997.

Transect	Year	Location	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
Port Etches	1997	Port Etches	24 July	1	IIA
Port Etches	1997	Etches Creek	24 July	4	IC
Constantine Harbor	1997	Constantine Creek	24 July	4	IIA
Constantine Harbor	1997	Constantine Creek	24 July	4	IC
Constantine Harbor	1997	Constantine Creek	24 July	3	IC
Constantine Harbor	1997	Constantine Creek	24 July	2	IIA
Constantine Harbor	1997	Constantine Creek	14 Aug.	2	IIB
Constantine Harbor	1997	Constantine Creek	14 Aug.	4	IIB
Constantine Harbor	1997	Constantine Harbor	14 Aug.	2	IIC
Constantine Harbor	1997	Constantine Harbor	14 Aug.	2	IIC
Vladnoff River	1997	Vladnoff River	16 Aug.	2	IIC
Constantine Harbor	1997	Constantine Harbor	5 Sep.	2	III

[a] Gollop and Marshall 1954

Table 13. Population trend for harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska during the fall in 1995, 1996, and 1997.

Study Area	Number of slopes	Total ducks	Spatial scale	Sex	Weighted mean slope	Standard error	P[a]
EPWS	77	12926	transect	both	0.3114	0.2637	0.241
WPWS	54	9543	transect	both	-0.2022	0.3869	0.604
EPWS	15	12926	region	both	0.2476	0.1653	0.158
WPWS	21	9543	region	both	-0.6412	0.2580	0.023
EPWS	3	12926	study area	both	0.3258	0.3826	0.551
WPWS	3	9543	study area	both	-0.2422	0.4796	0.702
EPWS	15	8595	region	male	0.1610	0.0921	0.104
WPWS	21	7064	region	male	-0.5688	0.2748	0.052
EPWS	15	4331	region	female	0.1414	0.0921	0.149
WPWS	21	2479	region	female	-0.1225	0.0404	0.007

[a] Probability of slope being significantly different than 0 (t test).

Table 14. Power to detect differences in population trends for harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound during the fall in 1995, 1996, and 1997.

Spatial scale	Sex	Standard error	P[a]	Power
transect	both	0.4682	0.275	0.190
region	both	0.3070	0.007	0.794
study area	both	0.6136*	0.407	0.079
region	male	0.2898	0.019	0.674
region	female	0.1006	0.017	0.700

[a] Probability of slope being significantly different than 0 (t test).

* pooled variance

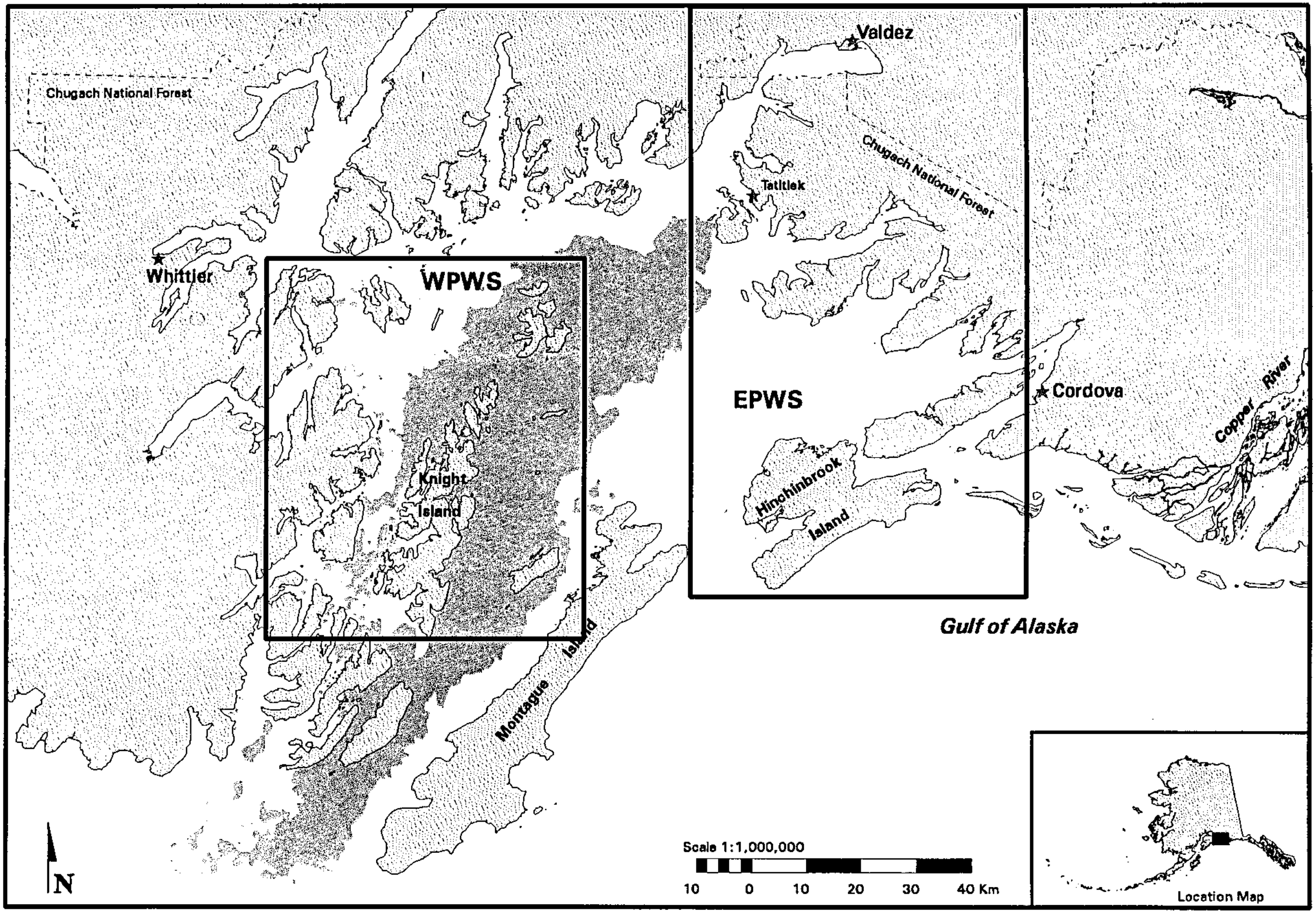


Figure 1. Map of Prince William Sound, Alaska showing areas affected by oil following the *Exxon Valdez* oil spill, and the general location of the western (WPWS) and eastern (EPWS) study areas.

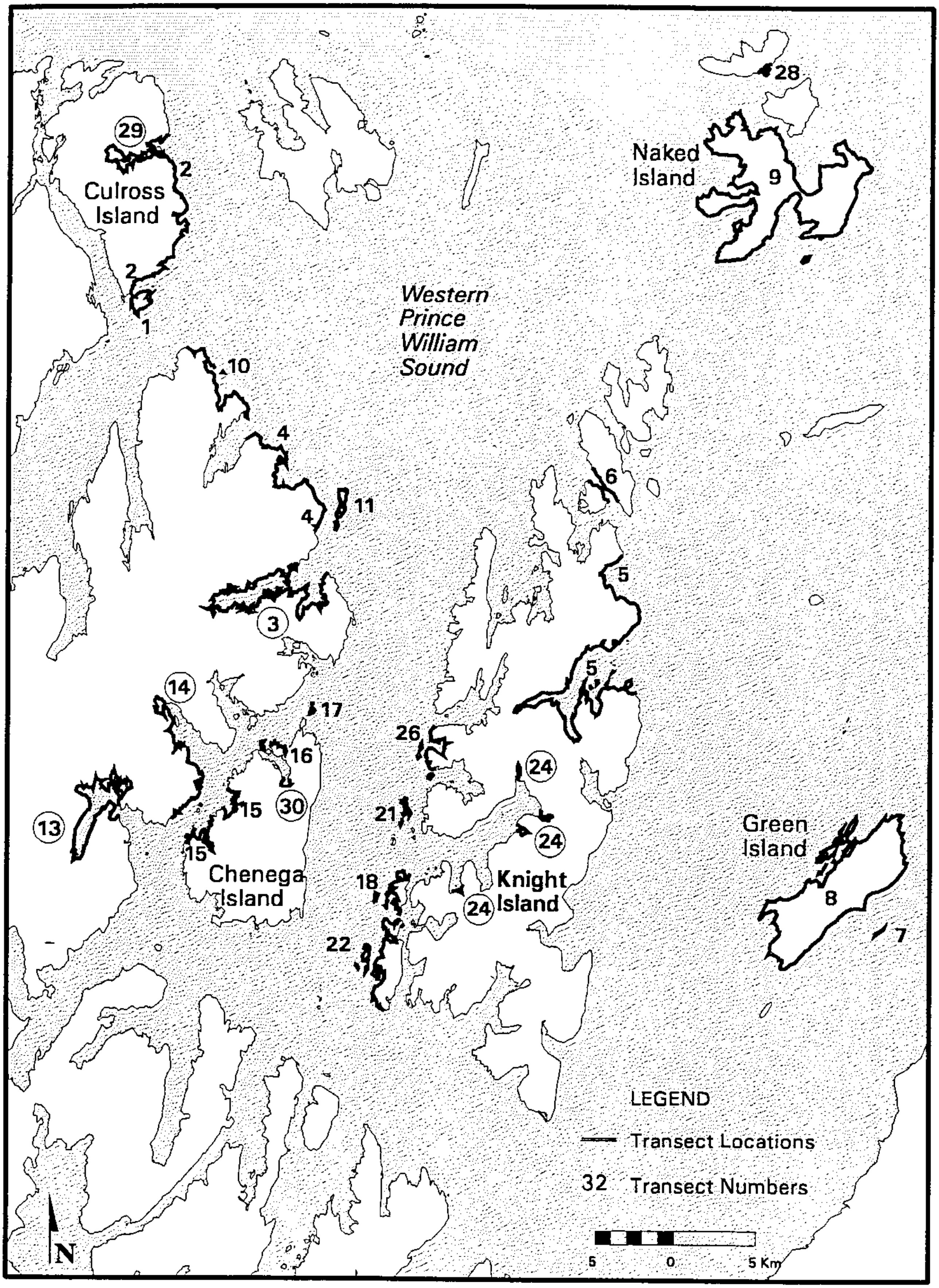


Figure 2. Location of transects surveyed for harlequin ducks in oiled areas of western Prince William Sound, Alaska in 1995, 1996 and 1997. Transect numbers are referenced in tables. Circled numbers indicate transects surveyed only during the fall for the presence of broods.

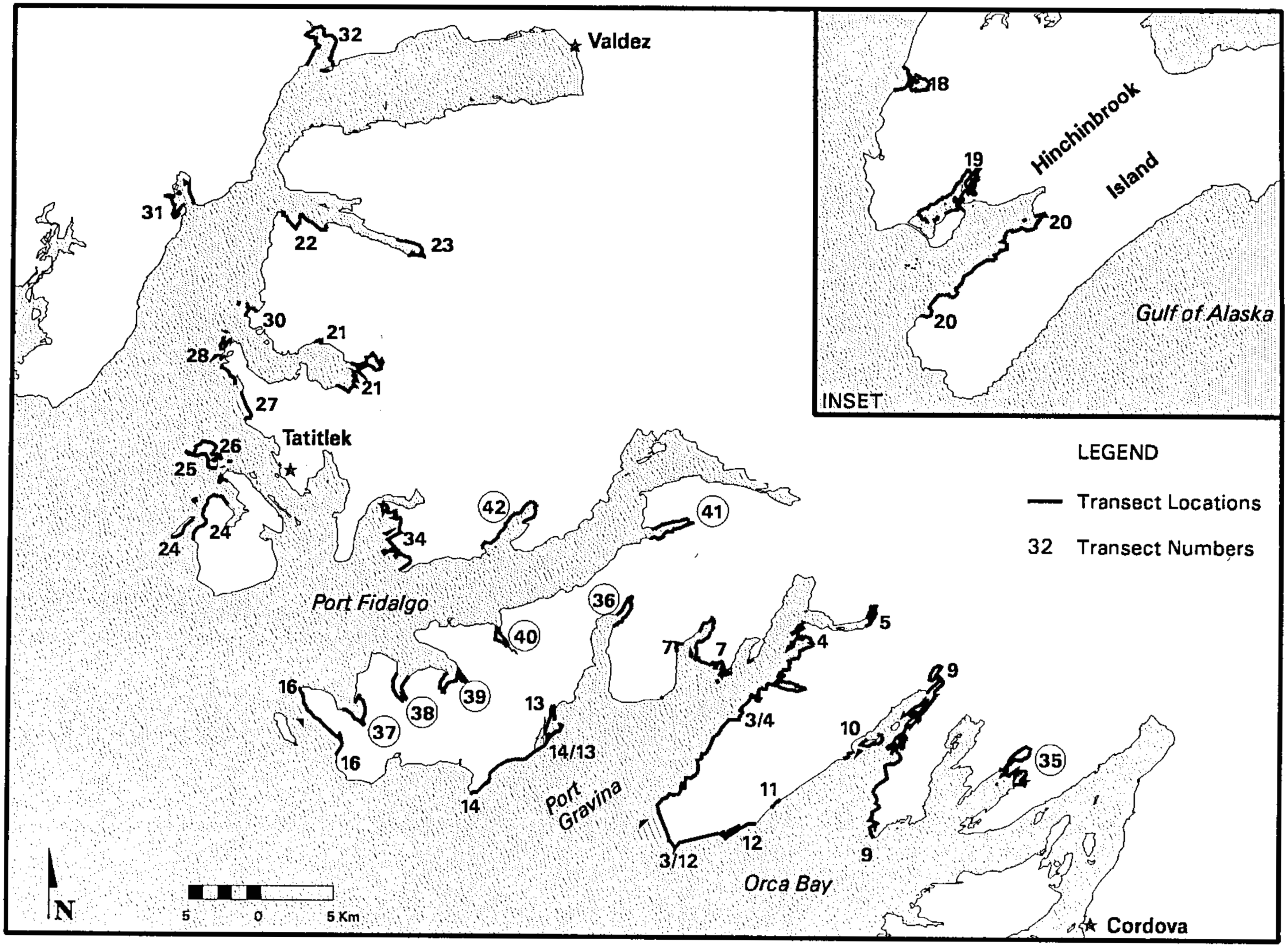


Figure 3. Location of transects surveyed for harlequin ducks in unoiled areas of eastern Prince William Sound, Alaska in 1995, 1996 and 1997. Transect numbers are referenced in tables. Circled numbers indicate transects surveyed only during the fall for the presence of broods.

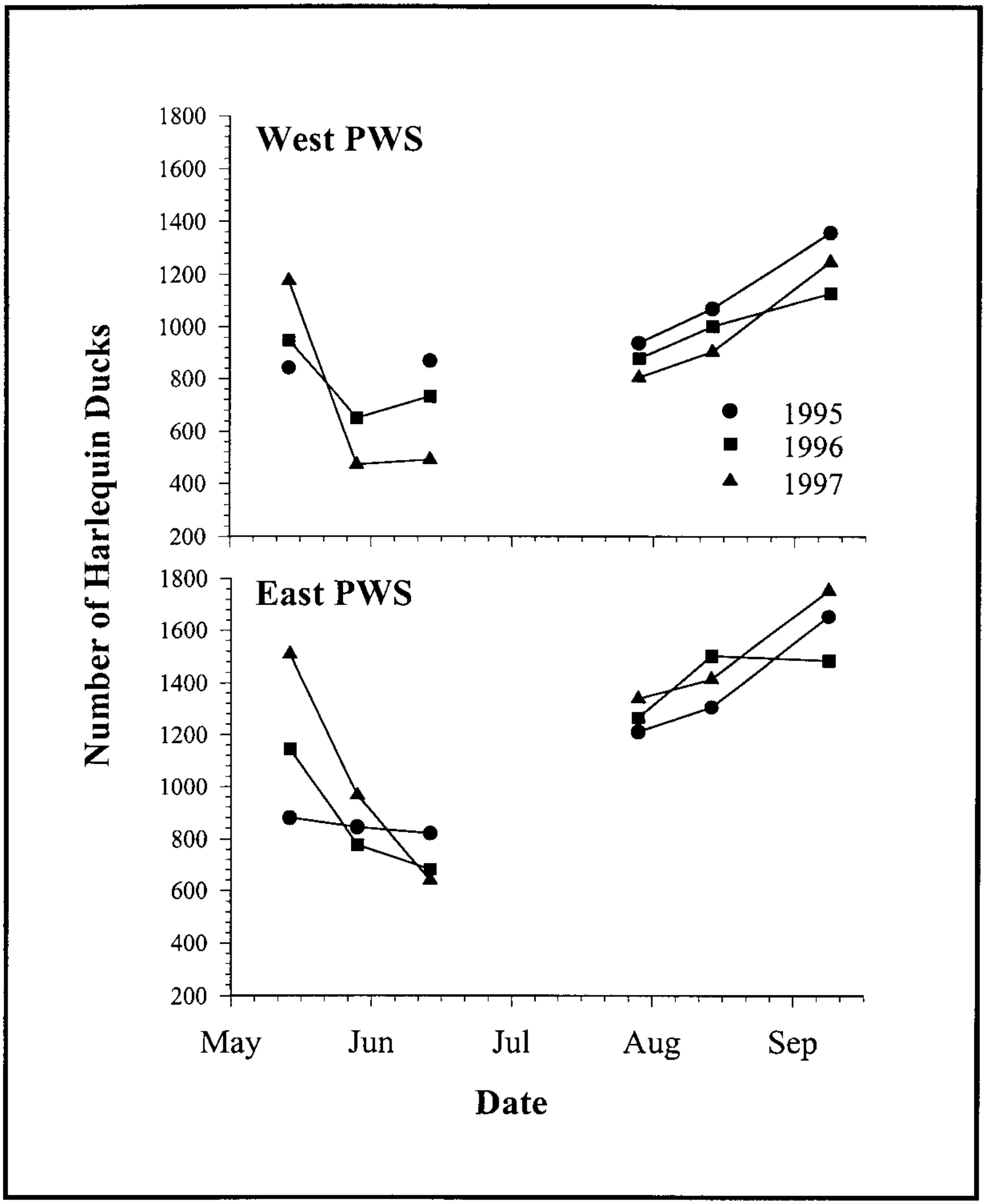


Fig. 4. Seasonal variation in the number of harlequin ducks observed in oiled areas of western (WPWS) and unoiled eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

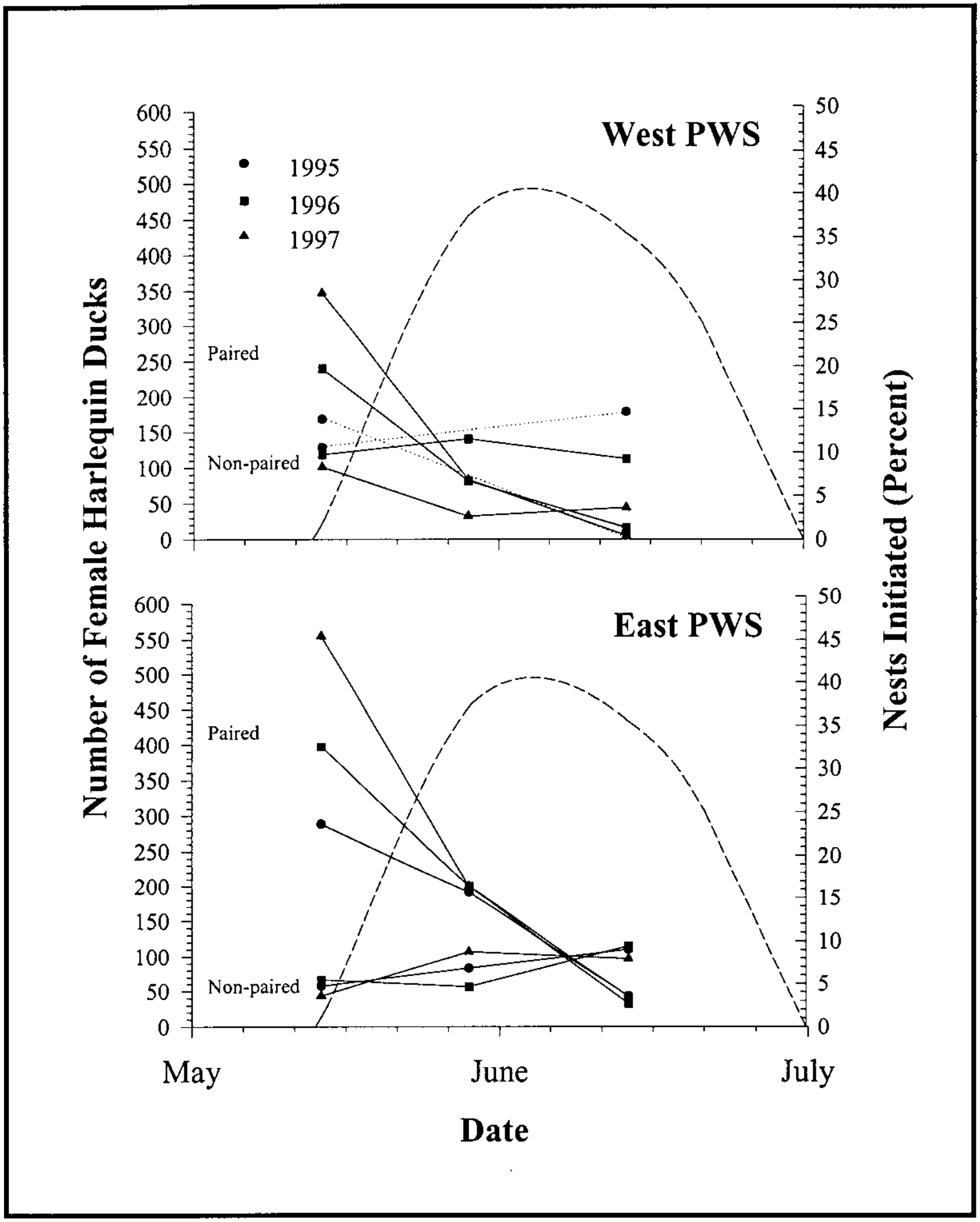


Fig. 5. Number of paired and non-paired female harlequin ducks observed during spring surveys in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997. Nest initiation curve derived by back-dating from the age of nests and broods observed in EPWS (Crowley 1996). Foul weather precluded the completion of the second spring survey in WPWS in 1995.

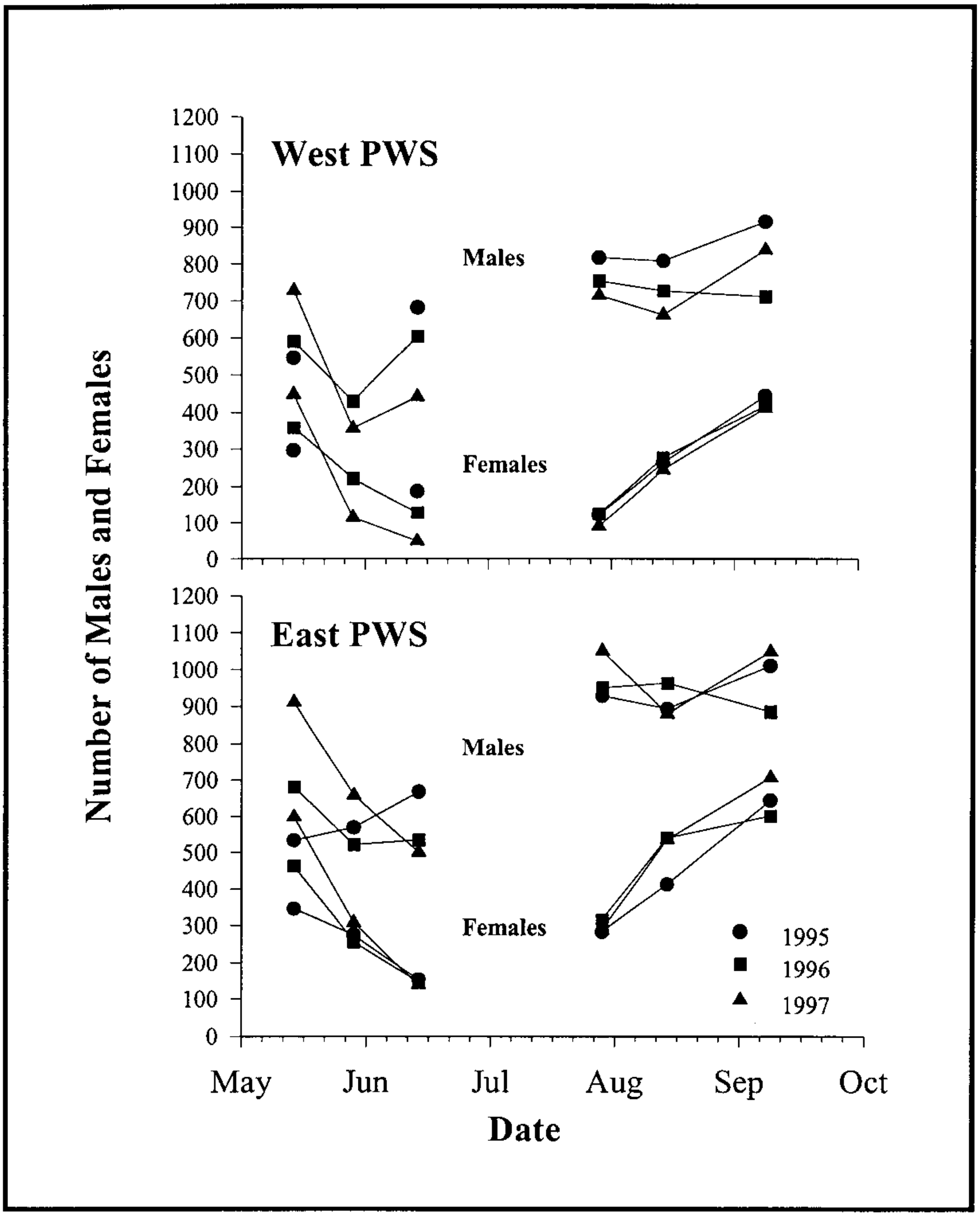


Fig. 6. Number of male and female harlequin ducks observed in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

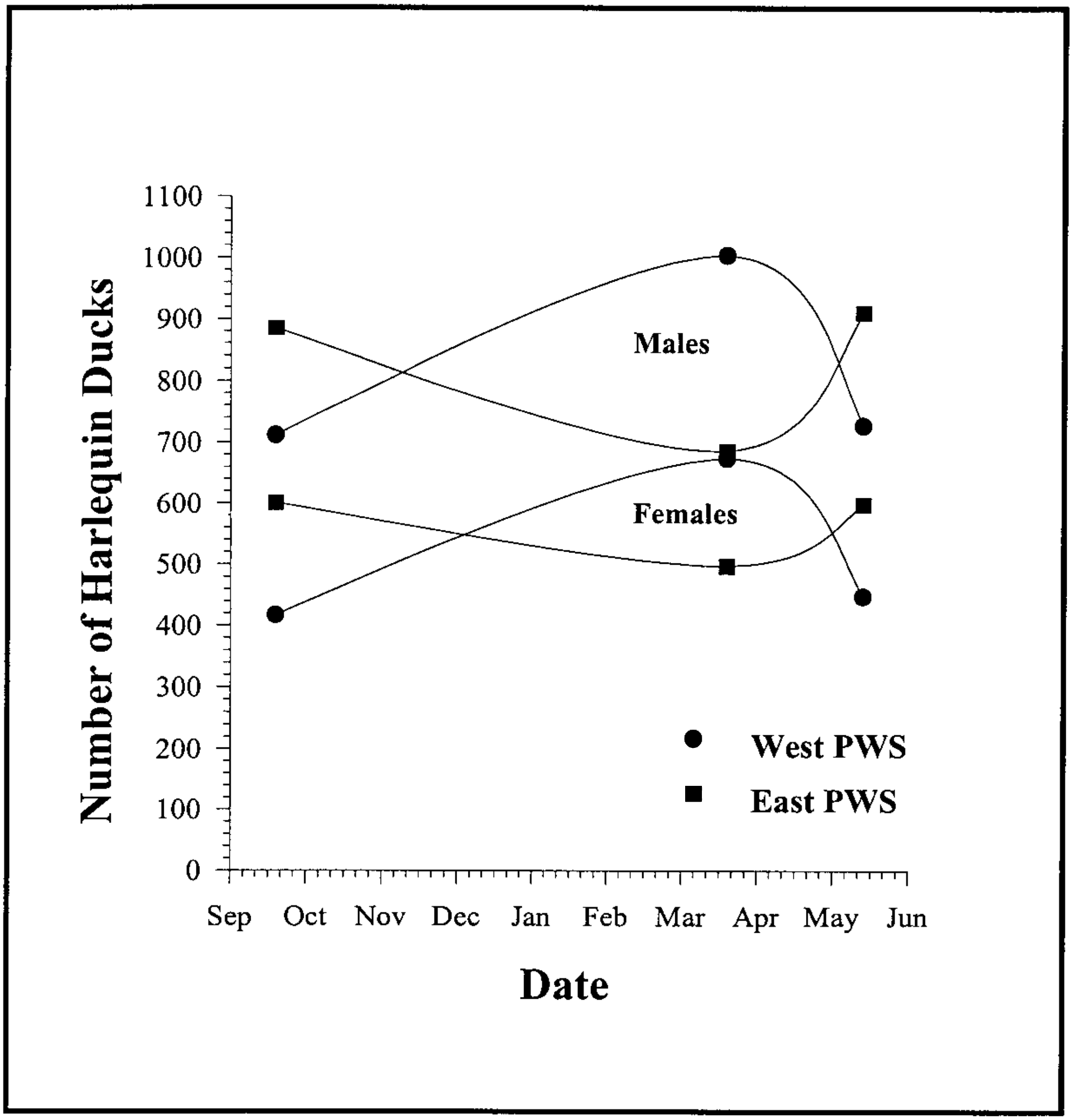


Fig. 7. Number of male and female harlequin ducks observed during September 1996, March 1997, and May 1997 in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska.

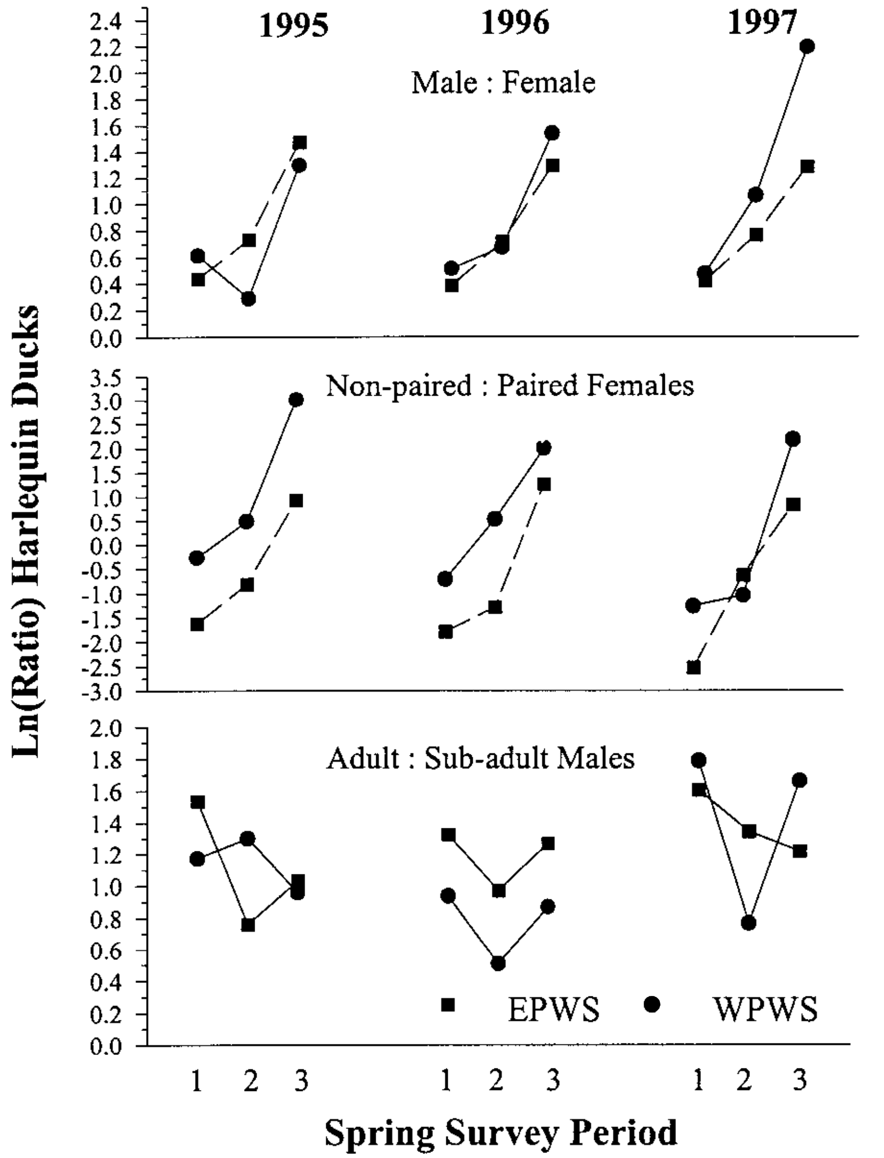


Fig. 8. Natural logarithm of ratios observed for harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

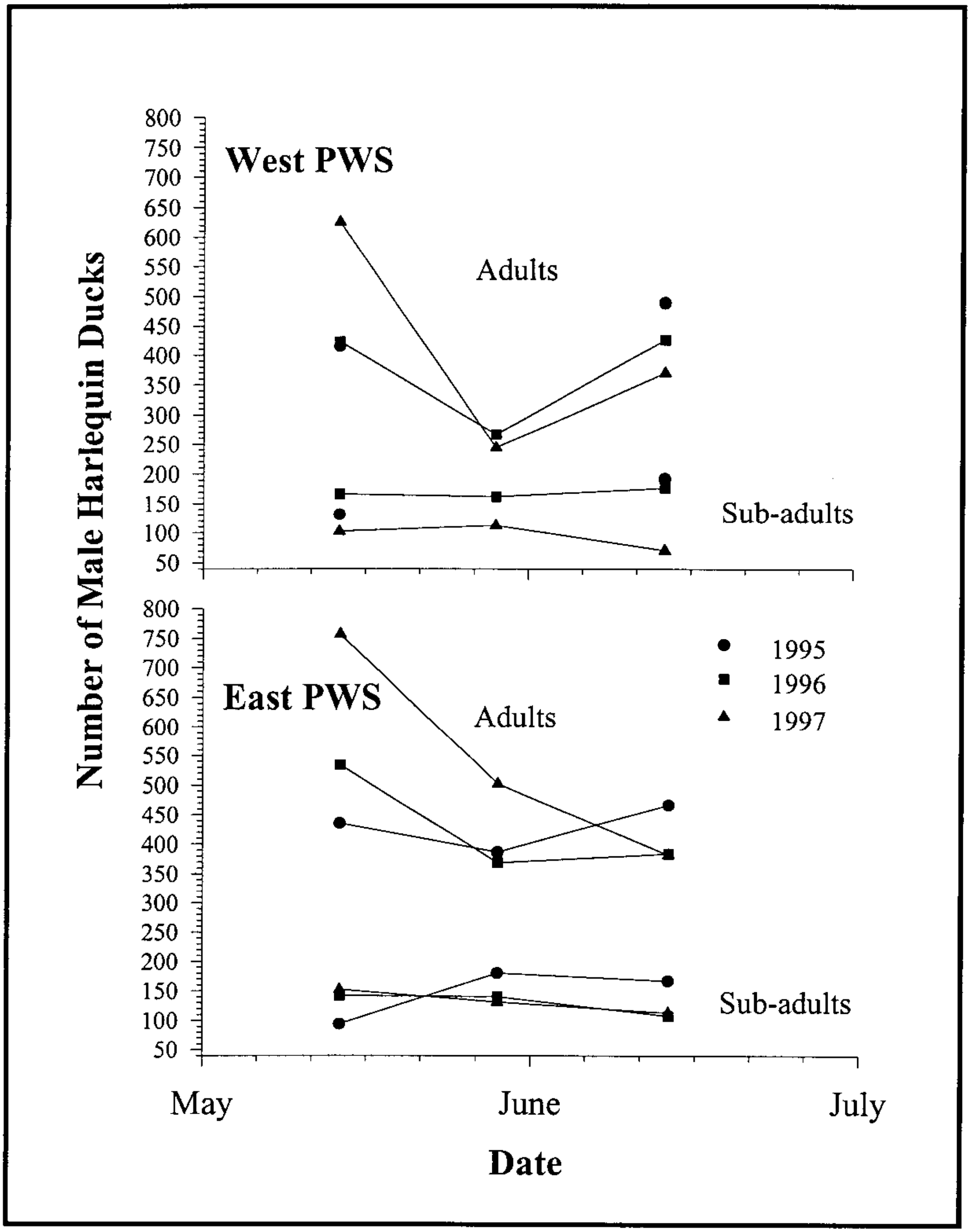


Fig. 9. Number of adult and sub-adult male harlequin ducks observed during the spring in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997. Foul weather precluded the completion of the second spring survey in WPWS in 1995.

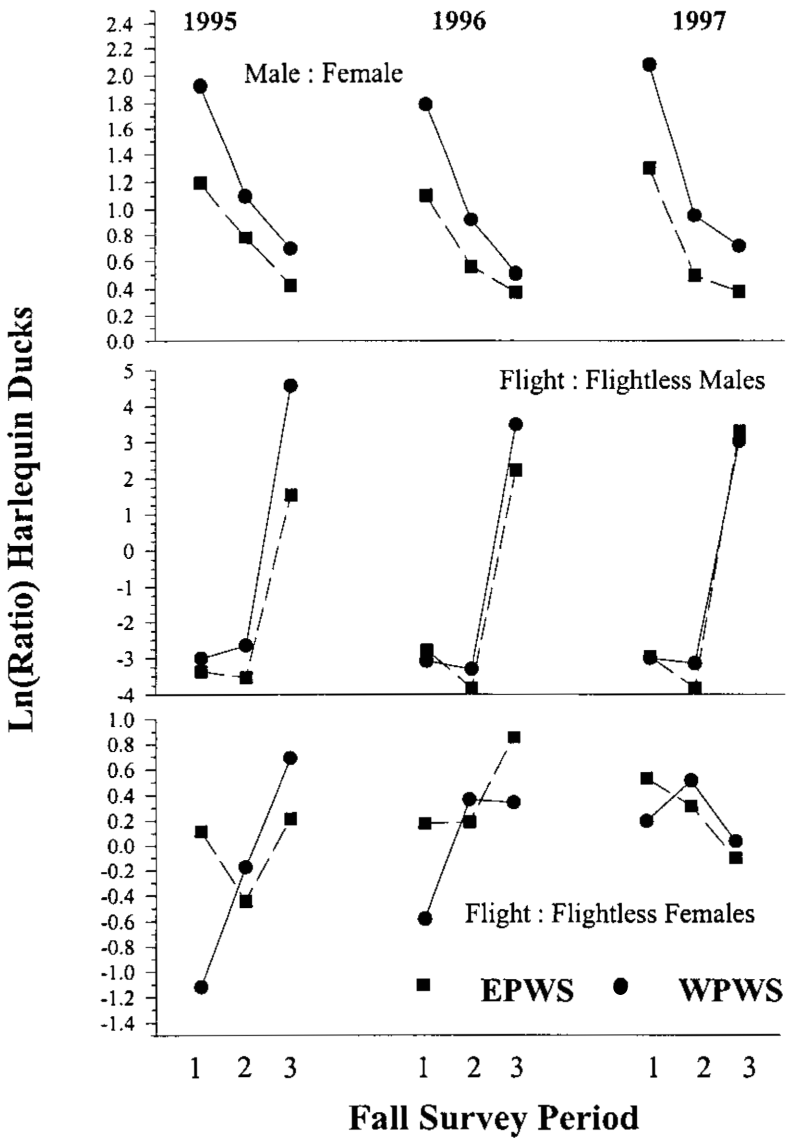


Fig. 10. Natural logarithm of ratios observed for harlequin ducks during the fall in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

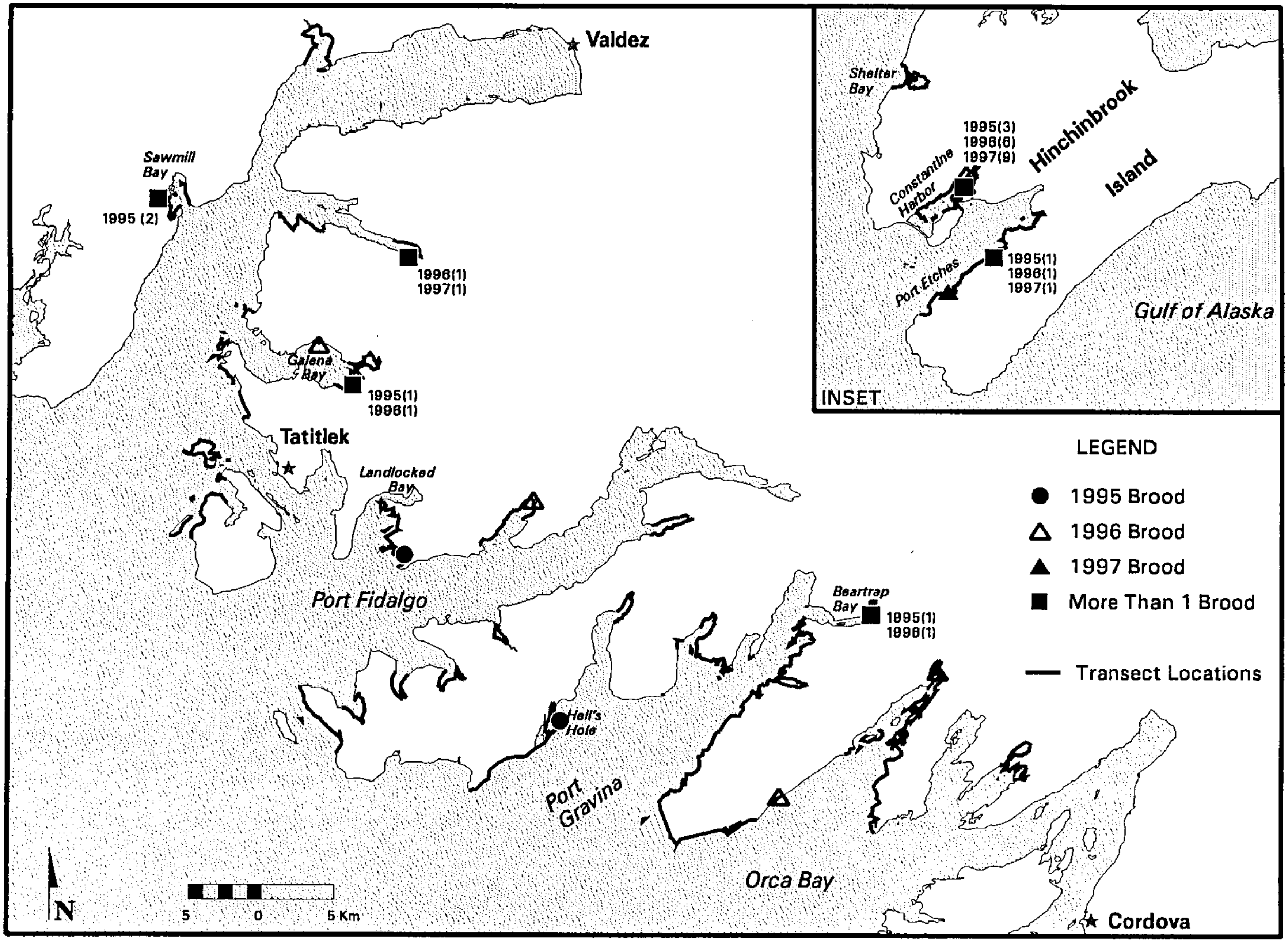
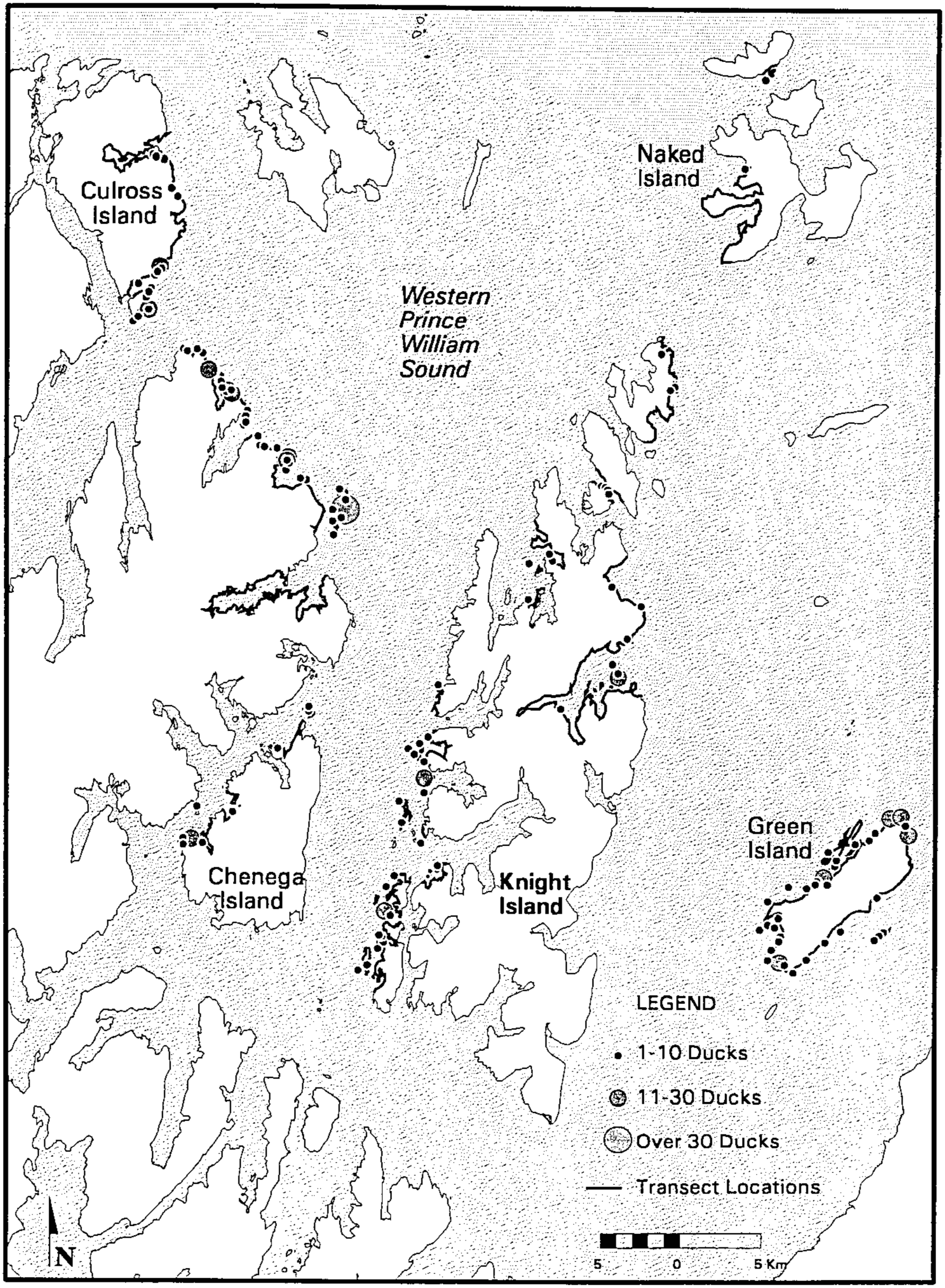
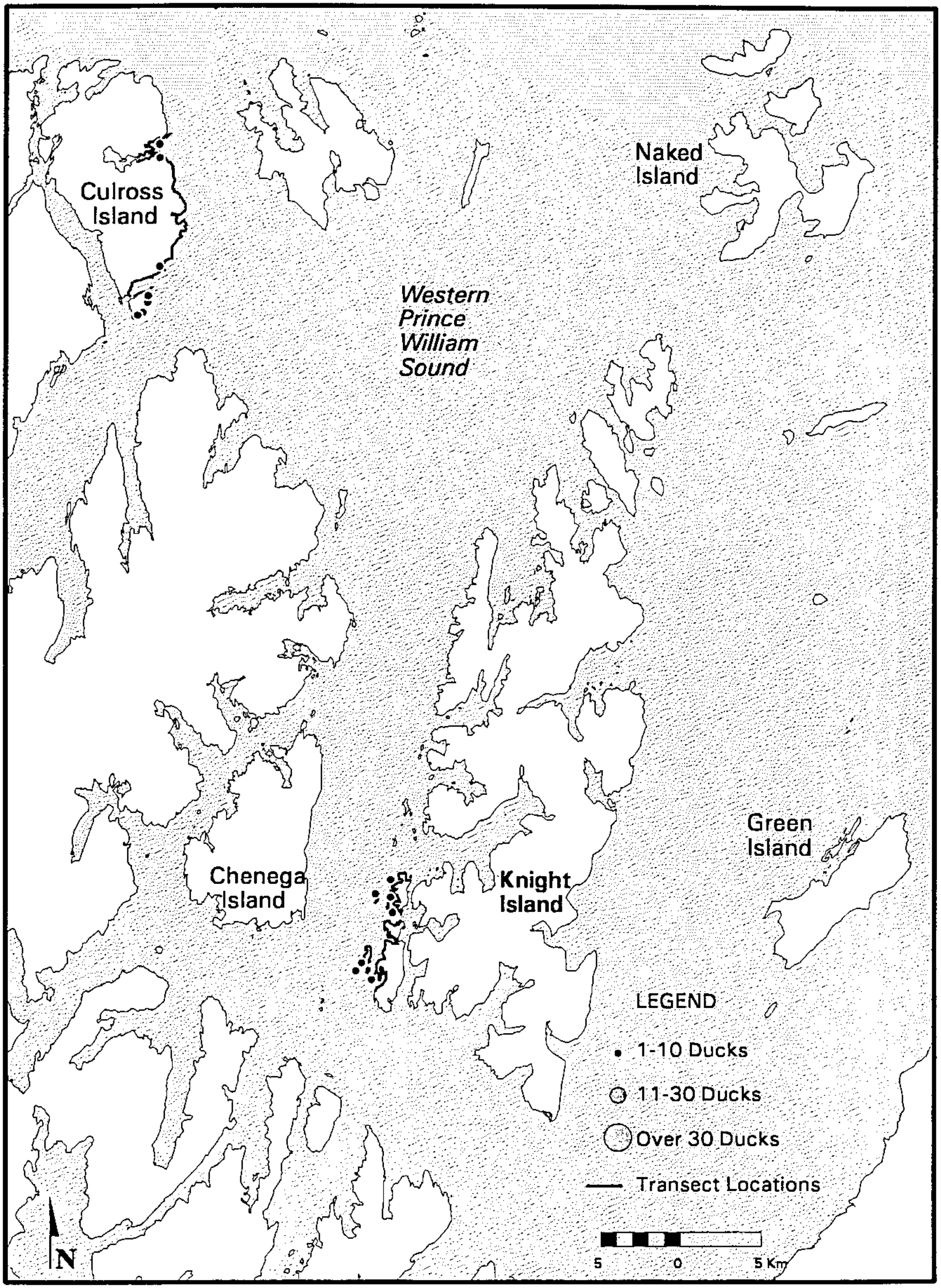


Figure 11. Location of harlequin duck broods observed in eastern Prince William Sound, Alaska in 1995, 1996 and 1997.

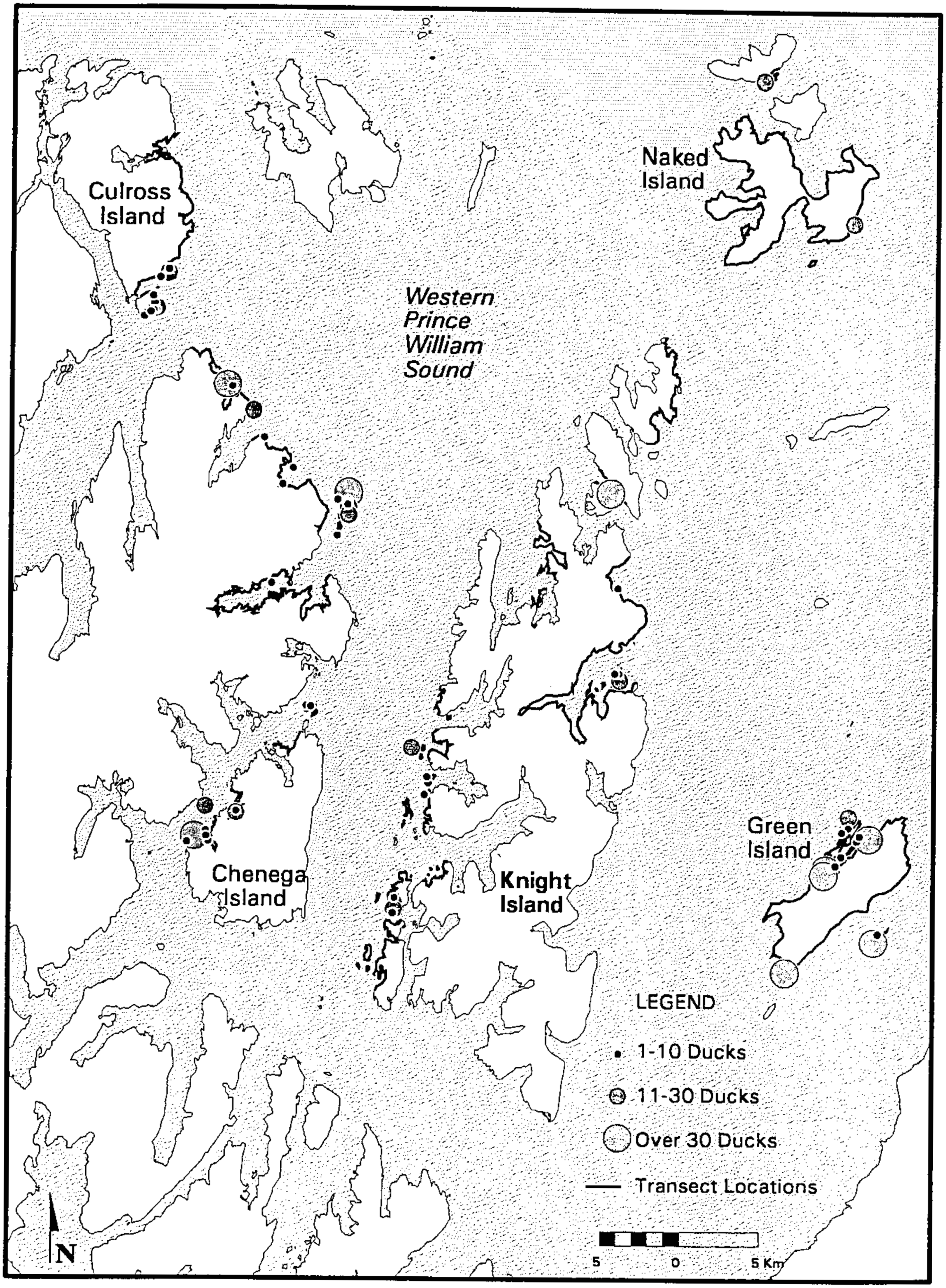
Appendix A: Location of harlequin ducks observed during the spring, fall, and winter in western and eastern Prince William Sound, Alaska in 1995, 1996, and 1997.



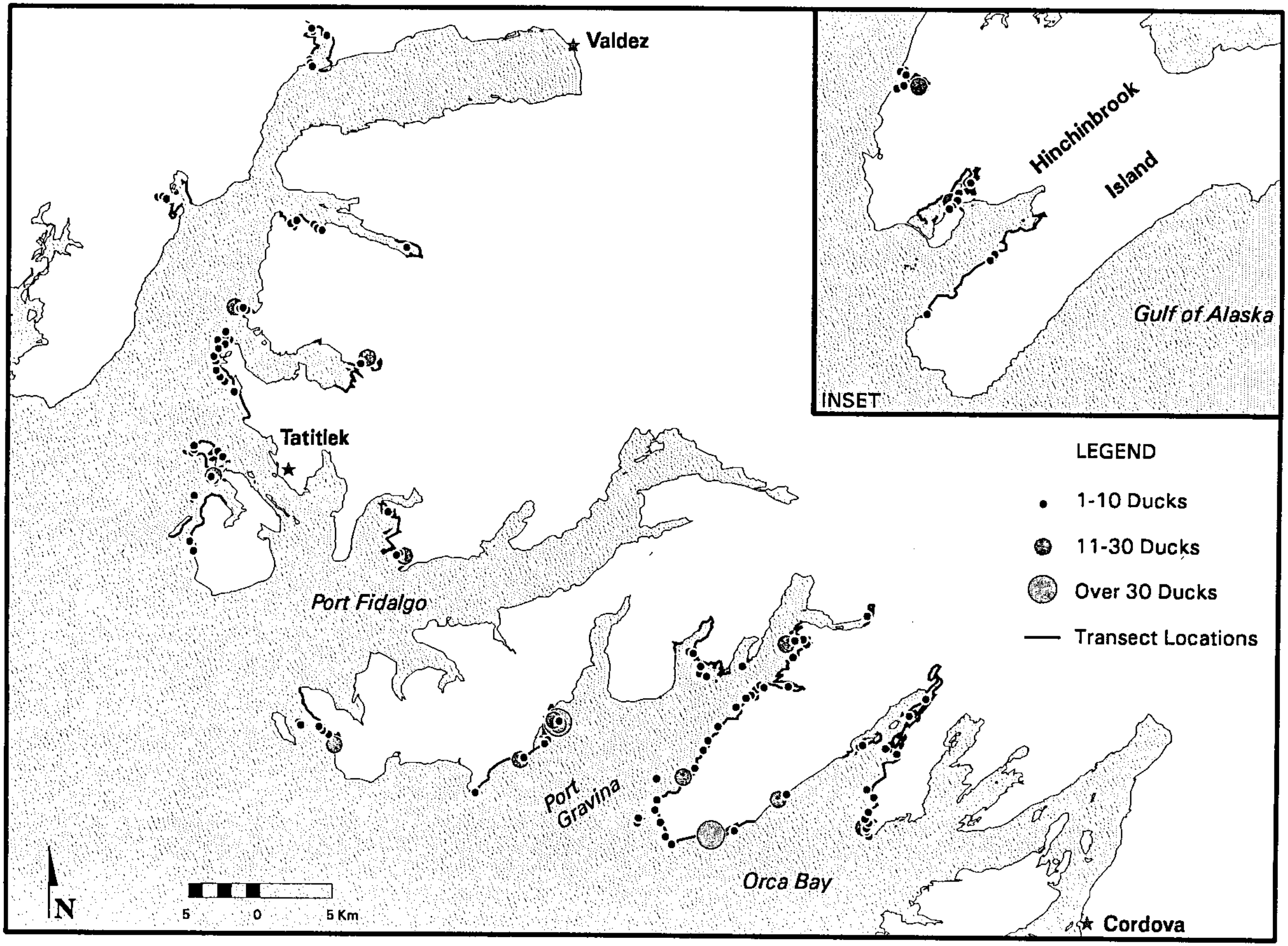
Appendix A1. Location of harlequin ducks observed in western Prince William Sound during the first spring survey (10 May-20 May) in 1995.



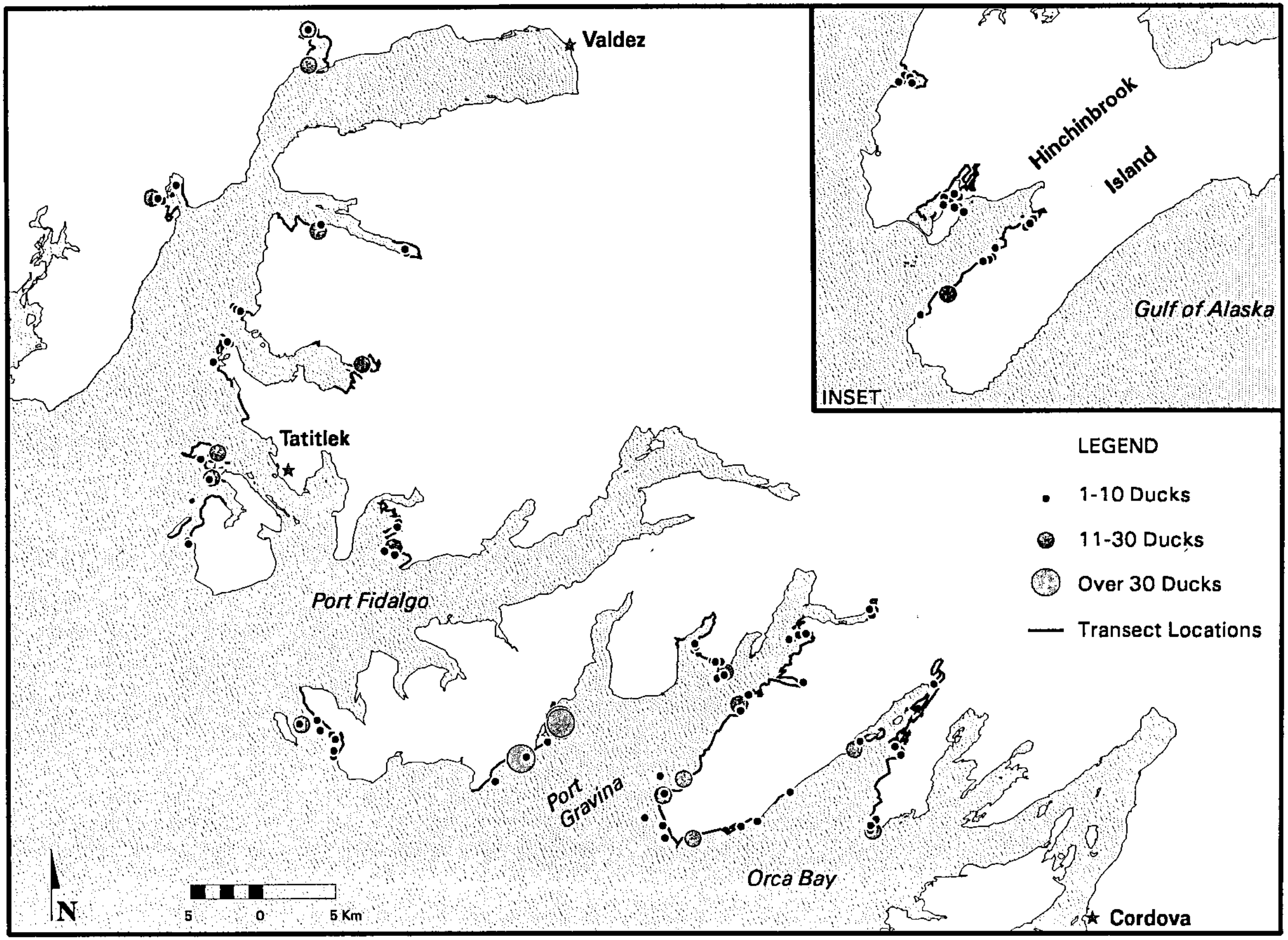
Appendix A2. Location of harlequin ducks observed in western Prince William Sound during the second spring survey (26 May-29 May) in 1995. Survey coverage was not completed because of poor weather.



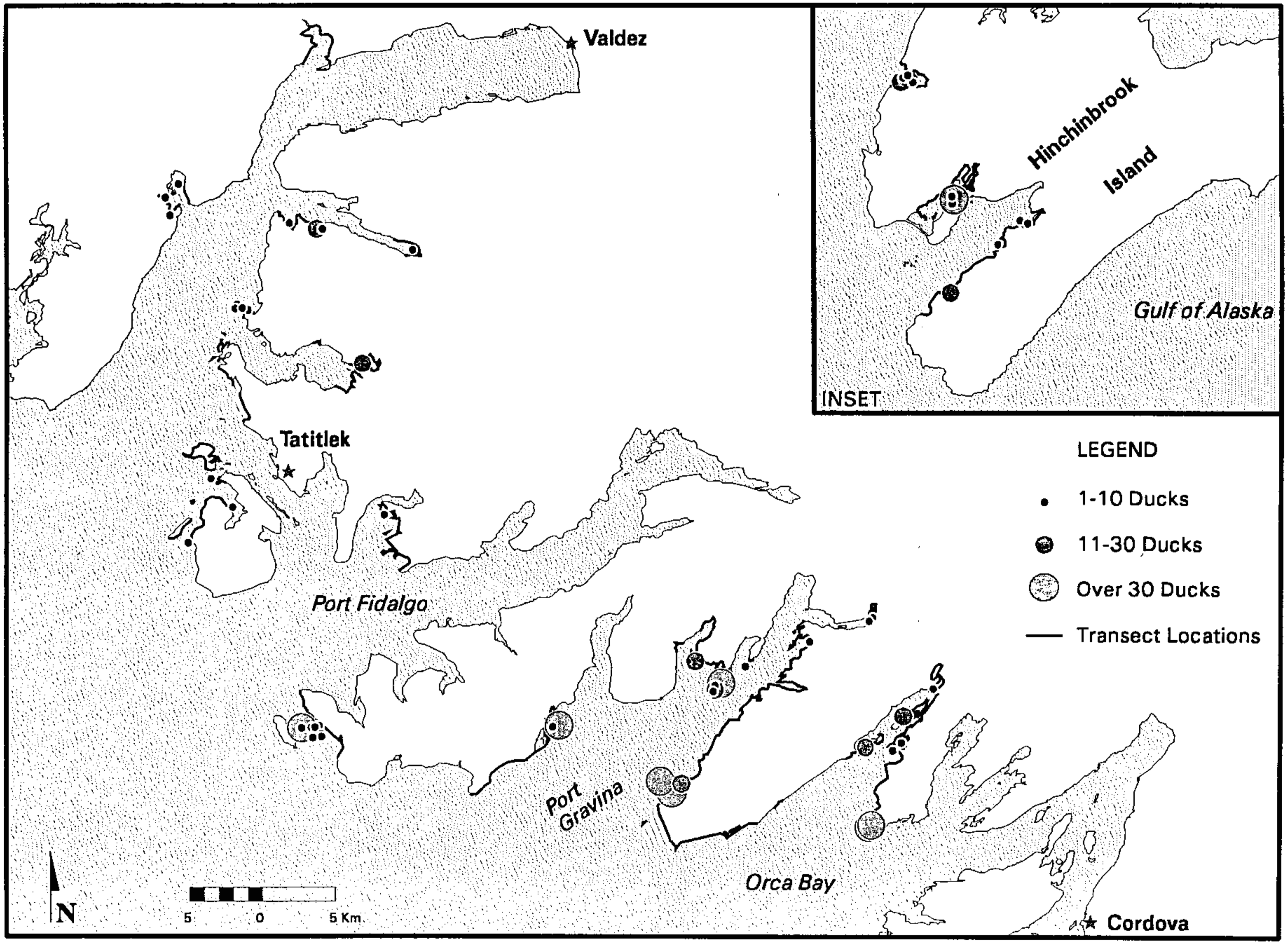
Appendix A3. Location of harlequin ducks observed in western Prince William Sound during the third spring survey (9 June-16 June) in 1995.



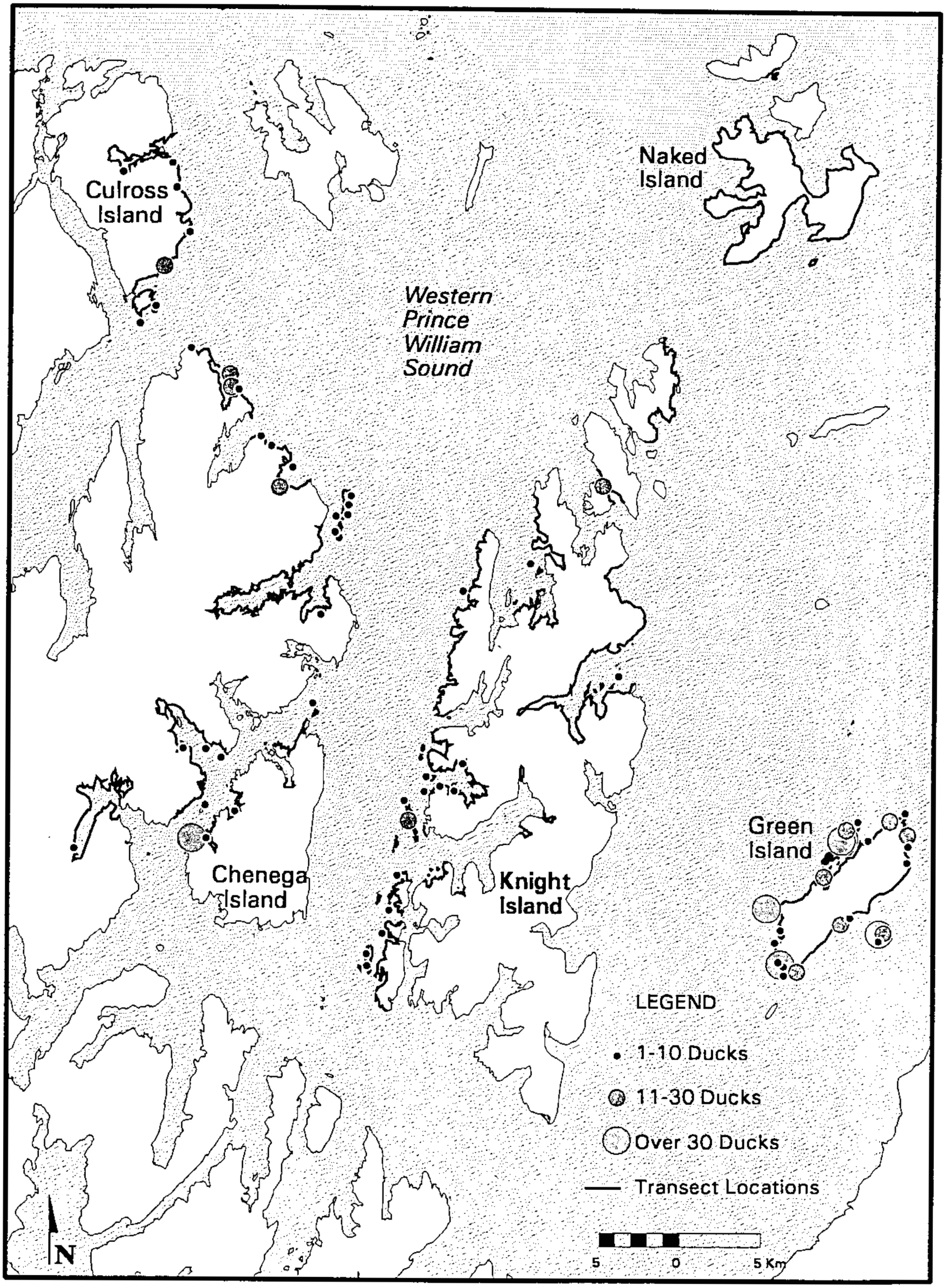
Appendix A4. Location of harlequin ducks observed in eastern Prince William Sound during the first spring survey (10 May-17 May) in 1995.



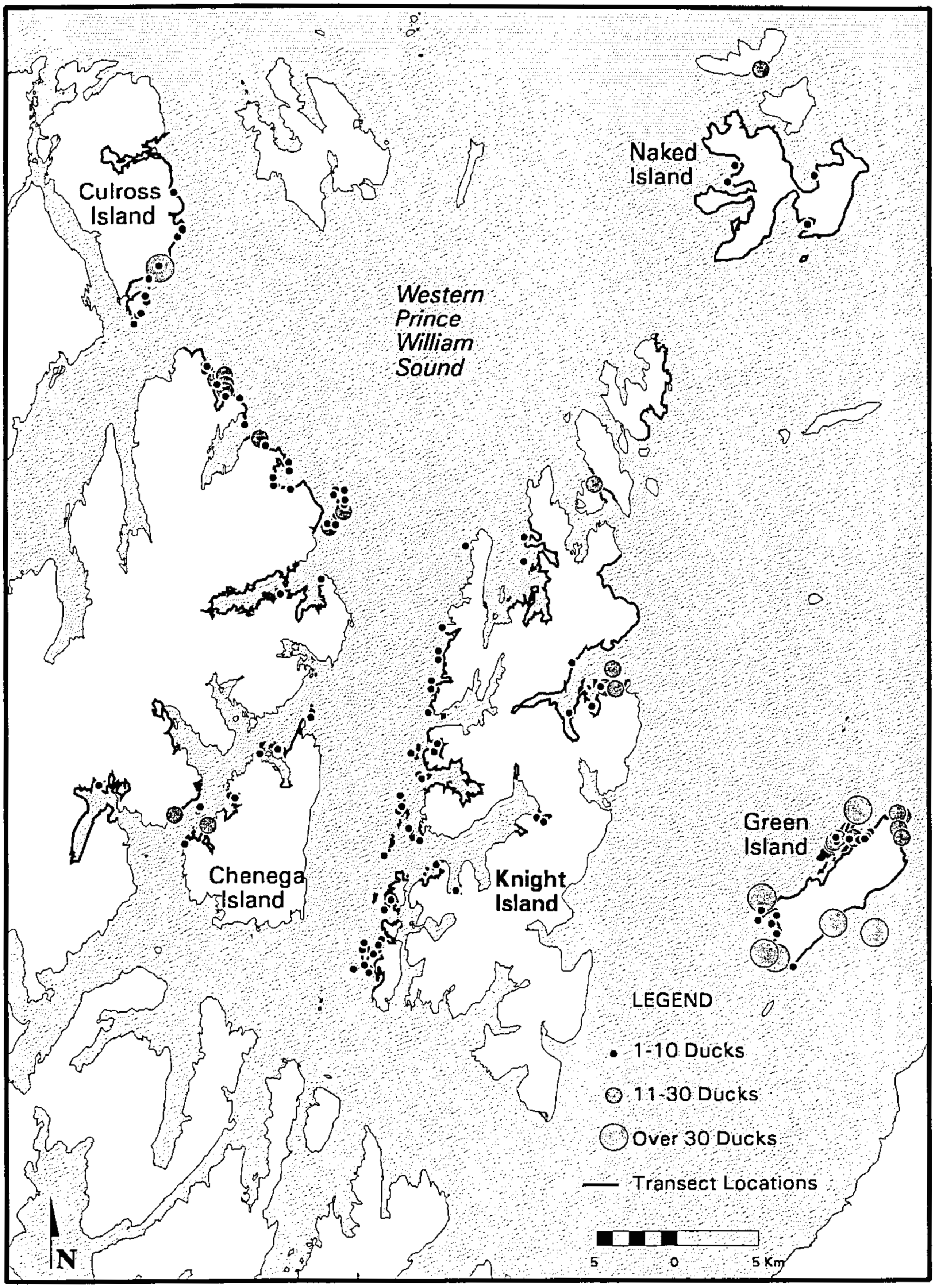
Appendix A5. Location of harlequin ducks observed in eastern Prince William Sound during the second spring survey (23 May-31 May) in 1995.



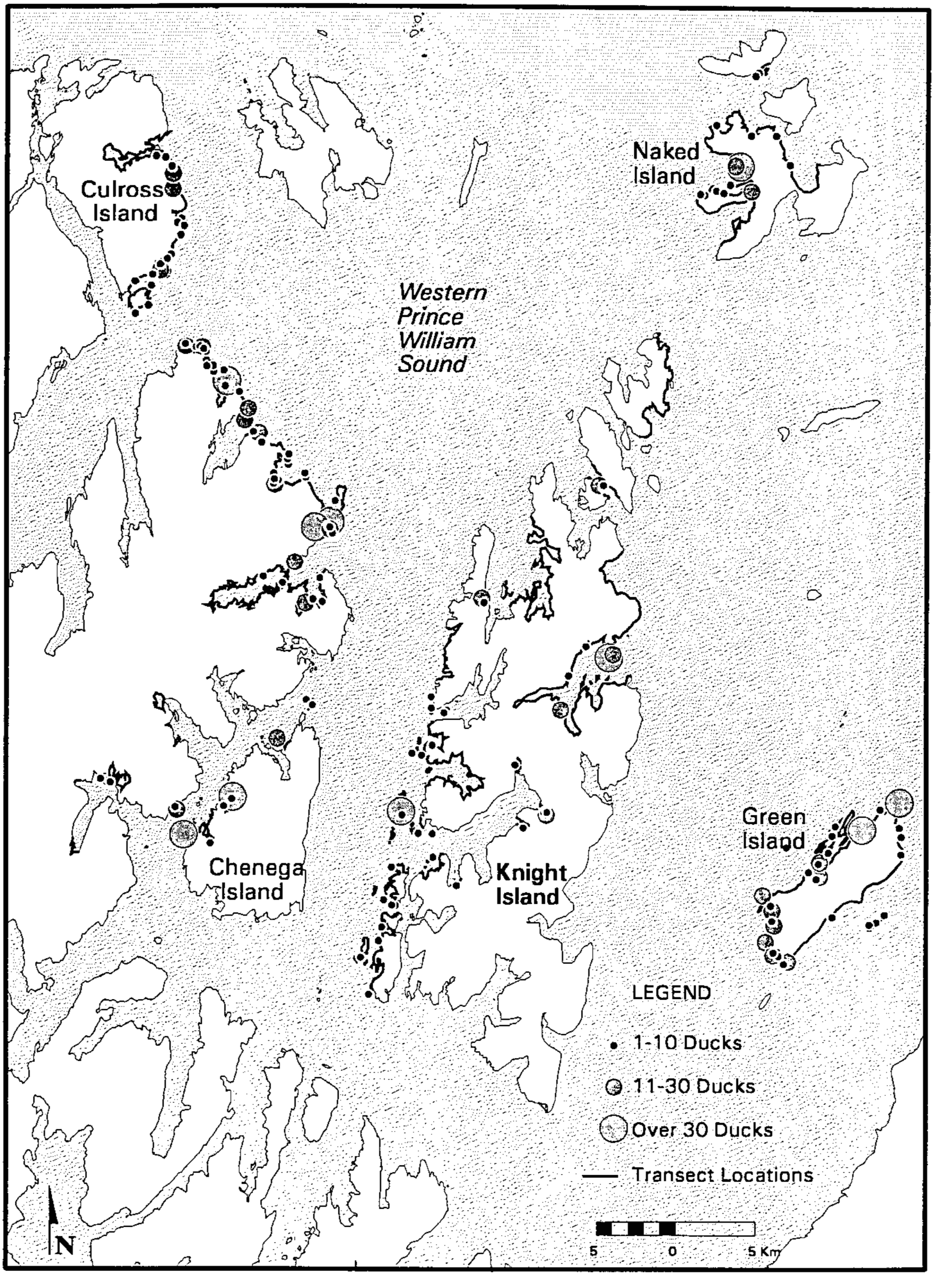
Appendix A6. Location of harlequin ducks observed in eastern Prince William Sound during the third spring survey (10 June-16 June) in 1995.



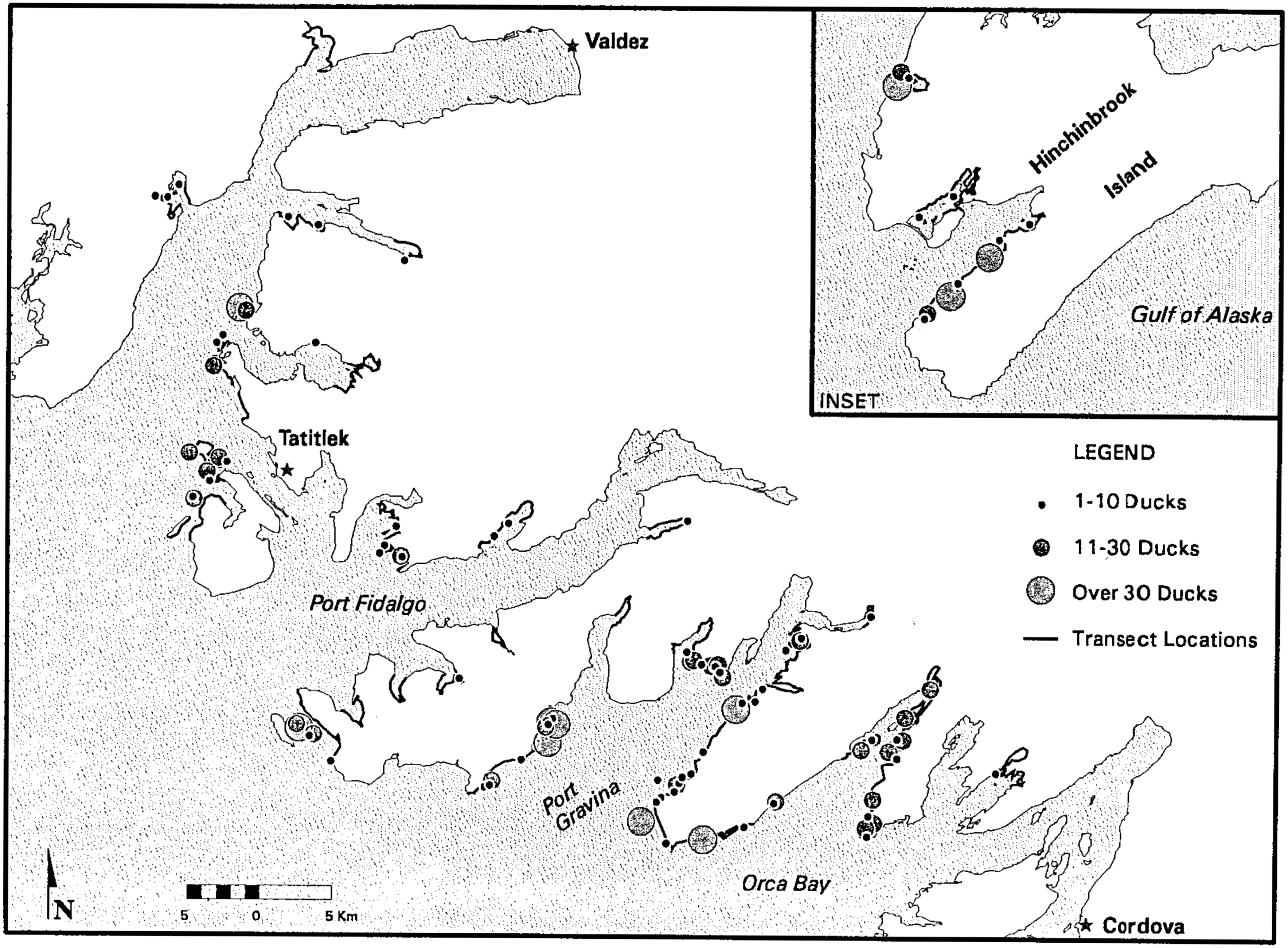
Appendix A7. Location of harlequin ducks observed in western Prince William Sound during the first fall survey (25 July-1 Aug.) in 1995.



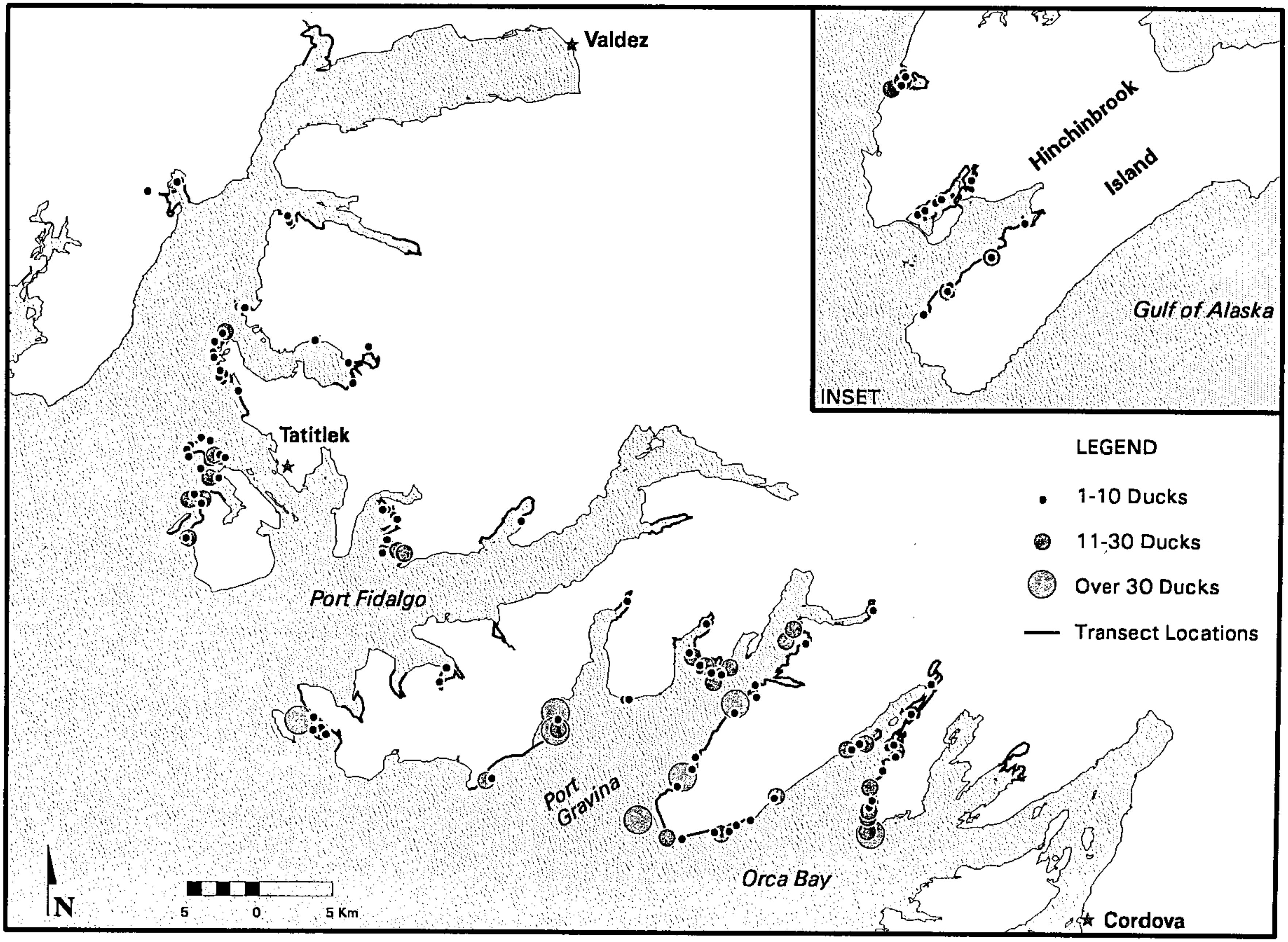
Appendix A8. Location of harlequin ducks observed in western Prince William Sound during the second fall survey (10 Aug.-18 Aug.) in 1995.



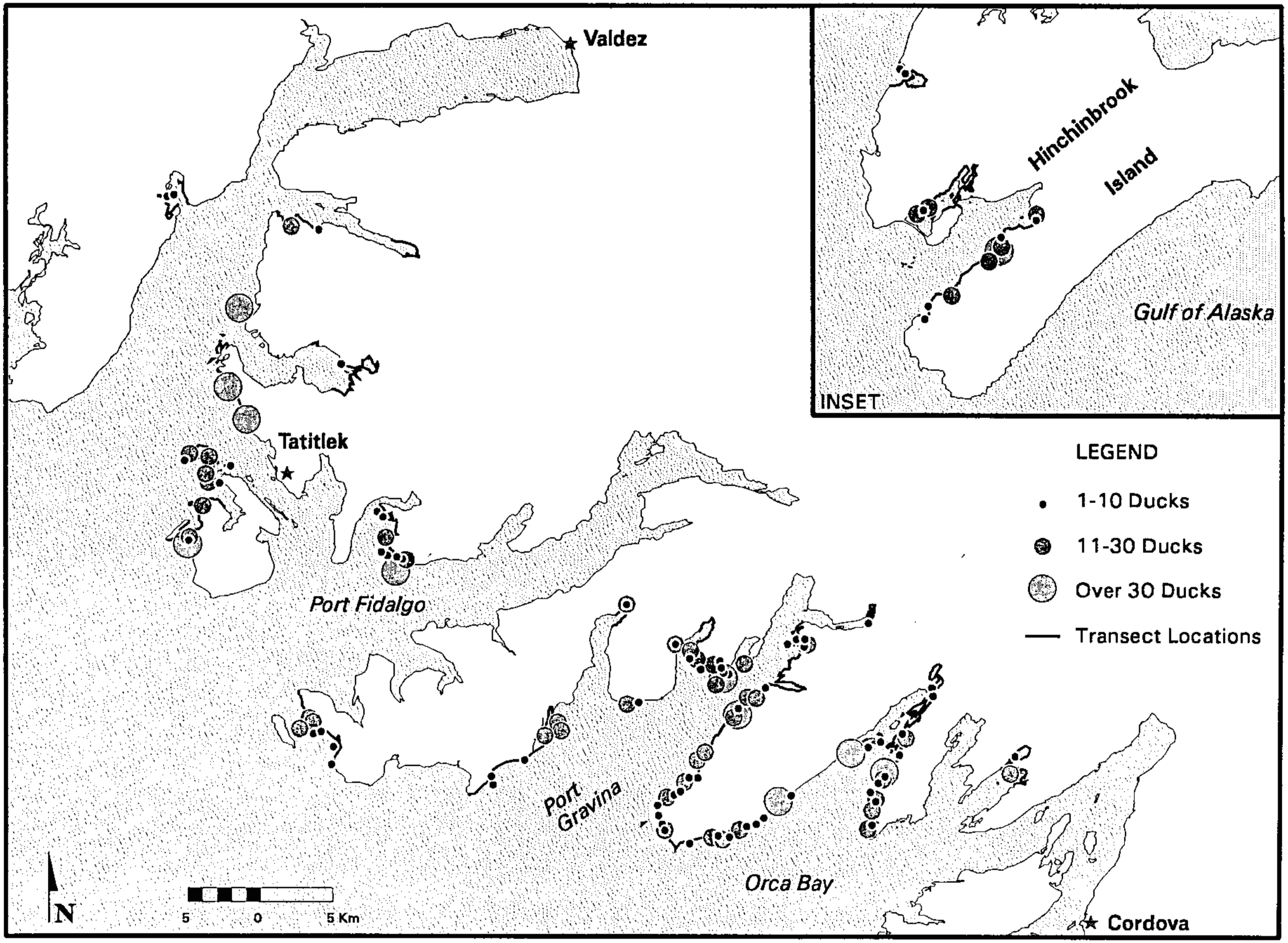
Appendix A9. Location of harlequin ducks observed in western Prince William Sound during the third fall survey (5 Sept.-14 Sept.) in 1995.



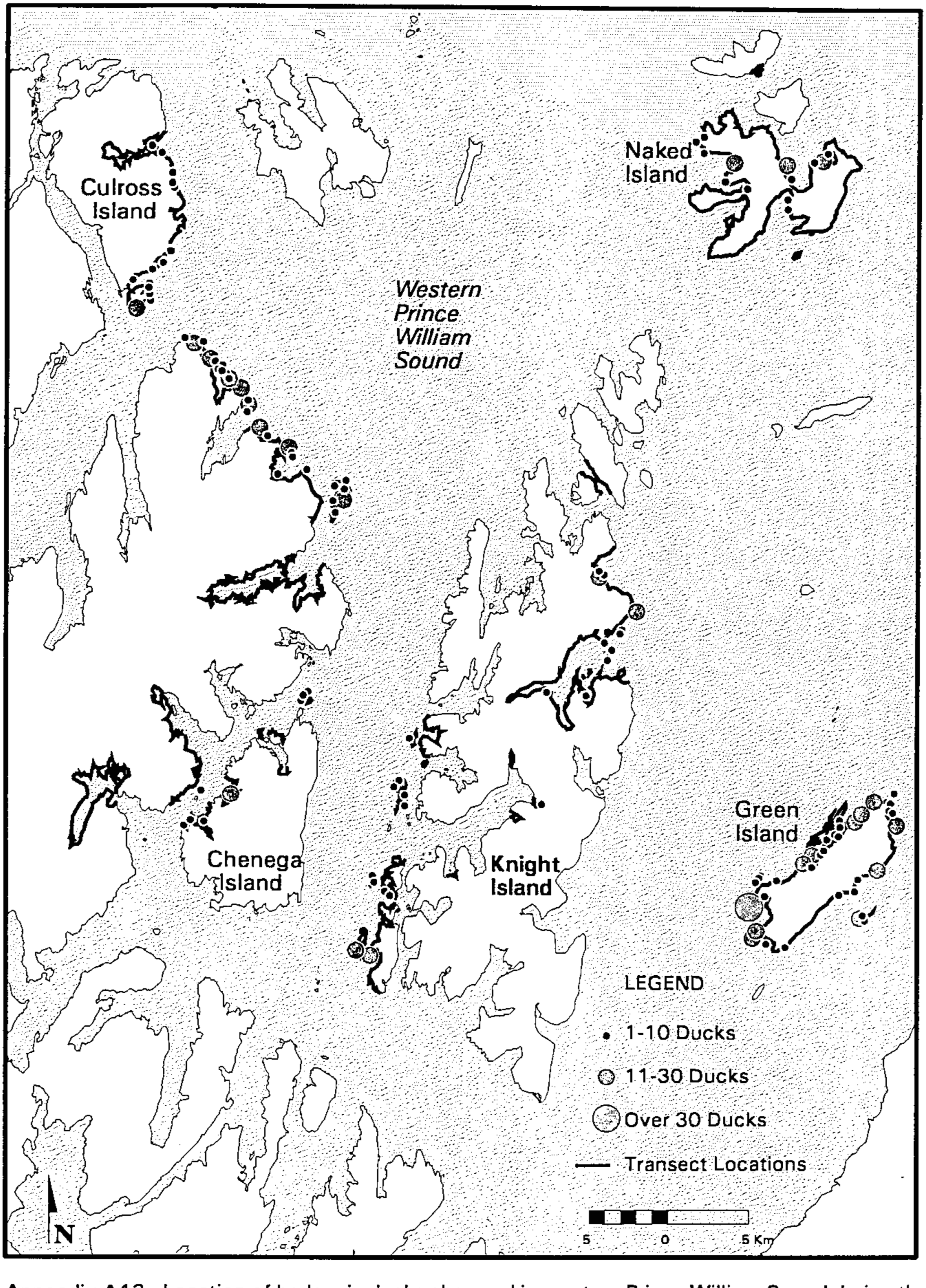
Appendix A10. Location of harlequin ducks observed in eastern Prince William Sound during the first fall survey (25 July-30 July) in 1995.



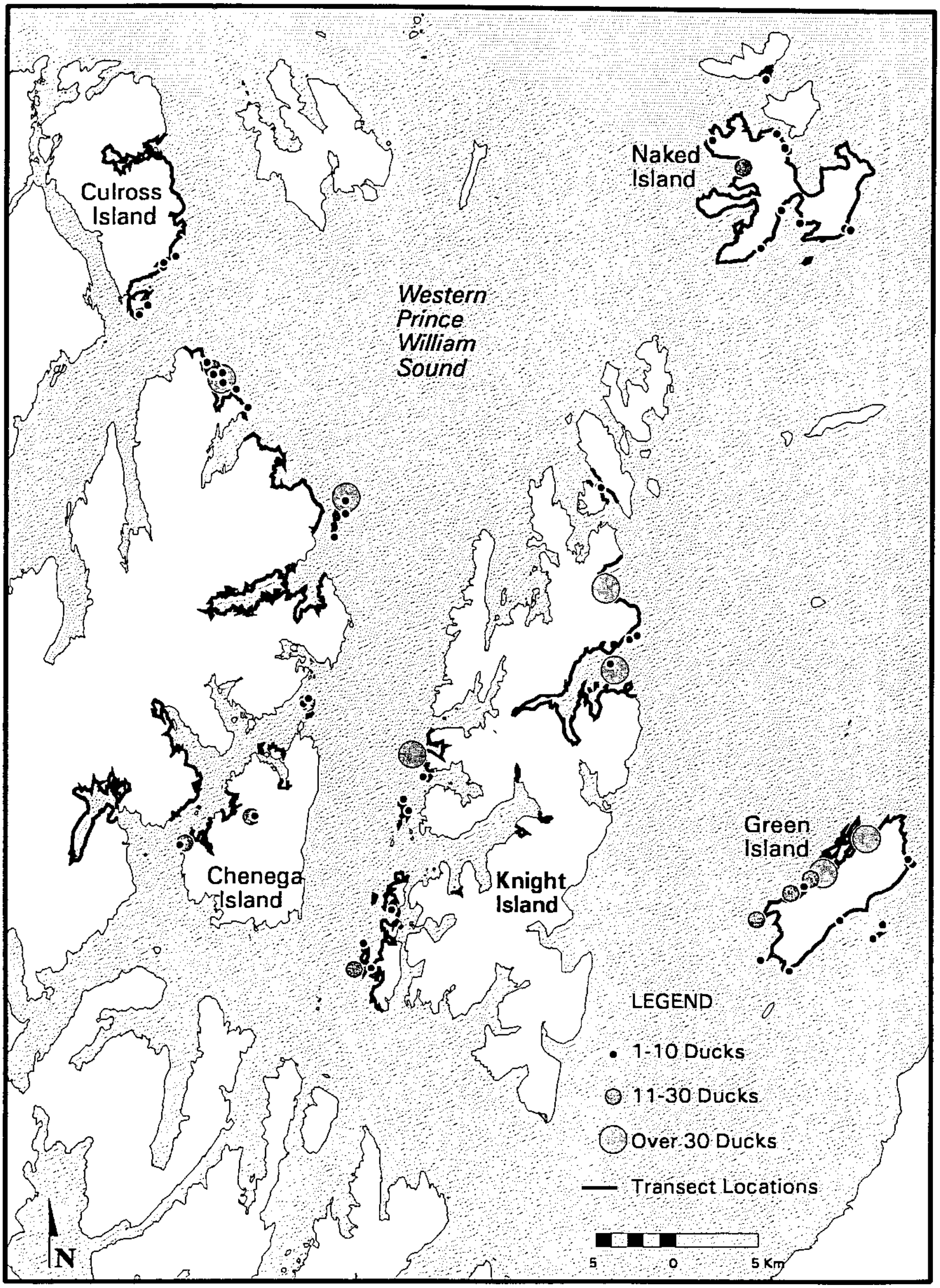
Appendix A11. Location of harlequin ducks observed in eastern Prince William Sound during the second fall survey (11 Aug.-17 Aug.) in 1995.



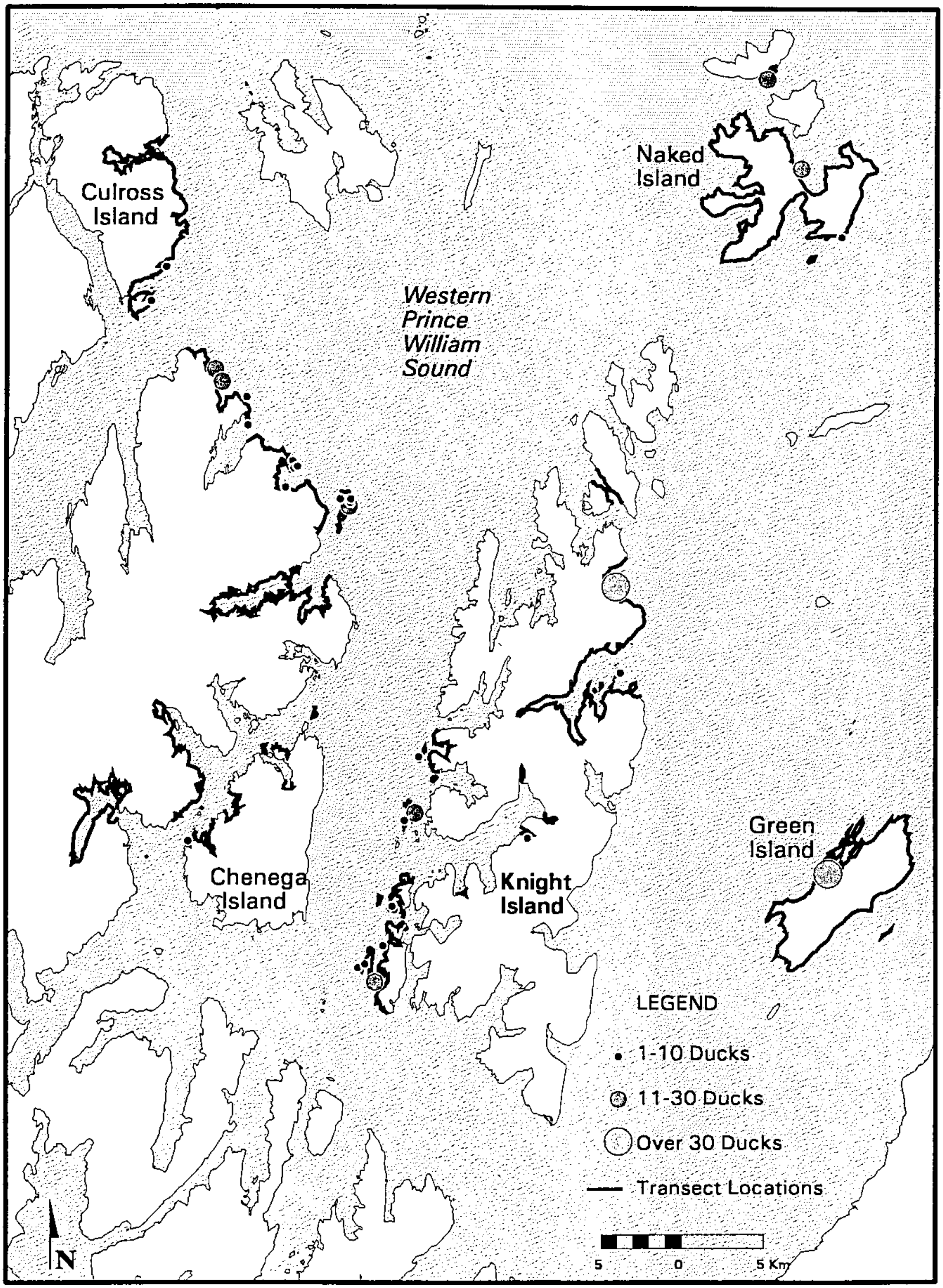
Appendix A12. Location of harlequin ducks observed in eastern Prince William Sound during the third fall survey (6 Sept.-12 Sept.) in 1995.



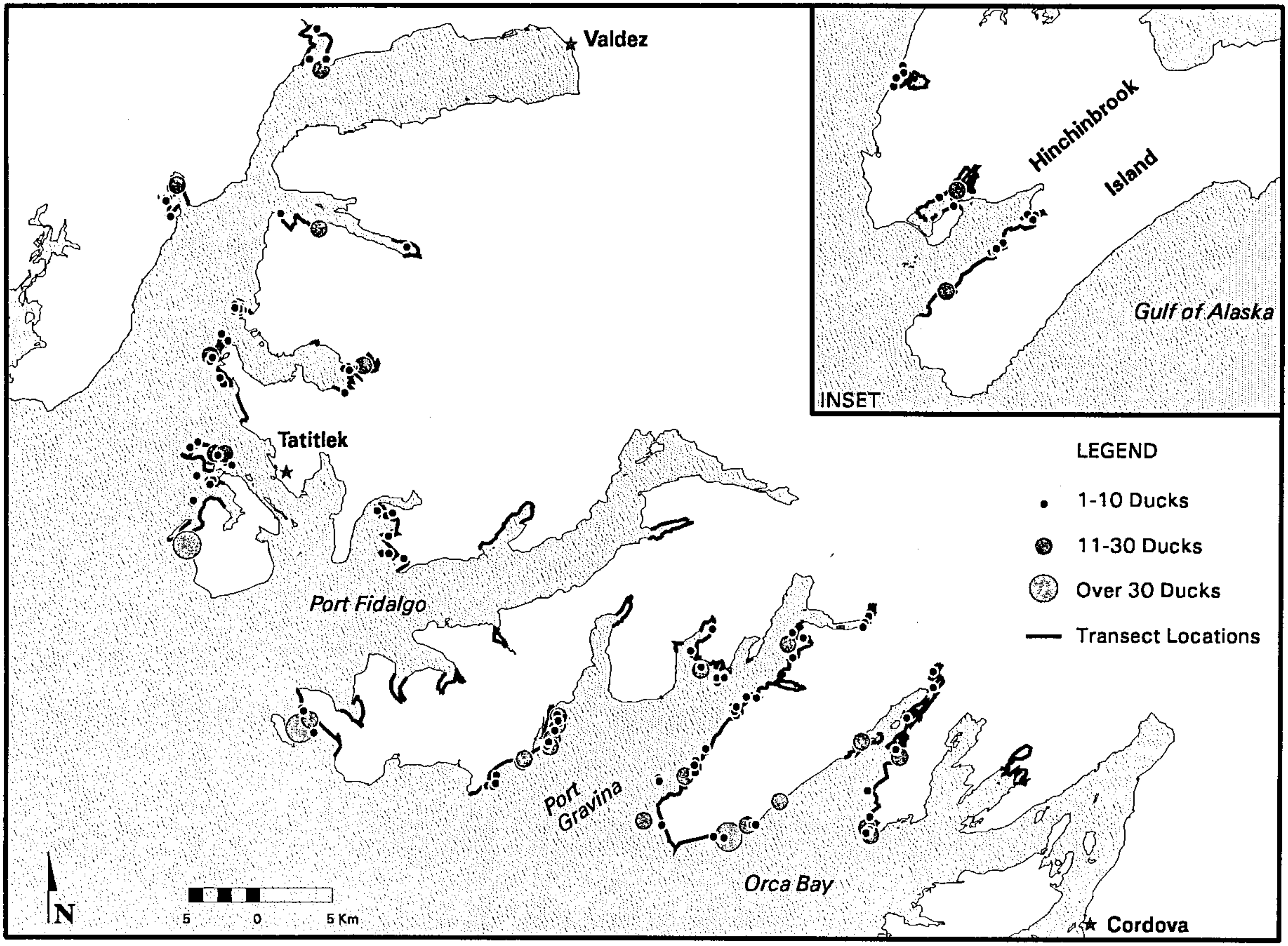
Appendix A13. Location of harlequin ducks observed in western Prince William Sound during the first spring survey (8 May-14 May) in 1996.



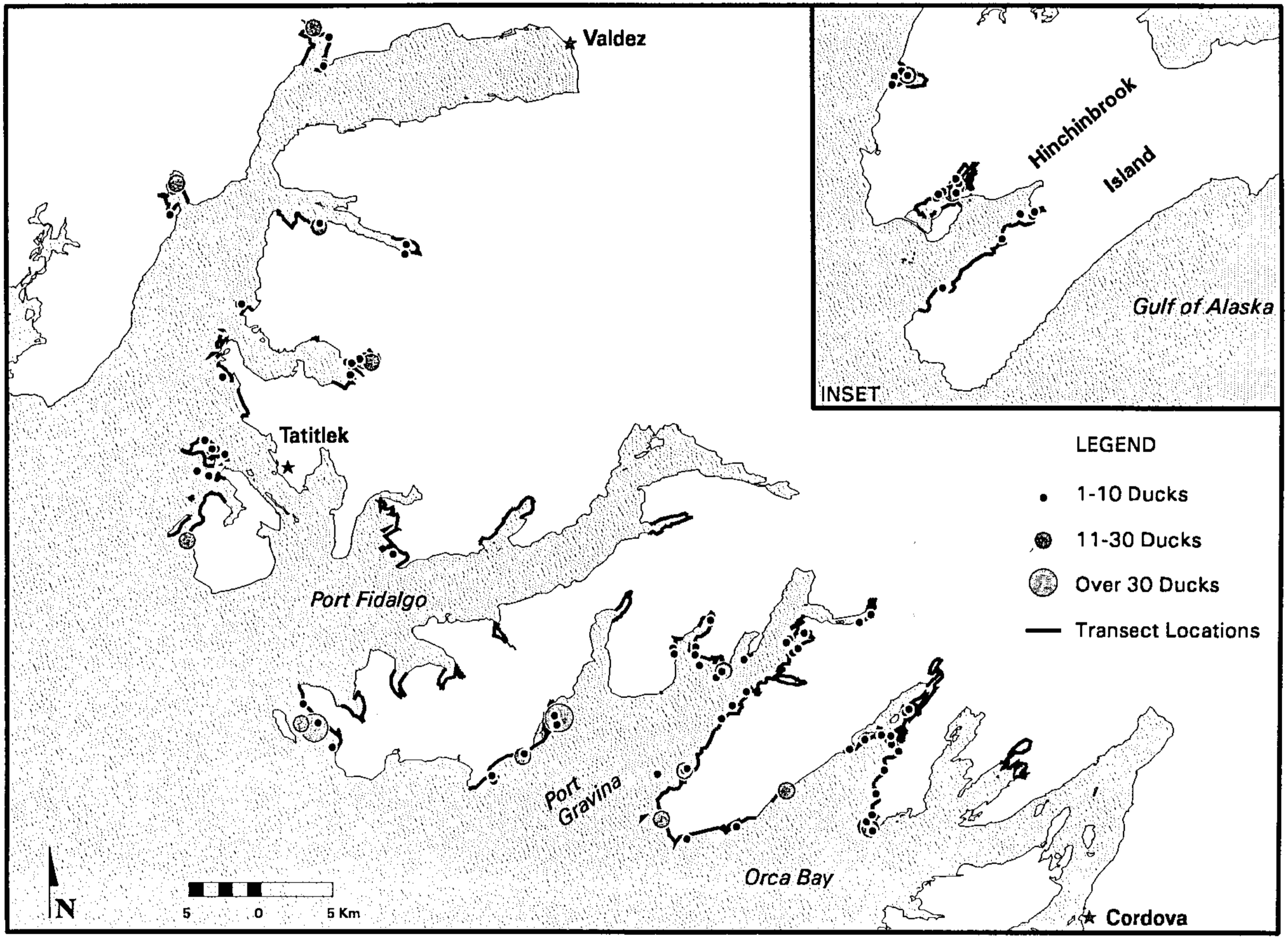
Appendix A14. Location of harlequin ducks observed in western Prince William Sound during the second spring survey (24 May-30 May) in 1996.



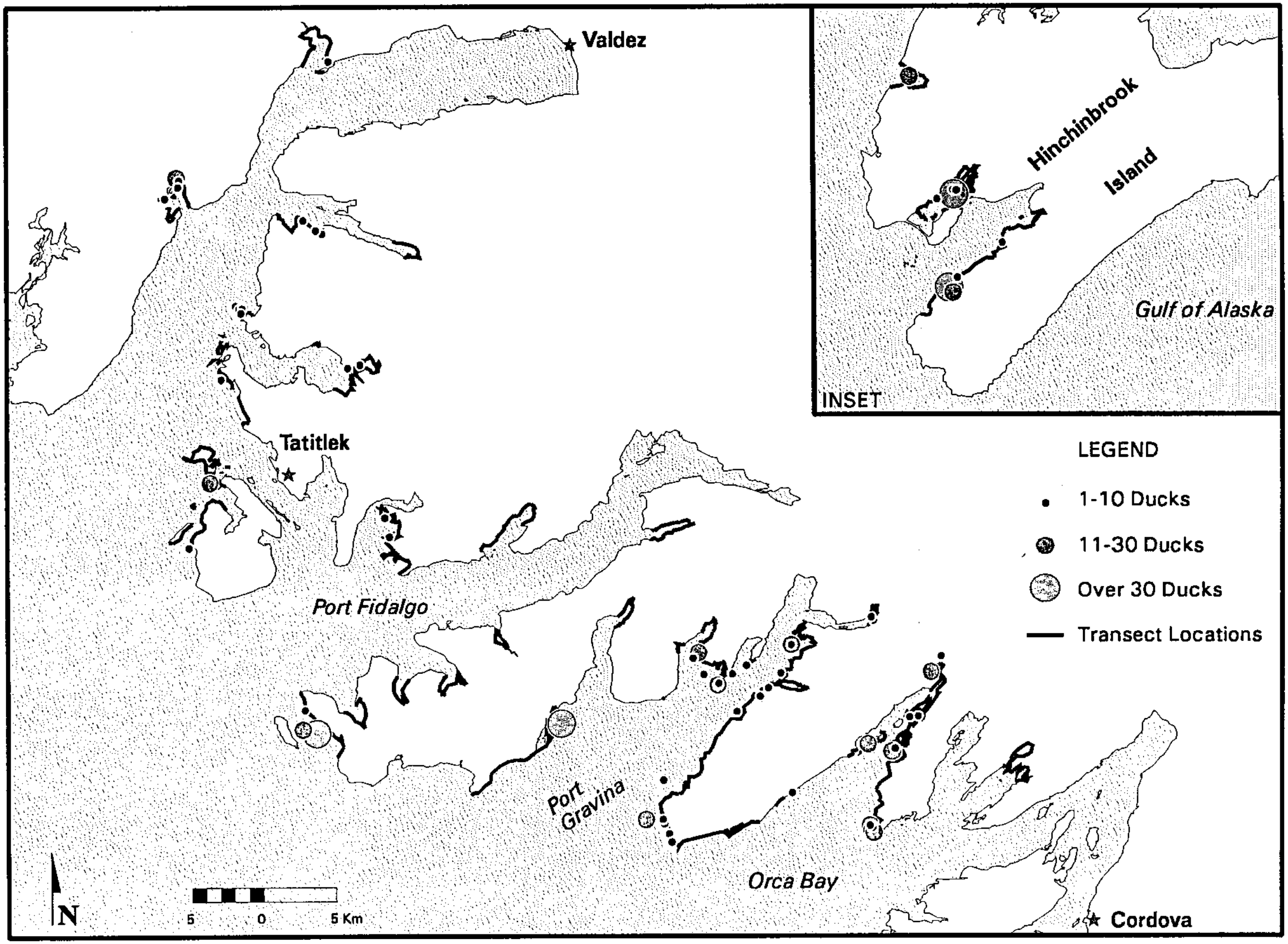
Appendix A15. Location of harlequin ducks observed in western Prince William Sound during the third spring survey (11 June-18 June) in 1996.



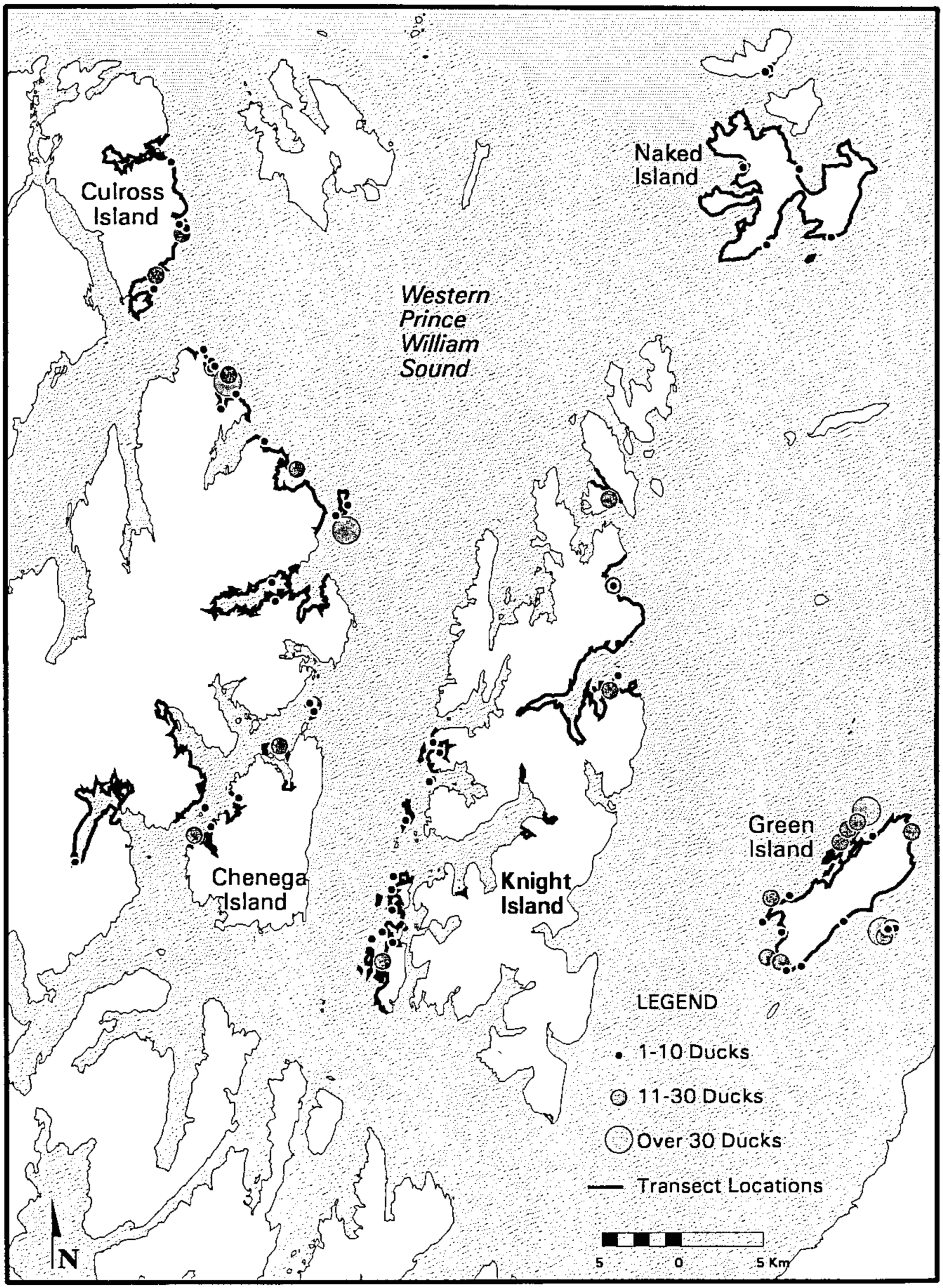
Appendix A16. Location of harlequin ducks observed in eastern Prince William Sound during the first spring survey (9 May-14 May) in 1996.



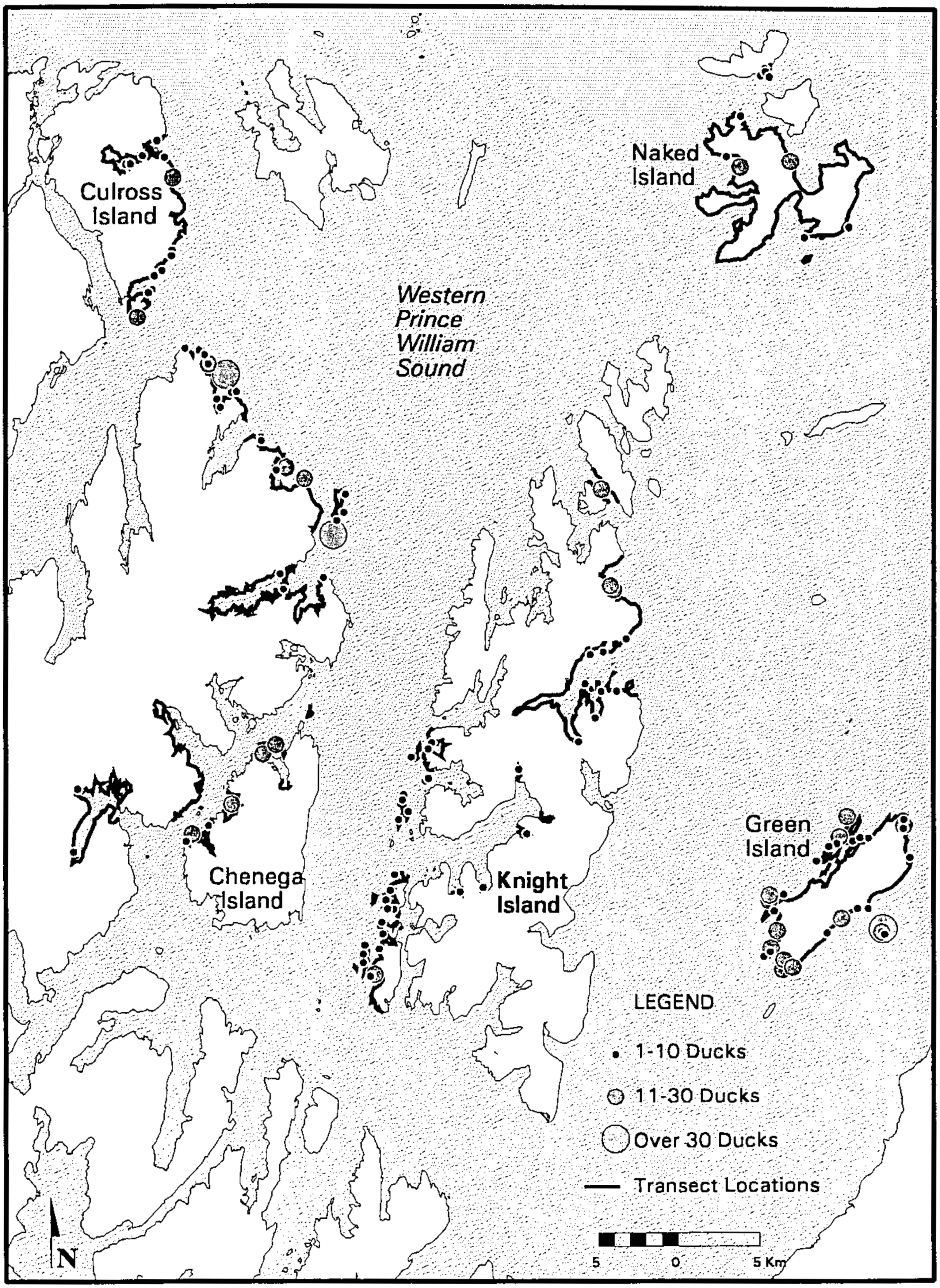
Appendix A17. Location of harlequin ducks observed in eastern Prince William Sound during the second spring survey (23 May-27 May) in 1996.



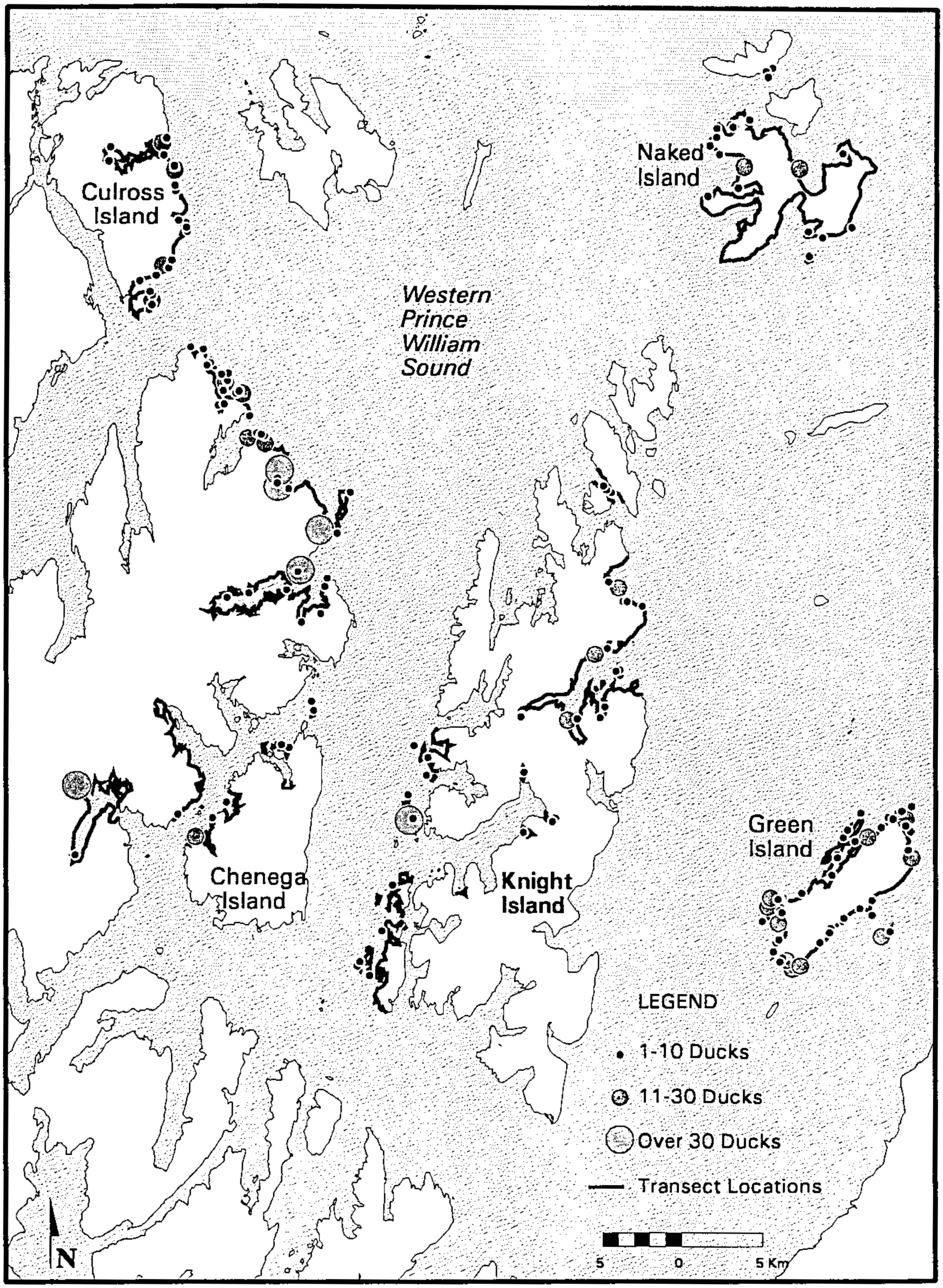
Appendix A18. Location of harlequin ducks observed in eastern Prince William Sound during the third spring survey (11 June-16 June) in 1996.



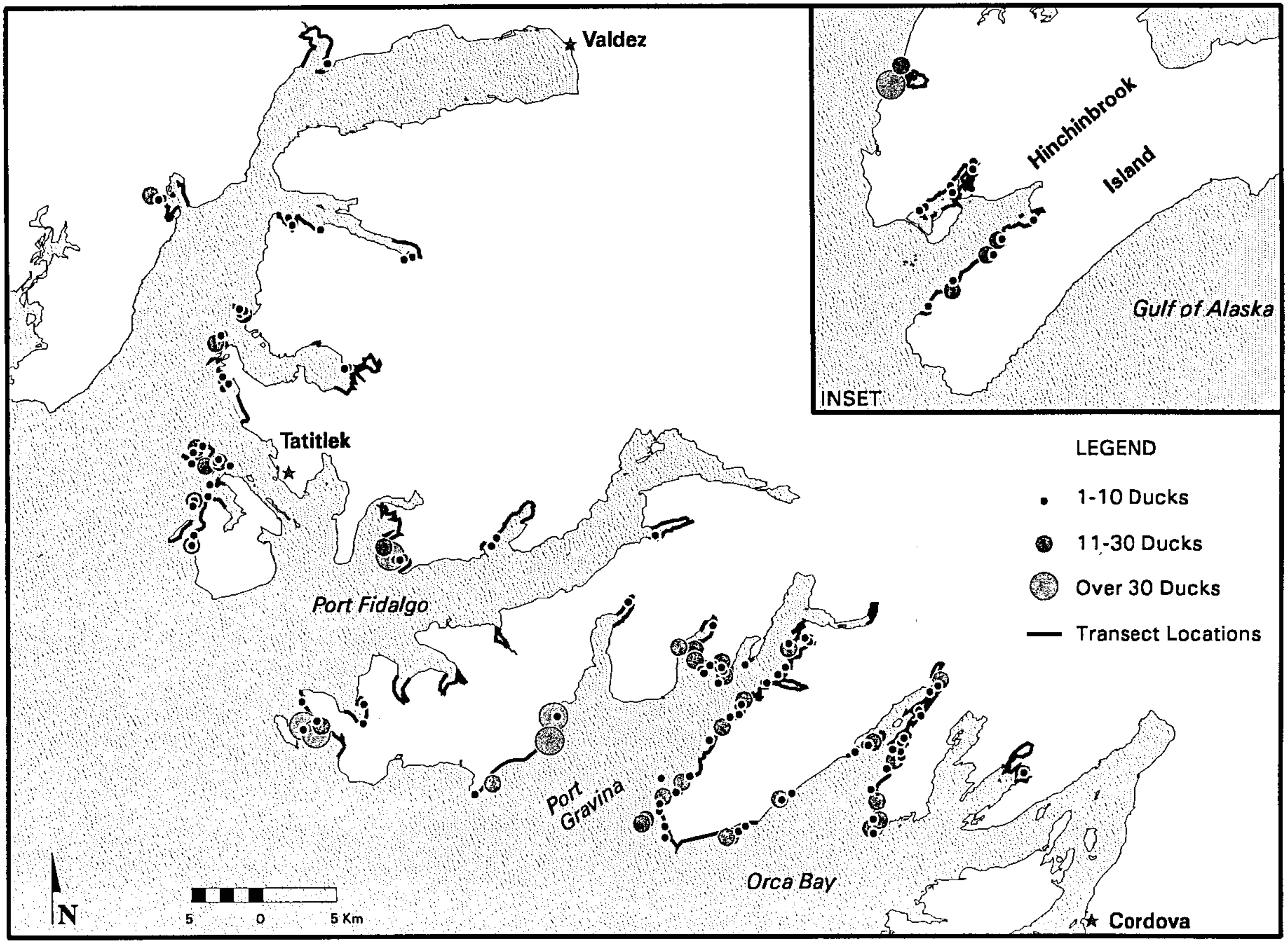
Appendix A19. Location of harlequin ducks observed in western Prince William Sound during the first fall survey (23 July-30 July) in 1996.



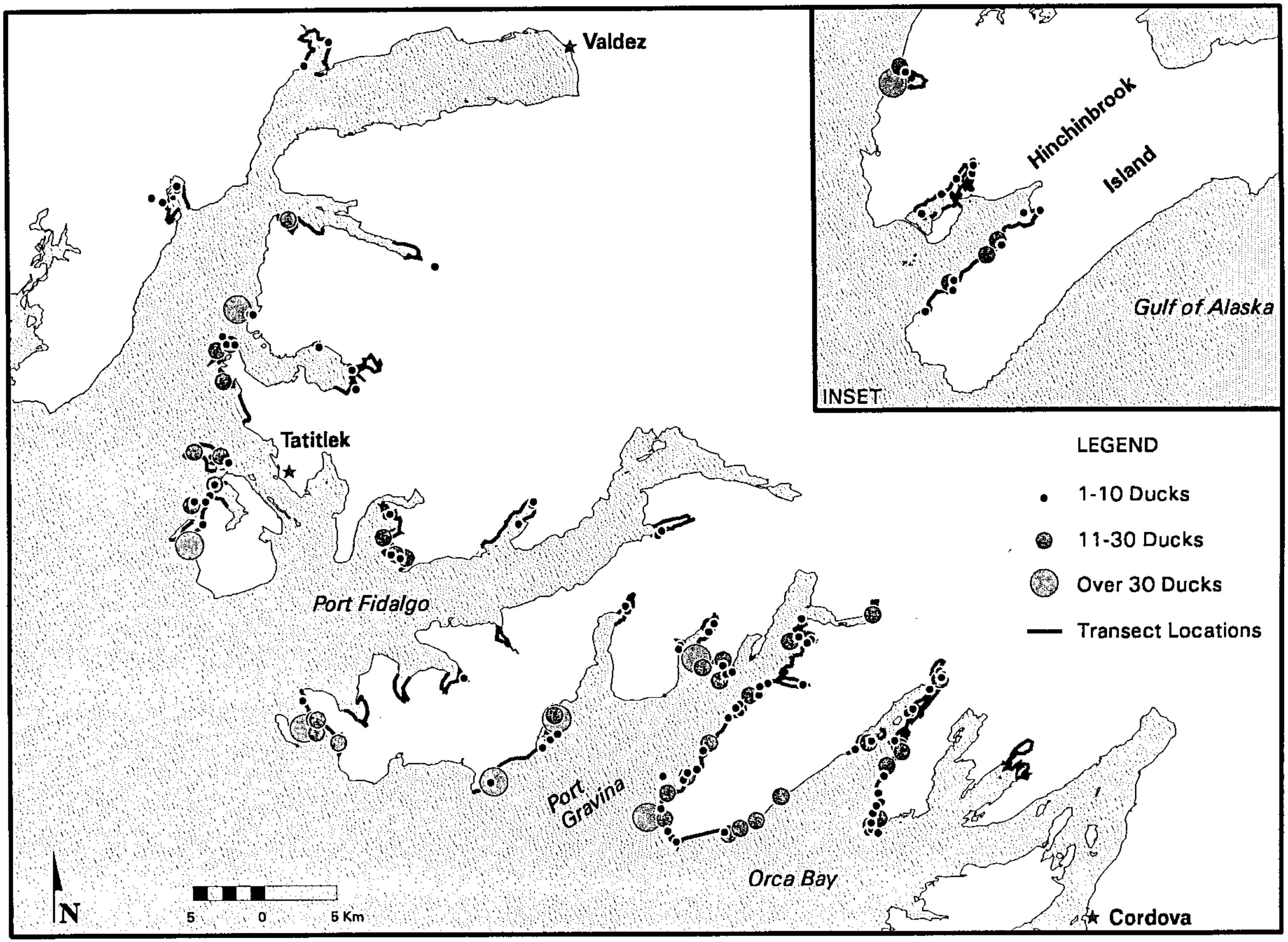
Appendix A20. Location of harlequin ducks observed in western Prince William Sound during the second fall survey (8 Aug.-15 Aug.) in 1996.



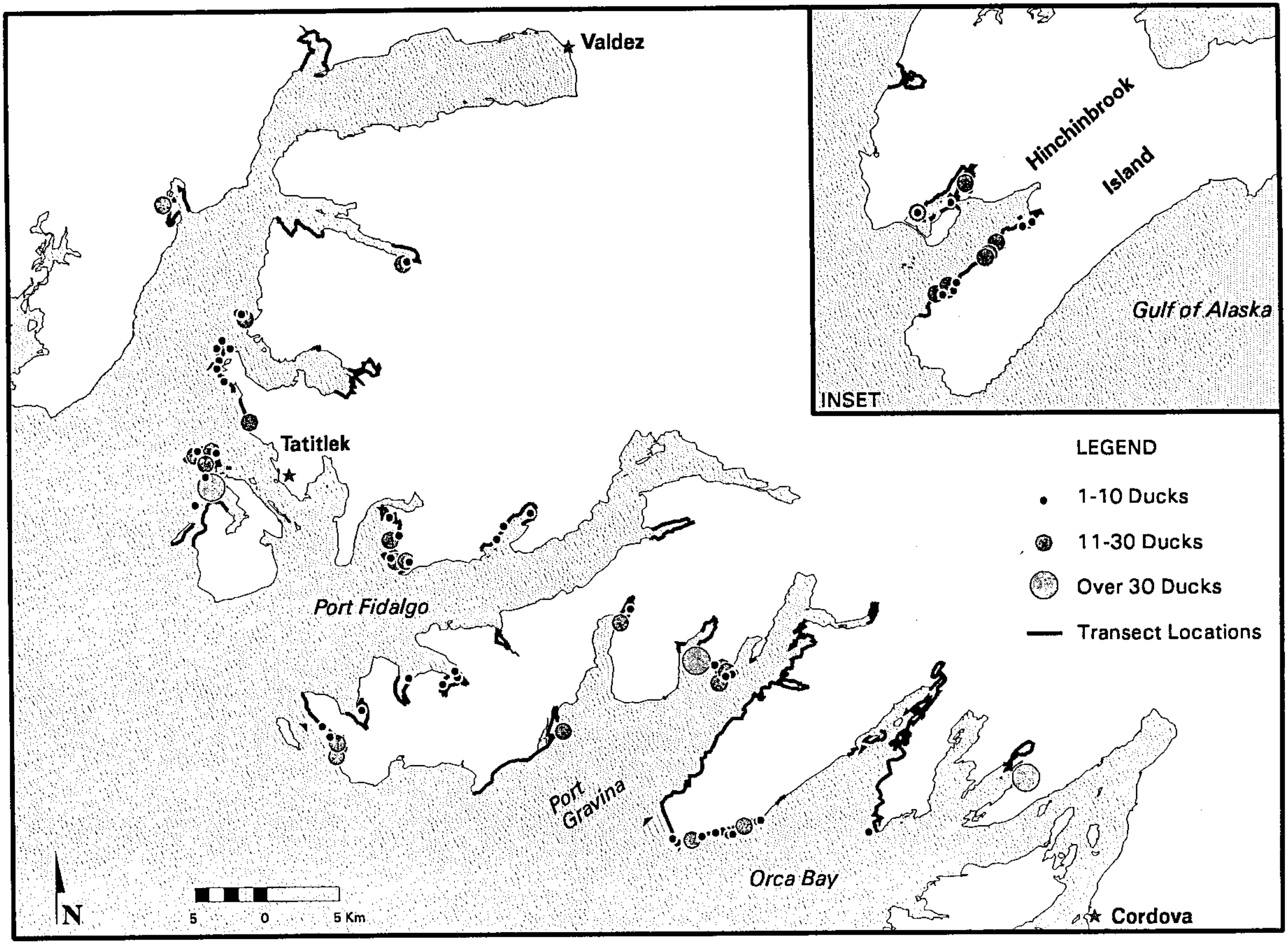
Appendix A21. Location of harlequin ducks observed in western Prince William Sound during the third fall survey (5 Sept.-13 Sept.) in 1996.



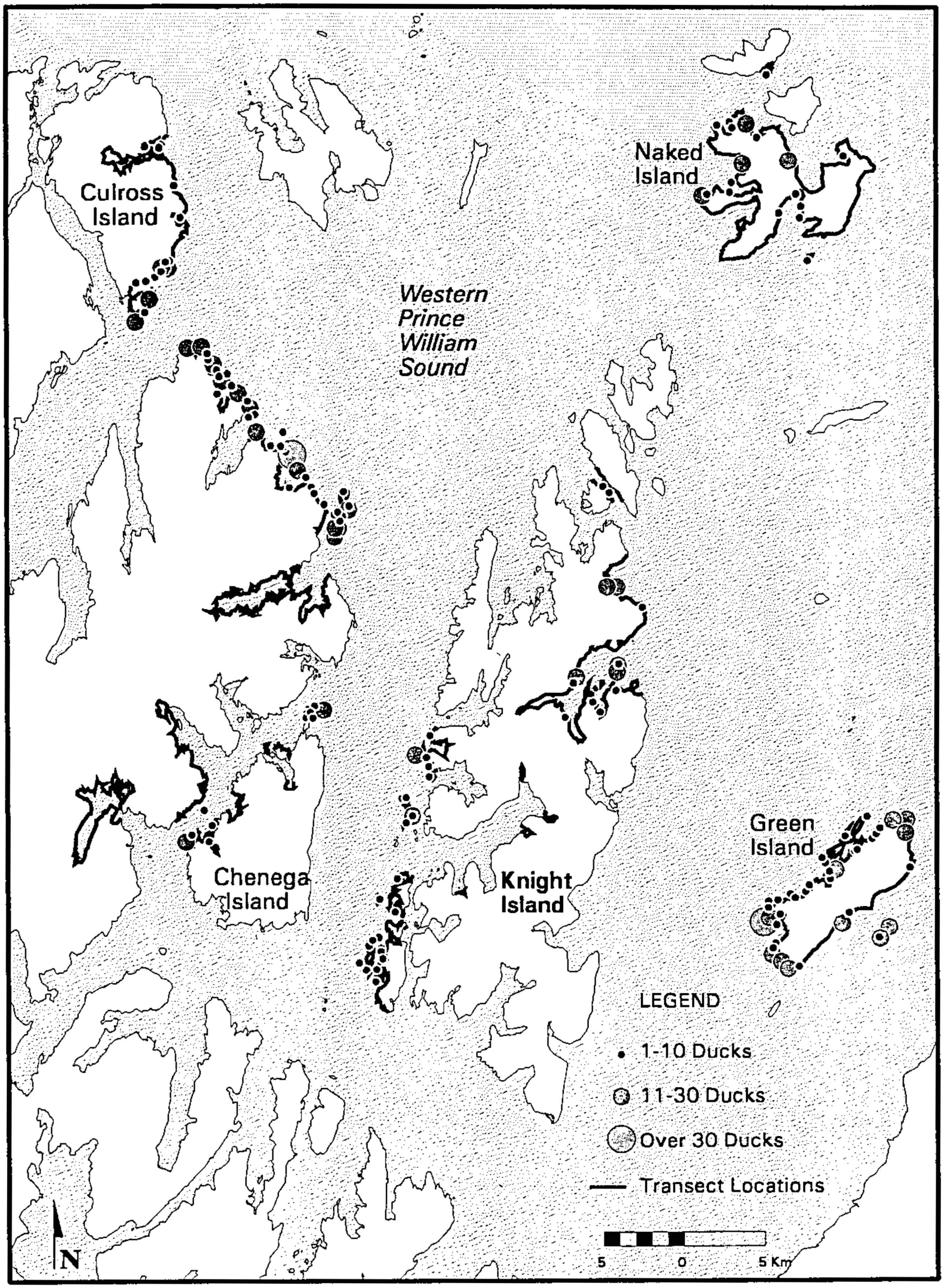
Appendix A22. Location of harlequin ducks observed in eastern Prince William Sound during the first fall survey (24 July-30 July) in 1996.



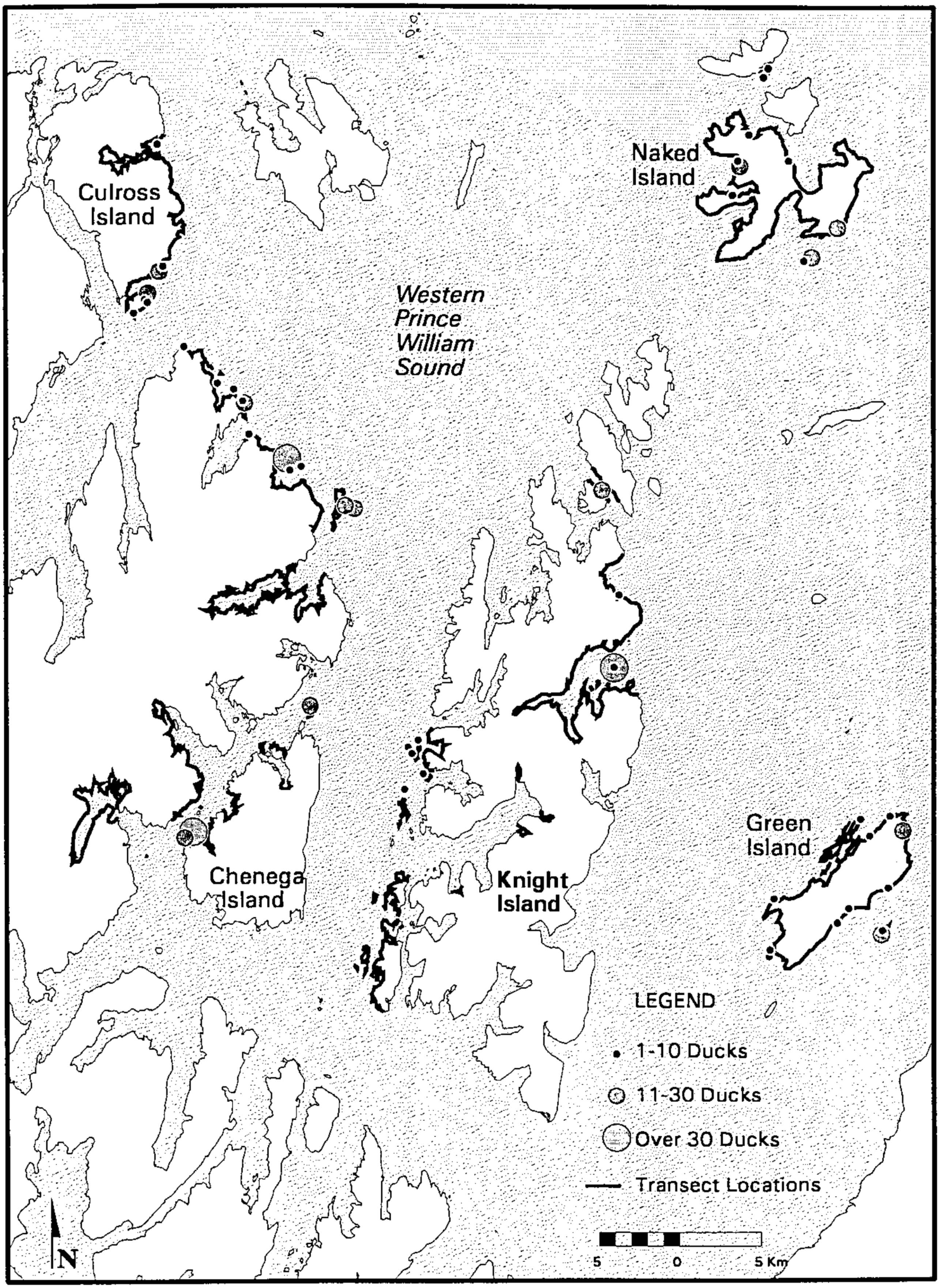
Appendix A23. Location of harlequin ducks observed in eastern Prince William Sound during the second fall survey (9 Aug.-17 Aug.) in 1996.



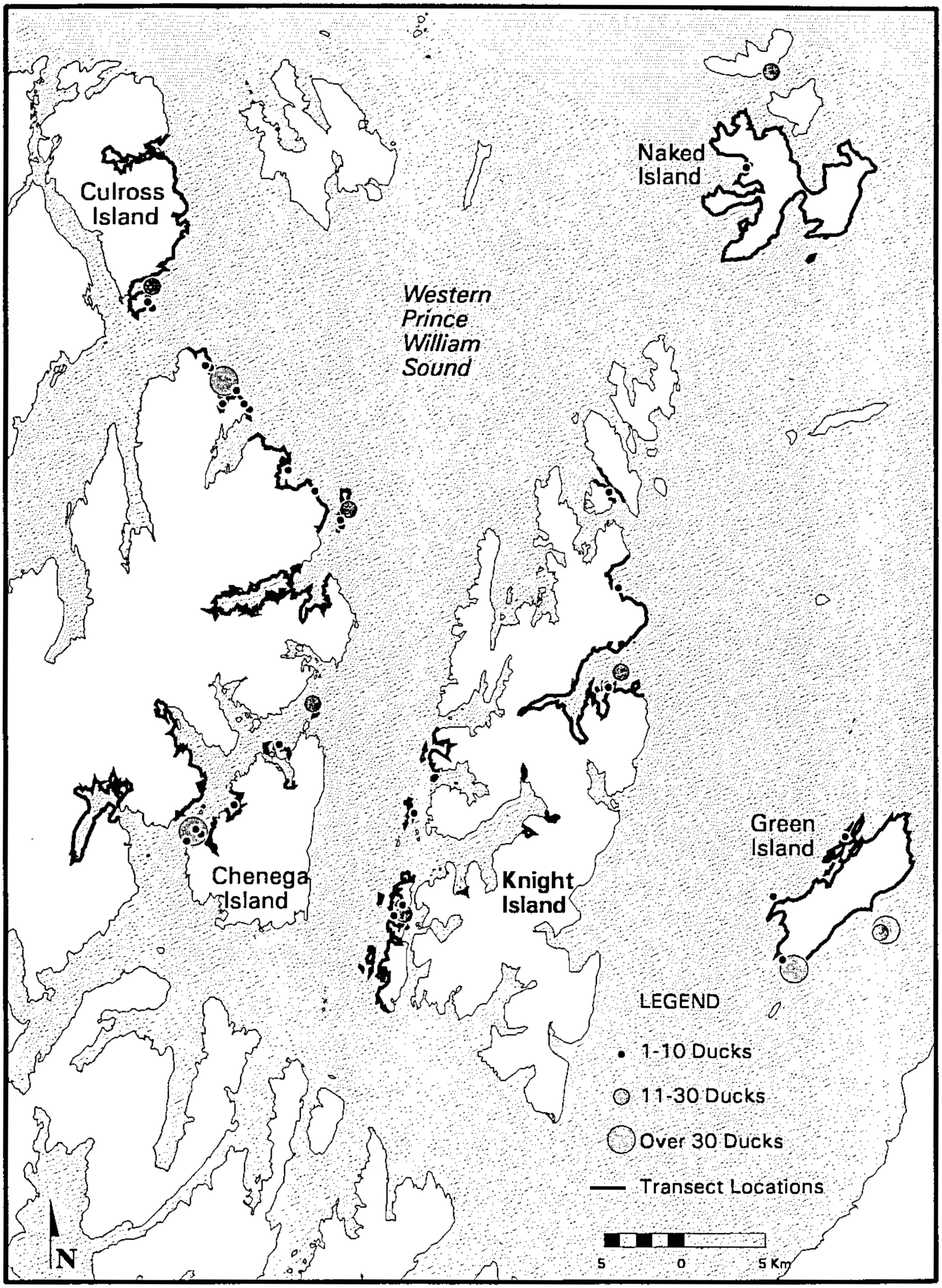
Appendix A24. Location of harlequin ducks observed in eastern Prince William Sound during the third fall survey (6 Sept.-10 Sept.) in 1996.



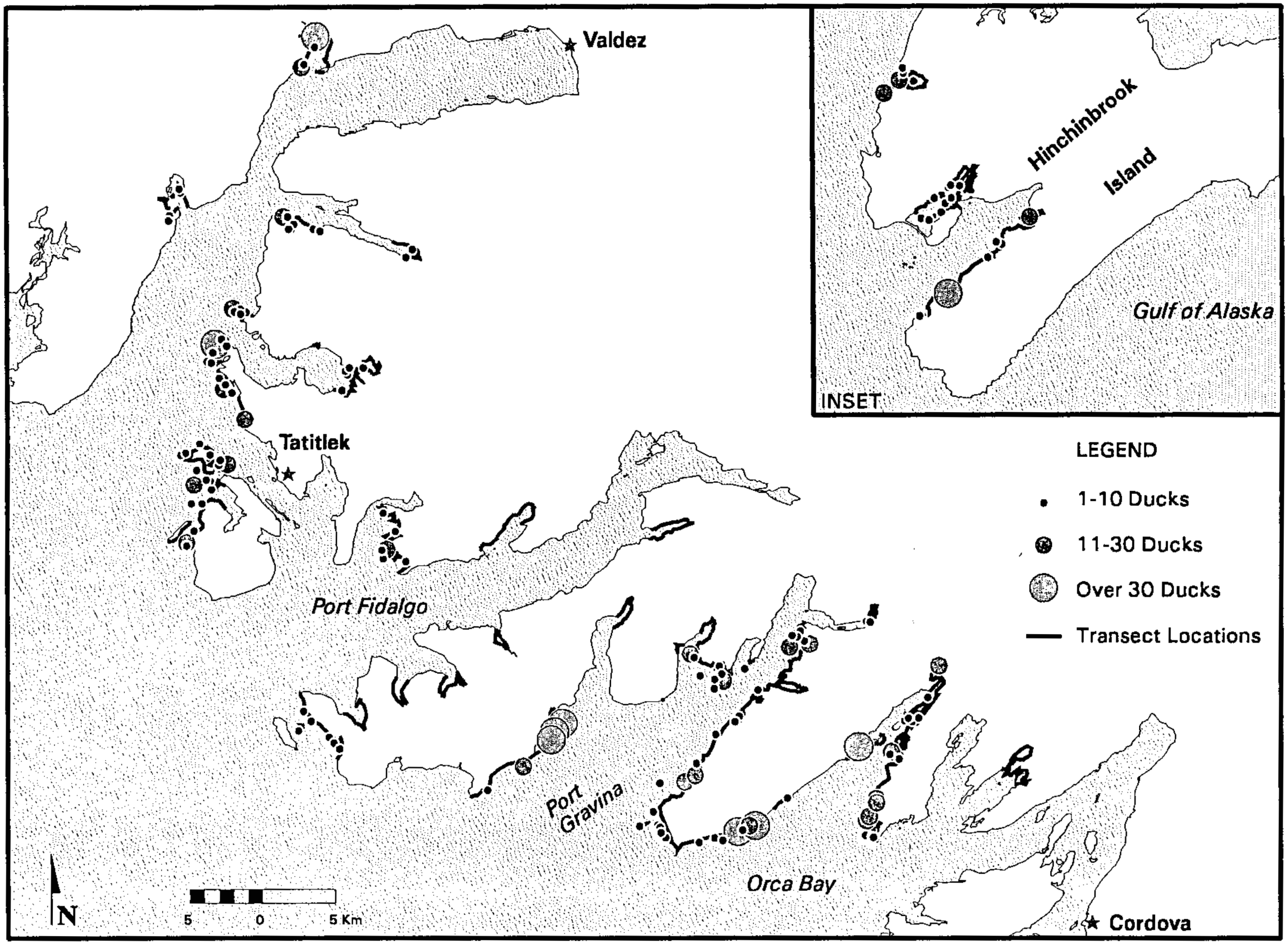
Appendix A25. Location of harlequin ducks observed in western Prince William Sound during the first spring survey (6 May-13 May) in 1997.



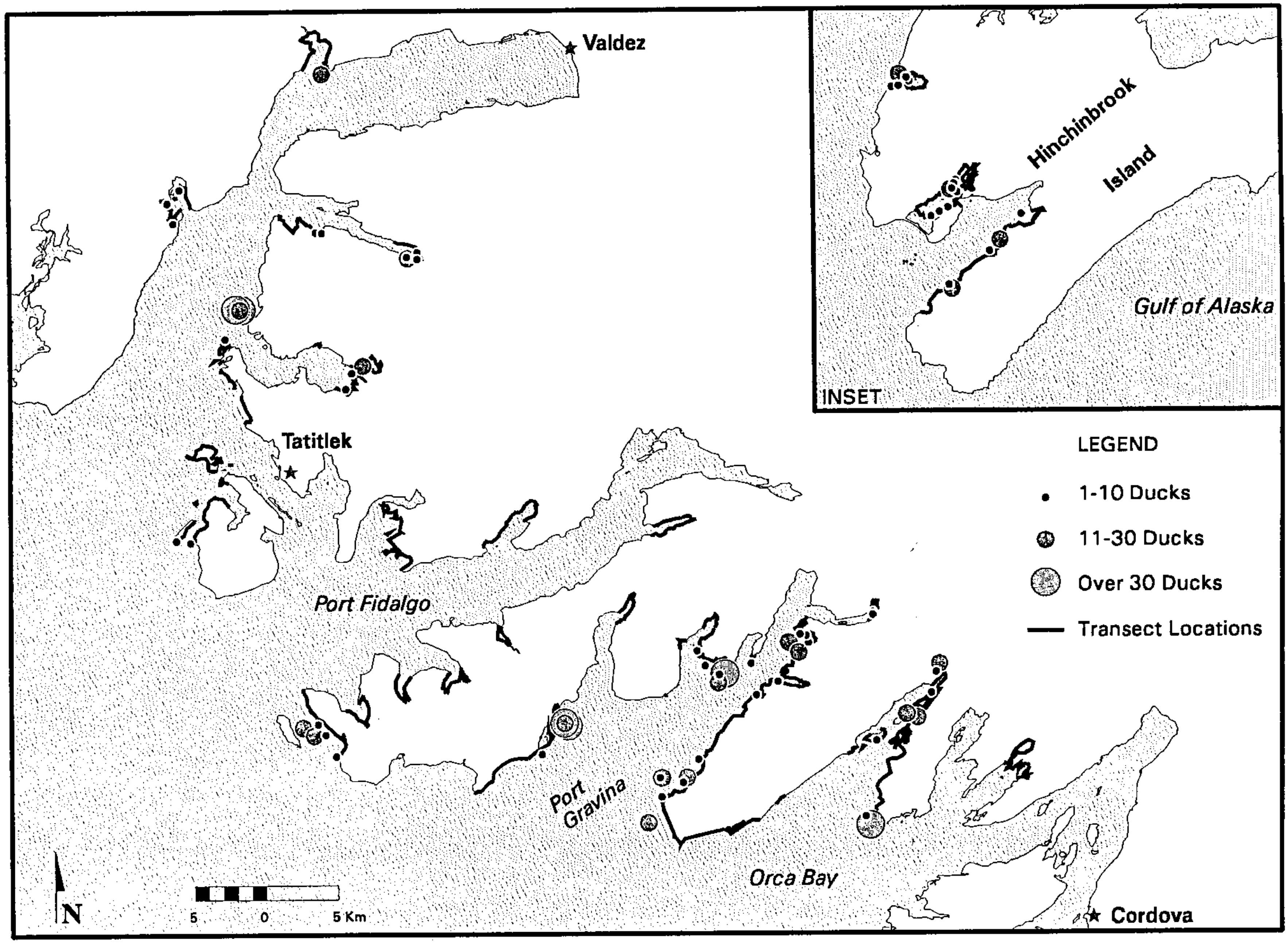
Appendix A26. Location of harlequin ducks observed in western Prince William Sound during the second spring survey (22 May-28 May) in 1997.



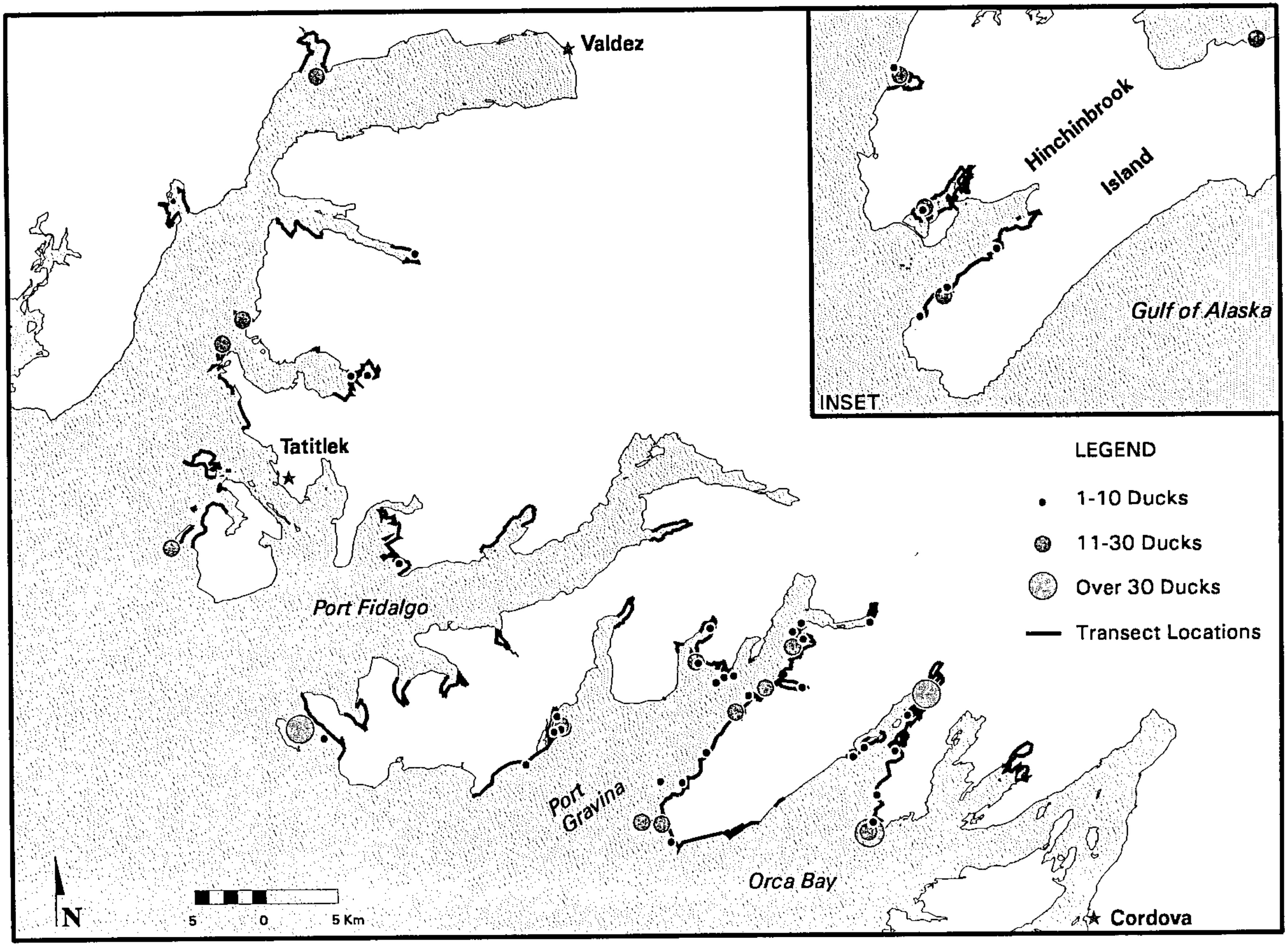
Appendix A27. Location of harlequin ducks observed in western Prince William Sound during the third spring survey (12 June-18 June) in 1997.



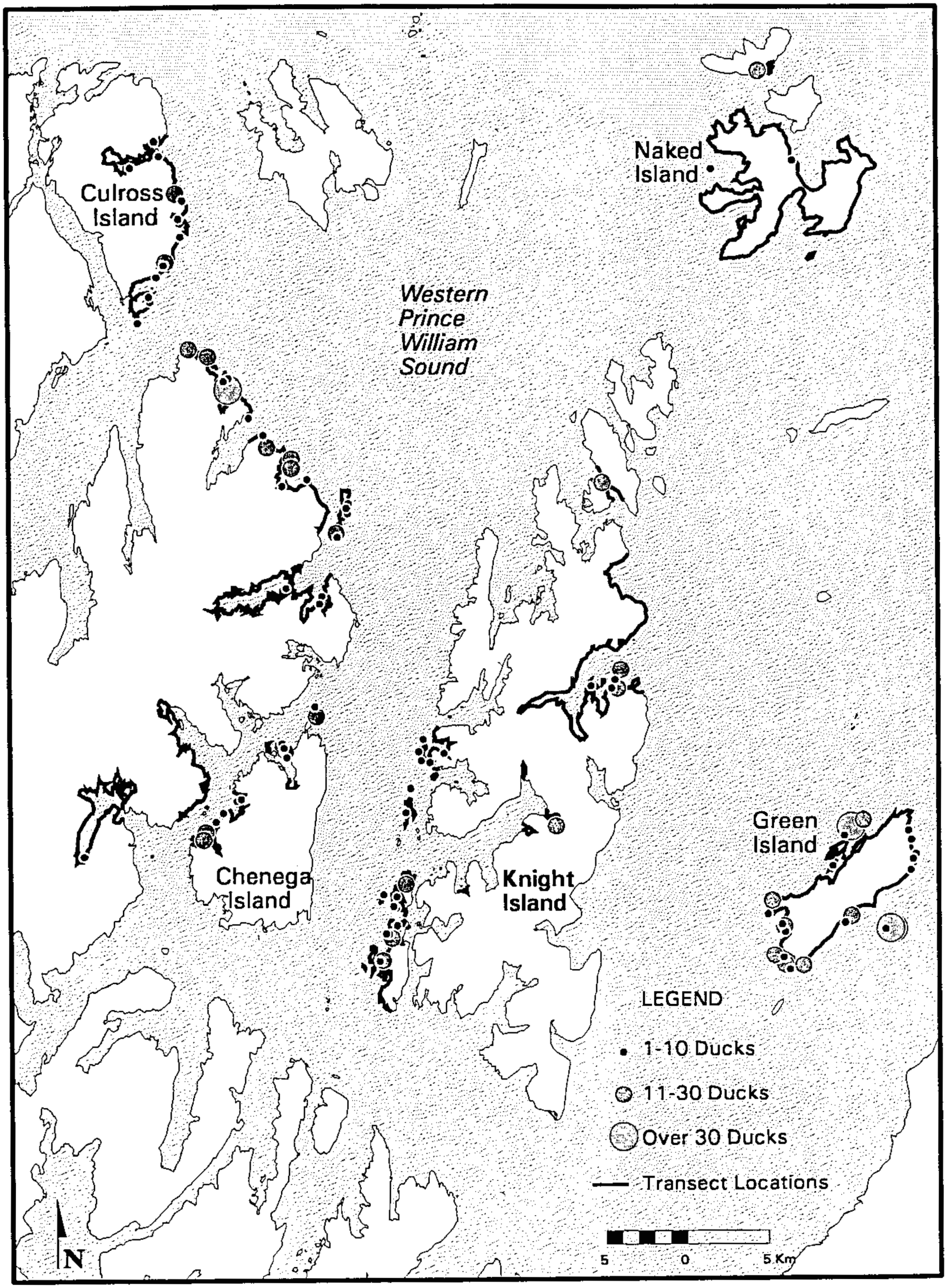
Appendix A28. Location of harlequin ducks observed in eastern Prince William Sound during the first spring survey (8 May-14 May) in 1997.



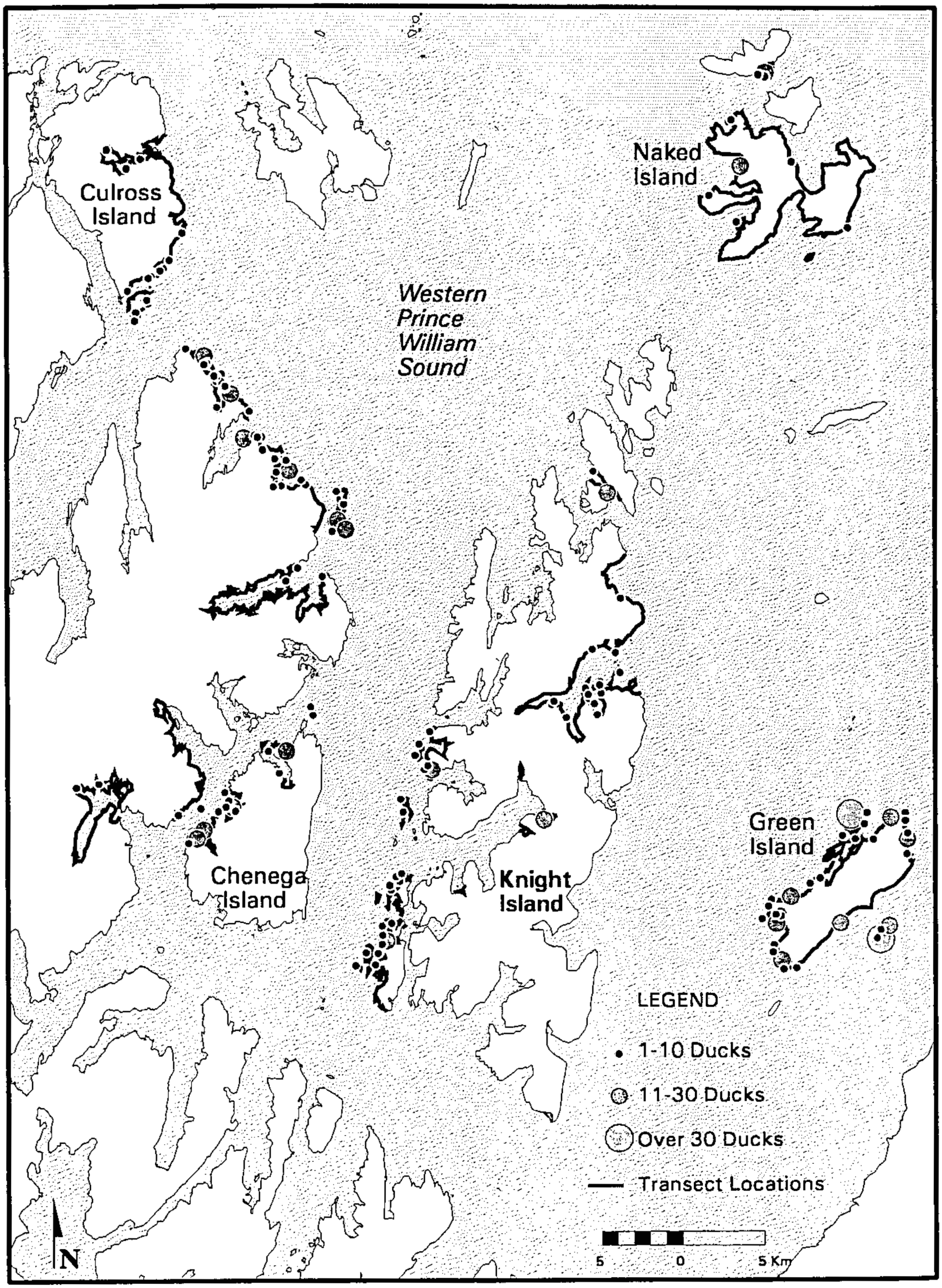
Appendix A29. Location of harlequin ducks observed in eastern Prince William Sound during the second spring survey (23 May-27 May) in 1997.



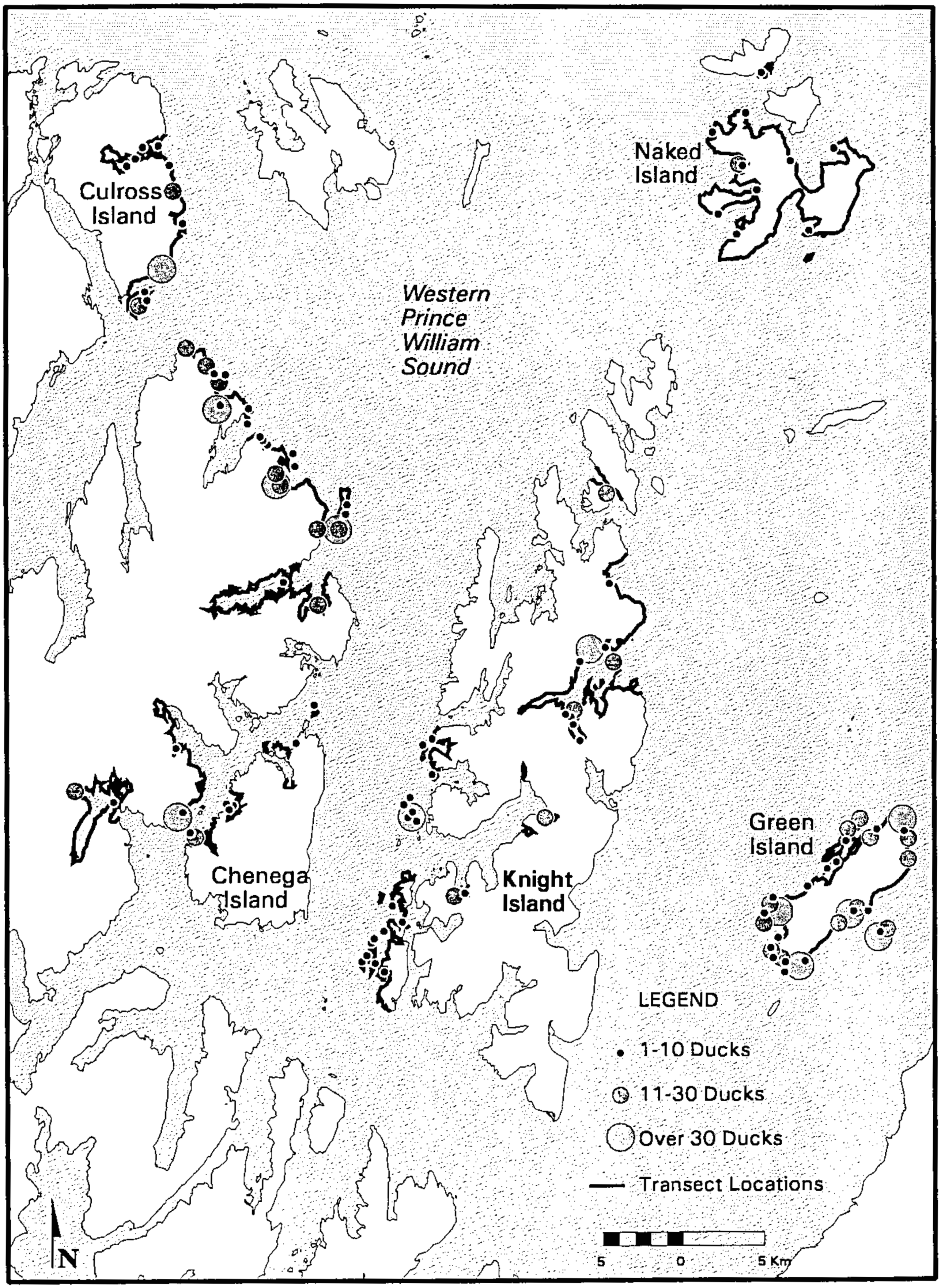
Appendix A30. Location of harlequin ducks observed in eastern Prince William Sound during the third spring survey (12 June-17 June) in 1997.



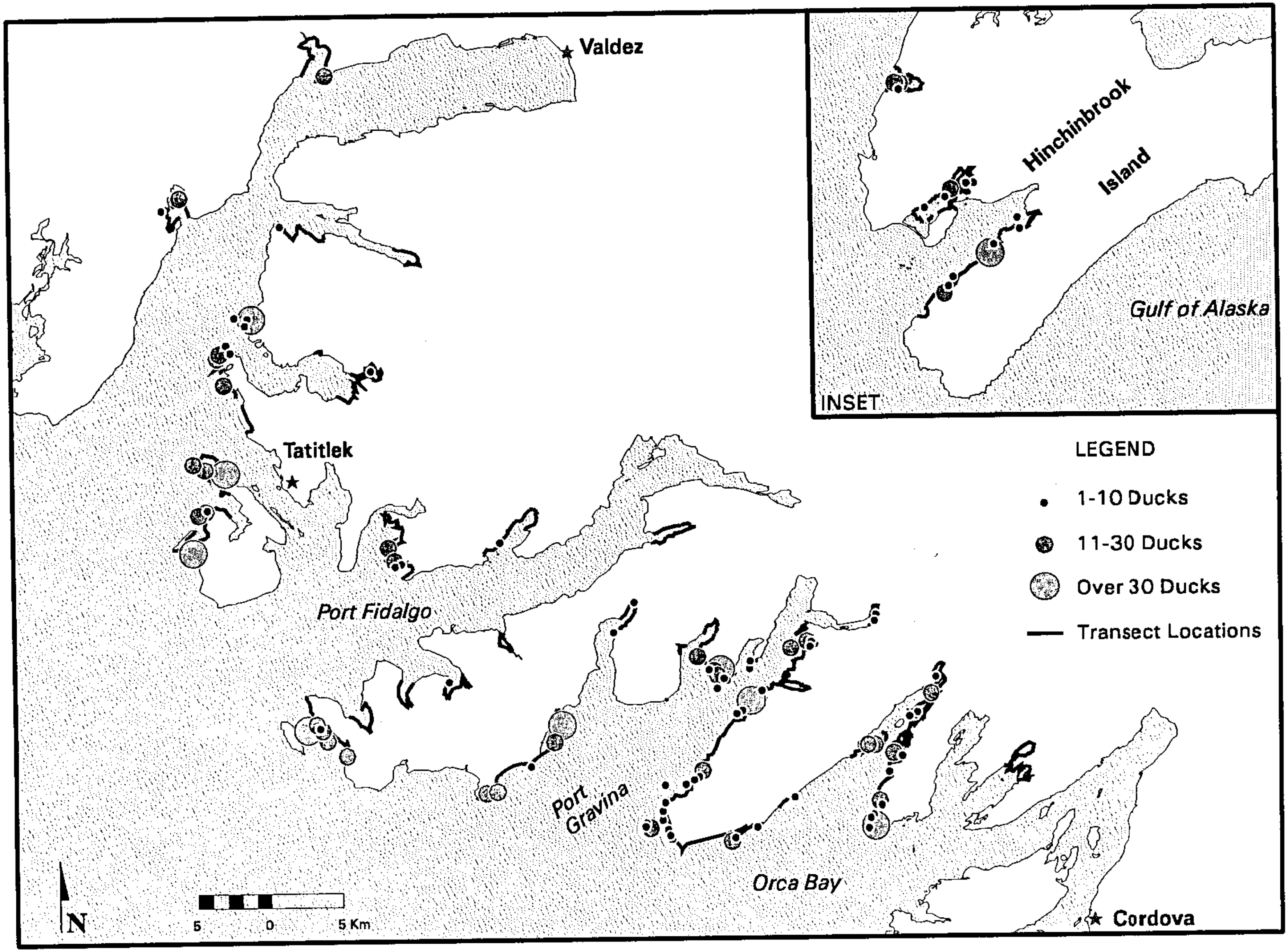
Appendix A31. Location of harlequin ducks observed in western Prince William Sound during the first fall survey (24 July-29 July) in 1997.



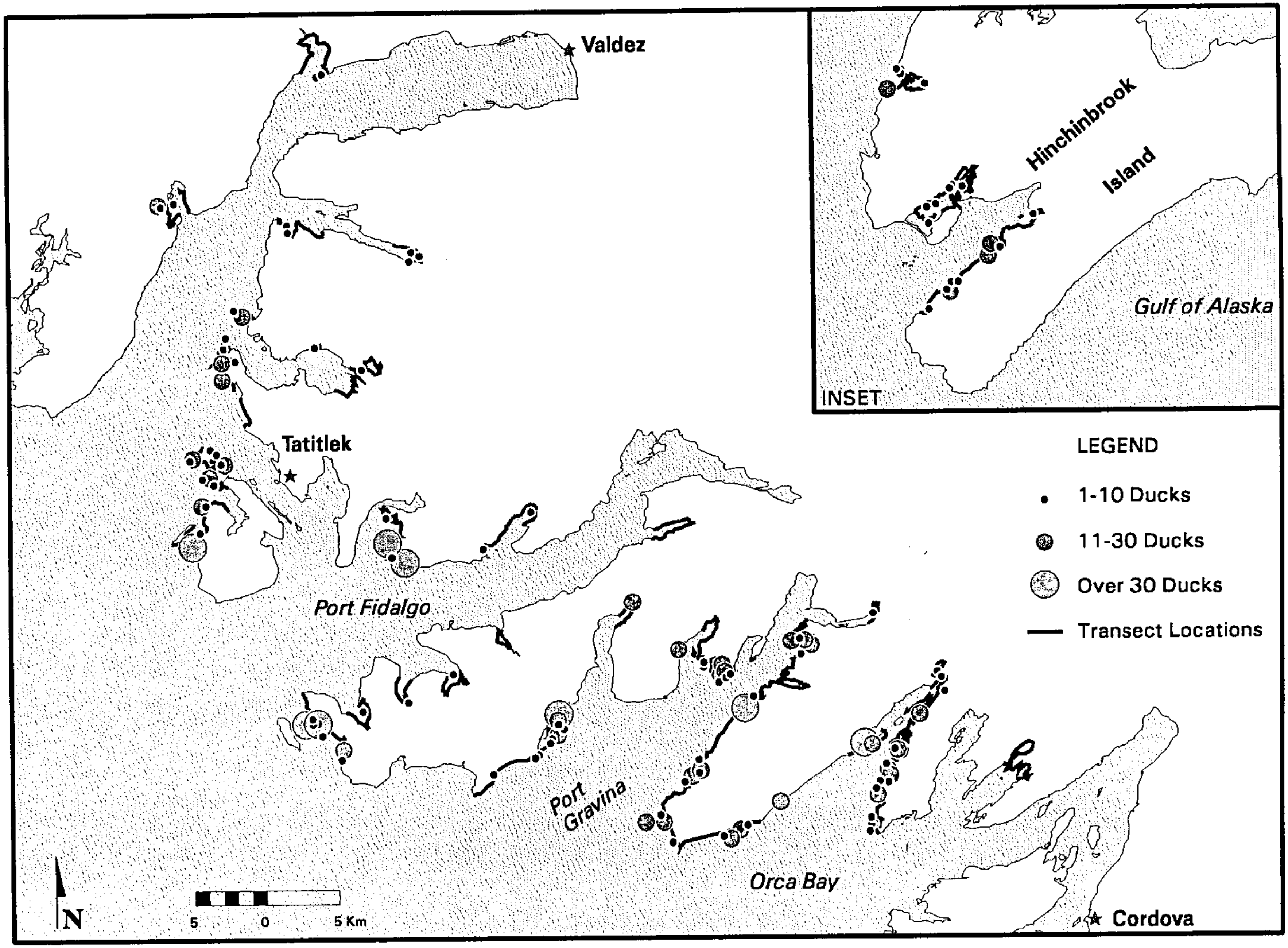
Appendix A32. Location of harlequin ducks observed in western Prince William Sound during the second fall survey (11 Aug.-17 Aug.) in 1997.



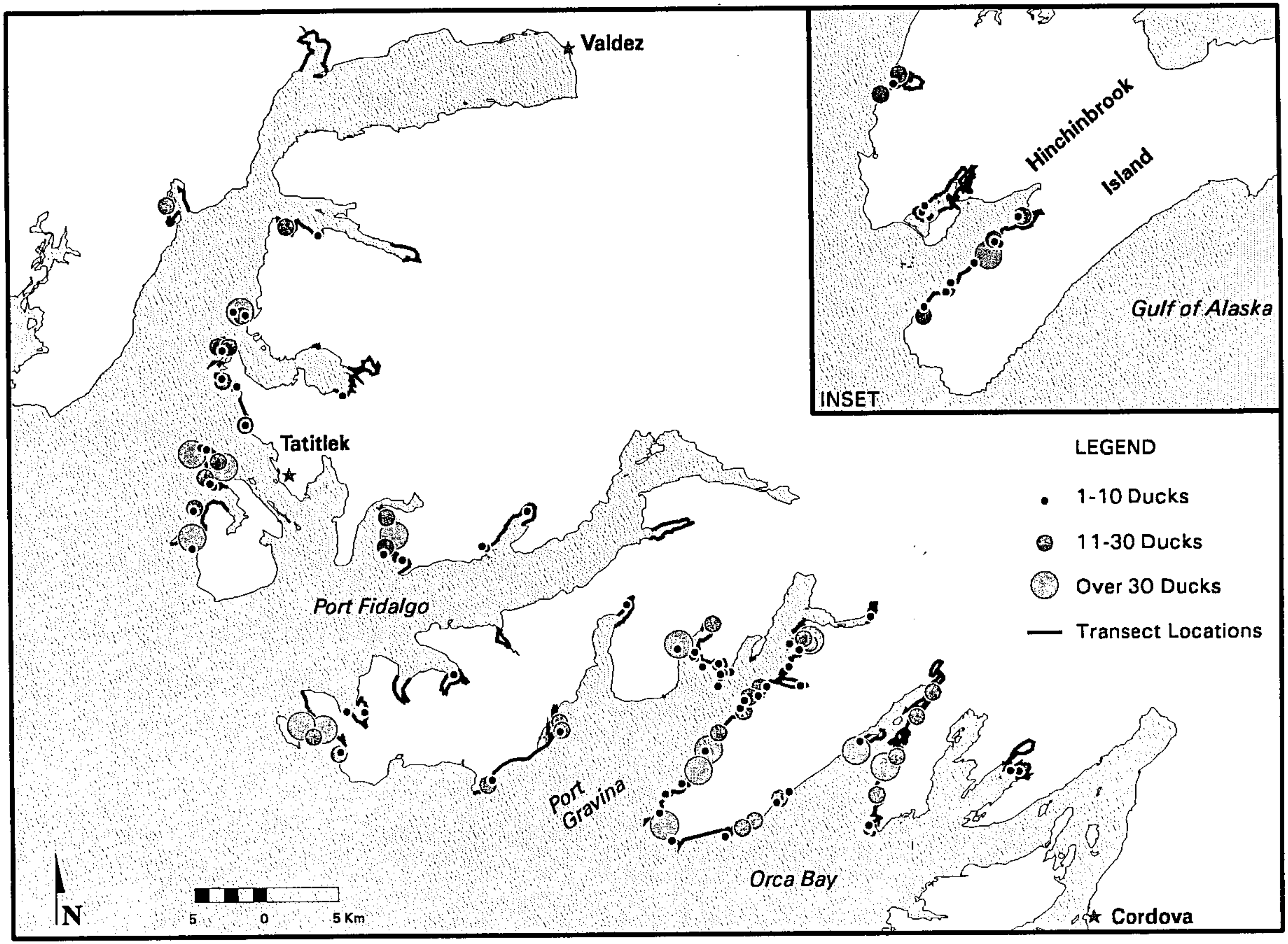
Appendix A33. Location of harlequin ducks observed in western Prince William Sound during the third fall survey (4 Sept.-11 Sept.) in 1997.



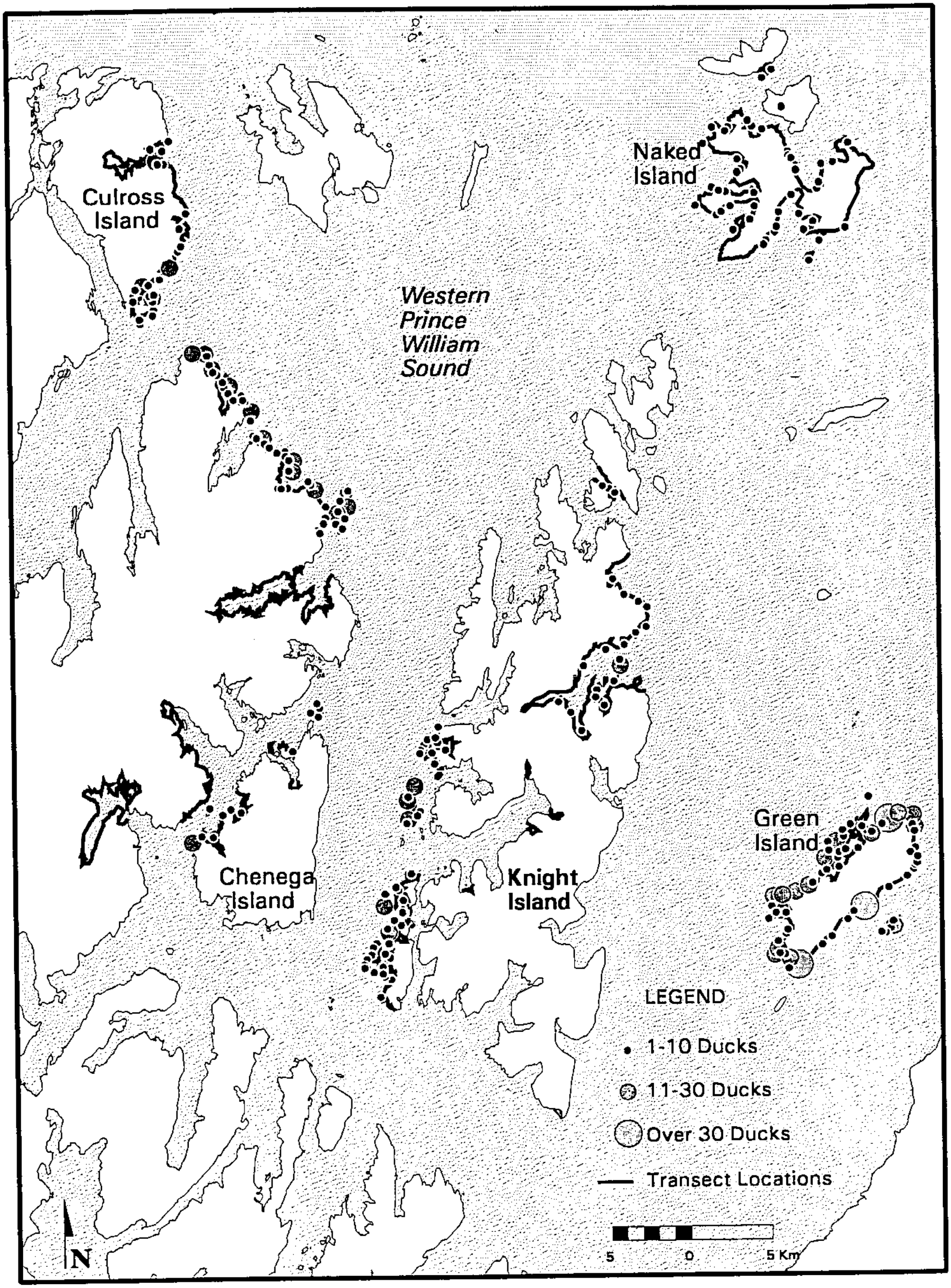
Appendix A34. Location of harlequin ducks observed in eastern Prince William Sound during the first fall survey (24 July-29 July) in 1997.



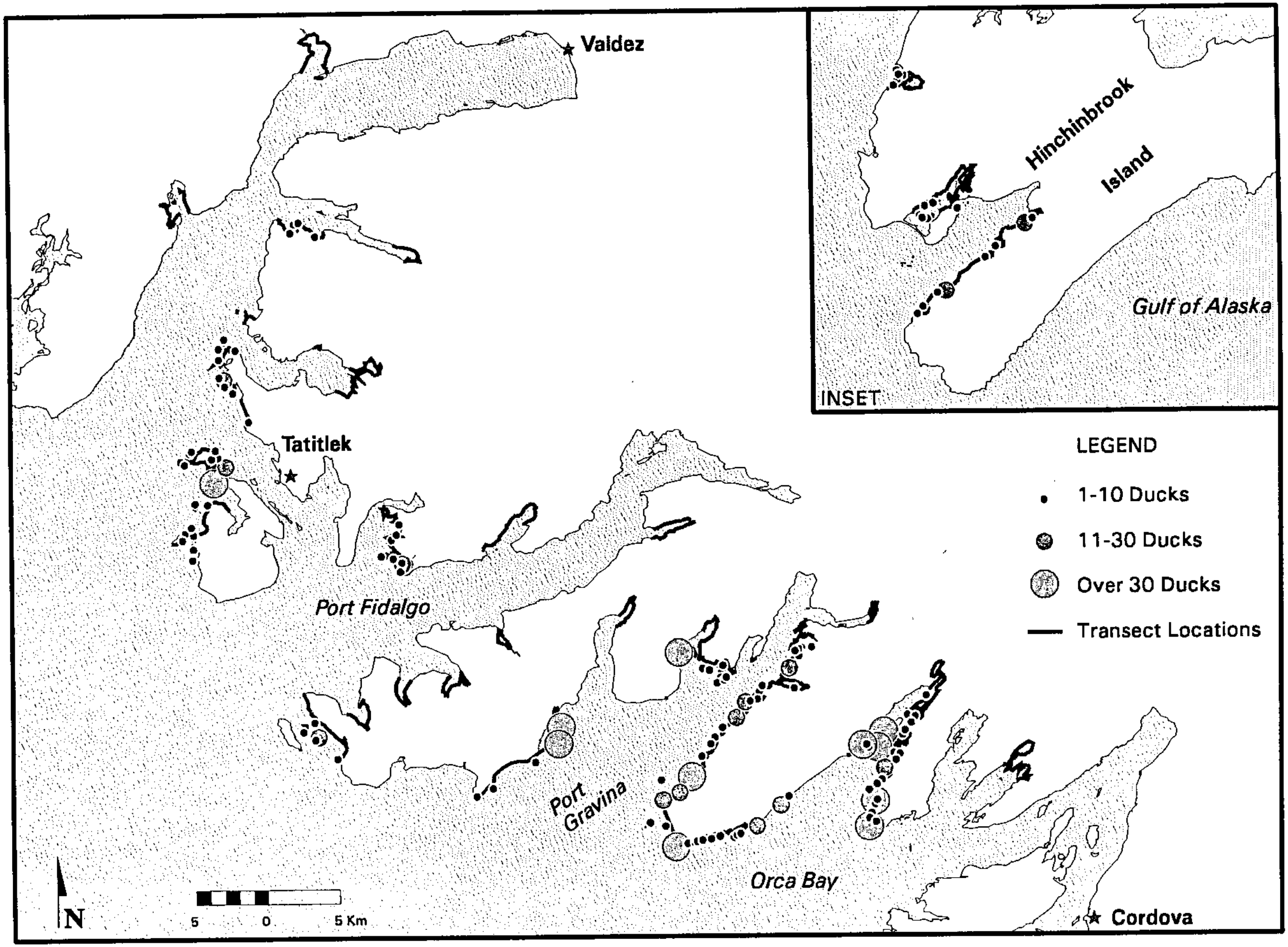
Appendix A35. Location of harlequin ducks observed in eastern Prince William Sound during the second fall survey (8 Aug.-16 Aug.) in 1997.



Appendix A36. Location of harlequin ducks observed in eastern Prince William Sound during the third fall survey (5 Sept.-10 Sept.) in 1997.



Appendix A37. Location of harlequin ducks observed in western Prince William Sound during the winter survey (13 March-19 March) in 1997.



Appendix A38. Location of harlequin ducks observed in eastern Prince William Sound during the winter survey (15 March-18 March) in 1997.

Appendix B: Number of harlequin ducks observed on transects during expanded fall survey coverage in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska in 1995, 1996, and 1997.

			Fall 1995			Fall 1996			Fall 1997		
Transect	Study Area	No.[a]	1[b]	2	3	1	2	3	1	2	3
Drier Bay	WPWS	24	0	6	52	0	12	21	12	12	36
Eshamy Bay	WPWS	3	1	4	47	6	12	64	4	12	33
Ewan Bay	WPWS	14	11	15	25	0	0	5	0	7	68
Hidden Bay	WPWS	29	0	0	0	0	7	12	3	10	12
Jackpot Bay	WPWS	13	10	3	5	5	17	55	2	6	24
Johnson Bay	WPWS	23	19	0	0	dns	dns	dns	dns	dns	dns
Masked Bay	WPWS	30	0	0	0	0	12	0	2	3	0
Total			41	28	129	11	60	157	23	50	173
Fish Bay	EPWS	42	5	1	dns[c]	4	4	30	3	3	11
Irish Cove	EPWS	40	0	0	dns	0	0	dns	0	0	0
Simpson Bay	EPWS	35	3	0	19	3	0	31	0	0	7
Snug Corner Cove	EPWS	37	0	0	dns	8	0	2	0	1	7
St. Matthew's Bay	EPWS	36	0	11	33	1	4	19	6	22	5
Two Moon Bay (west)	EPWS	38	0	3	dns	0	0	5	0	1	0
Two Moon Bay (east)	EPWS	39	5	8	dns	0	3	21	1	8	1
Whalen Bay	EPWS	41	1	0	dns	12	8	0	0	0	0
Total			14	23	52	28	19	108	10	35	31

[a] Transect numbers referenced in Fig. 2 and Fig. 3.
[b] Fall survey number.
[c] did not survey

Appendix C: Traditional Ecological Knowledge.

Raven and the Harlequin duck

> Raven was going to marry a harlequin duck. Formerly, Raven was white, and he said to the duck: "I wish you would make me as pretty as you are." The duck answered: "I will do so." She did, but then a baidarka showed up from around the point, and the duck said: "I'm sorry that I cannot finish you." "Do not finish me," said Raven, "just smear some charcoal on me." After doing so she left him and went to the water (story told by Chief Makari Feodorovich Chimovitski as recorded in Birket-Smith 1953).

Traditional Ecological Knowledge (TEK), a system of understanding one's environment, is built over generations, as people depend on the land and sea for their food, materials, and culture (Huntington and Mymrin 1996). TEK is based on observations and experience, evaluated in light of what one has learned from one's elders. Historically, the survival of communities depended upon the reliability of this detailed knowledge.

We can improve our understanding of the environment and ecological processes by integrating the findings of western science and traditional knowledge into one complimentary process. One goal of gathering traditional ecological knowledge is to use traditional knowledge in resource management (Ferguson and Messier 1997). Another goal is to understand TEK as its own system, supporting a unique culture. Traditional ecological knowledge can provide a long-term perspective often lacking in western scientific studies by contributing information on long-term changes in distribution and abundance of wildlife populations and the ecological factors that influenced those changes. Regarding the oil spill, this process is aimed at understanding the injury and recovery of the resources affected by the spill.

The importance of a particular species, be it for food, clothing, or ceremonial purposes, to the inhabitants of a region, greatly influences the amount of traditional knowledge associated with that species. The Chugach settlement pattern reflects a subsistence lifestyle based on the efficient exploitation of a variety of resources (Hassen 1978). However, by the time Birket-Smith (1953) and de Laguna (1956) conducted their research in the early 1930's, Chugach society and culture had already experienced almost 200 years of contact with European and American cultures. This "outside" contact often forced lifestyle changes and introduced imported goods, including foods, all of which ultimately reduced dependence on the local environment. Consequently, many of the details involving life during the pre-contact period have been forgotten (Hassen 1978).

In this report we use a broad definition of TEK, defining it as a composite of indigenous, local, and experiential knowledge (Miraglia 1998). TEK is reinforced, revised, and accumulated by each generation through the addition of local and experiential knowledge. As TEK is rarely written down, we interviewed residents of PWS to record their knowledge of harlequin ducks. Our methods were modeled after those of Huntington and Mymrin (1996). Community elders and hunters were interviewed either individually or in groups. When possible, this information was compared with past studies or historical accounts. Information on traditional and current use of harlequin ducks for food and clothing is also presented to indicate the significance of this resource to the Alaska native communities in PWS.

Residents of PWS most commonly refer to the harlequin duck as the "rock duck", although its Aluutiq name is *ungunguasaaq* (Stanek 1985). The name rock duck obviously refers to the ducks' preference to roost on large exposed rocks in the coastal intertidal habitats where they live.

Harlequin ducks are rarely hunted in modern times (PWS residents pers. comm., Scott et al.1996). Harlequin ducks were not included among the seven waterfowl species harvested by Tatitlek residents from 1987 to 1989 (Stratton 1990), nor were they among the species of waterfowl harvested for food by Chenega residents in the early 1960's (Stratton and Chisum 1986). Harlequin ducks were also rarely hunted in the recent and distant past. Birket-Smith (1953) and Hassen (1978) do not report the hunting of harlequin ducks in PWS. Historically, Tatitlek residents did not hunt harlequin ducks, at least in appreciable numbers (Stratton 1990). Harlequin duck skeletal remains have not been found at archeological sites excavated in PWS. The largest of these sites, the Paluvik midden sites, located at the southern end of Hawkins Island, span a 2000 year period and include thirty species of birds (Linda Yarborough, pers. comm.). Although Paluvik is located outside the core traditional subsistence use areas of Tatitlek (Stratton 1990), the species and relative abundance of waterfowl in the Paluvik sites reasonably portray the traditional and current harvest among Tatilek hunters (PWS residents, pers. comm.).

Lack of use in this century does not appear to be due to any scarcity of ducks. Harlequin ducks were commonly seen in Prince William Sound in the early 1900's (Grinnell 1908) and Chenega residents regularly observed them in PWS in the 1930's (Charlie Selanoff, Jack Kompkoff pers. comm.). Rather, it is because people generally "don't care for the taste" and harlequin ducks are especially "difficult to pick." The latter refers to the difficulty of removing the feathers from the bird, also referred to as plucking. Because of the value of feathers (see below), the act of plucking rather than skinning birds, may have been introduced through European contact (Rick Knecht, Museum of the Aleutians, pers. comm.). In general, PWS native people ate harlequin ducks only during shortages of more preferred species of birds, and other animals. "Rock ducks were passed up" if other species were plentiful (PWS residents, pers. comm.).

We would also expect to find TEK about animals if used for ceremonial purposes or clothing. Hassen (1978) states that although the Chugach caught birds for food, their most important value rested in their feathers and beaks. Bird parkas were worn in PWS in the late 1700's, but no species are mentioned (Merck 1980). However, harlequin ducks do not appear to be a species used significantly in making clothing or for decorative or ceremonial purposes (Birket-Smith 1953, Fitzhugh and Crowell 1988, Black 1991, Hassen 1978, Dr. Aron Crowell, Smithsonian

Institute pers. comm., Amy Steffian, Alutiiq Museum, pers.comm., John Johnson, Chugach Alaska Corporation, pers. comm.). None of the PWS natives interviewed seem to recollect the use of harlequin ducks for clothing or ceremonial purposes. Not being used for clothing and lack of ceremonial importance may reflect their minor importance as a food source.

PWS native people have knowledge of the distribution, life history, and habits of harlequin ducks, but as they were rarely sought, they attracted less interest and attention than species of greater importance in the traditional lifestyle. Further, recent geological events along with human induced changes to the PWS ecosystem (commercial fishing, sea otter revival, oil spill, and a variety of other economic activities) have further complicated the ability to link specific wildlife population changes to specific causes. Thus, it is difficult to quantify both how present day distribution and abundance compare with past years and the exact influence specific events may have had on any population changes. However, some qualitative comparisons can be made based on TEK gathered from Native experts. These are presented below:

Native experts believe the decline in herring stocks has had the greatest negative effect on sea duck populations in general, including harlequins. Traditional knowledge reports that ducks on both eastern and western PWS have been affected by the decline in herring, which was worsened after the oil spill. The magnitude of this effect on harlequin ducks is unknown. The 1964 Alaskan earthquake, the re-populating of sea otters (*Enhydra lutris*) in PWS, and the oil spill's deleterious effect on intertidal organisms are all believed to have contributed to a decline of seaduck populations. No specific values can be assigned to these parameters.

Harlequin ducks, along with other seaducks, feed on herring spawn. Herring populations began a noticeable decline around the time of World War II. However, the first year in living memory that herring did not spawn in Tatitlek Narrows was in 1993, four years after the oil spill. The herring decline also led to changes in spawning distribution with the largest decline along the northeast shore of PWS, including the Tatitlek Narrows. The decline in herring spawn caused a decline in most sea duck populations, as sea ducks feed heavily upon this seasonally abundant food source. Because the herring decline occurred throughout PWS, not just in oiled areas, the sea duck decline was also throughout PWS. However, because herring spawn about two weeks later on Chenega side of PWS and this later spawning does not attract as many ducks as in EPWS, the decline in herring has less of an effect on WPWS populations.

Harlequin ducks move between EPWS and WPWS. Most of those interviewed believed there are no well-defined eastern and western populations of harlequin ducks in PWS, but rather ducks move between areas, thus all being at some direct or indirect risk from direct oil exposure or its effects on the food chain. However, the degree of interchange throughout PWS is unknown. Thus, if there is significant interchange, survey comparisons between EPWS and WPWS must be interpreted with caution, especially when assessing recovery.

Intertidal organisms are also an important food source of harlequin ducks. Intertidal habitats and their organisms have been altered in several ways. Intertidal areas were uplifted during the 1964 Alaskan earthquake. Intertidal areas in many locations throughout WPWS were oiled by the spill, leading to a decline in intertidal organisms. This reduced food supplies, and therefore intertidal areas could support fewer ducks. Weathered and relatively unweathered crude oil can still be found on some beaches in WPWS where it may still be affecting ducks.

Native experts also believe that the distribution and abundance of seaducks has changed with the re-populating of PWS by sea otters. As sea otter populations increased, they altered the intertidal environments in ways that reduced the types of foods available to harlequin ducks. Harlequin ducks eat a variety of intertidal invertebrates including snails (*Littorina* and *Lacuna spp.*), blue mussels (*Mytilius sp.*), limpets (*Lottia* sp.), and chitons (*Tonicella sp.*) (Patten et al. 1998). This food reduction may result from direct competition for prey or by otters feeding habits having caused other ecological changes that ultimately reduced the prey populations on which ducks depend.

Harlequin ducks do not appear to have nested or reared broods in PWS in large numbers prior to the spill. Those interviewed do not recall observing a brood in PWS nor does anyone recall gathering, or recall anyone else gathering, harlequin duck eggs from nests.

Summary

We sought traditional knowledge about harlequin ducks from residents of PWS communities to compare with our findings. Harlequin ducks have not been, nor are presently important commodities in the traditional lifestyle of the PWS native population. Thus, less traditional knowledge exists for this species than for other more valued species. This led to difficulty in gathering sufficient traditional knowledge to compare with our studies and assess the injury and recovery of harlequin ducks as a result of the oil spill. While many ducks were killed directly by the oil, and subsequent spill effects worsened the situation, it is not clear whether the oiled areas are still suffering from additional long-term impacts. The herring population crash was identified as one of the most significant spill-related impacts to the ducks, and since the herring crash occurred throughout PWS, the ducks in EPWS may be affected over the long-term in a similar way to those in WPWS. An interchange of ducks between EPWS and WPWS is believed to occur. This interchange of ducks between EPWS and WPWS questions the validity of comparing the two populations as a means of measuring recovery. The 1964 earthquake, the large increase in sea otter populations, and the oil spill have all interacted to affect sea ducks, including harlequins. Historically, there is no oral record of harlequin ducks nesting or brood rearing within PWS.

PWS residents: The following elders and hunters were interviewed for this report: Gary Kompkoff, Chief of Tatitlek, Charlie Selanoff, Ed Gregorieff, Don Kompkoff, Jack Kompkoff, Ken Vlasoff, Roy Totemoff, Steve Totemoff, Fred Vlasoff, Louis Vlasoff, and Tim Johnson.

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Appendix D: Comparison with U.S. Fish and Wildlife Service marine bird surveys

Introduction

The United States Fish and Wildlife Service (USFWS) conducted shoreline and offshore surveys of all marine birds in Prince William Sound during March and July in most years from 1989 through 1998 (EVOS project /159). Results from these surveys have been used to document trends in harlequin abundance in oiled and unoiled areas of Prince William Sound (Irons et al. 1988, Klosiewski and Laing 1994, Agler and Kendall 1997). Because no significant trend was detected for harlequin ducks in oiled areas, while the harlequin population increased in unoiled areas, it was concluded that harlequin ducks in oiled areas of PWS have not recovered from the EVOS (Agler and Kendall 1997).

We analyzed winter and summer survey data collected from 1989 through 1996 by the USFWS to determine whether trends in abundance would compare similarly when analyzed by ours (see Methods) and the USFWS' methods. We also compare trends with respect to season (timing of surveys) and survey effort (geographic extent). We thank the USFWS for providing us their survey data. We have not, as yet, provided them the courtesy of reviewing this comparison prior to submission to the EVOS Trustee Council. They employ a different survey design and utilize different analytical techniques based on their goals and objectives. The following discussion is intended to compare harlequin duck survey techniques in order to determine the best method to assess recovery, and clarify some of the uncertainty surrounding the current status of harlequin ducks in PWS.

Transects surveyed by the USFWS are distributed throughout PWS (Agler and Kendall 1977). Because harlequin ducks utilize shoreline habitats, and we do not survey offshore transects, we excluded offshore transects surveyed by the USFWS from our comparisons. Areas of overlap exist between ours and USFWS surveys, however, unlike the USFWS, we do not survey in unoiled areas of north-western PWS or oiled areas of south-western PWS. We combined transects that were in close proximity to each other (region spatial scale; see Methods) because this reduced the amount of variability associated with small movements by ducks among transects in a centralized area and, at least for USFWS data, it removed a proportion of the variability caused by the large number of transects with no harlequin observations. The location of regions and the number of transects in each region differed between the USFWS' surveys and ours because survey coverage varied. We partitioned the USFWS' transects in unoiled areas into five regions for winter and summer surveys, and six regions during the summer and five regions during the winter for transects in oiled areas.

We calculated that the USFWS counted 19,834 harlequin ducks during 5 years of surveys, of which 10,213 ducks were counted during the summer (overall density = 1.84 ducks/km) and 9,621 ducks were counted during the winter (overall density = 3.32 ducks/km) when survey coverage was approximately 50% less than summer surveys (Table D1). The number of harlequin ducks varied annually from 982 - 2707 ducks for summer surveys and from 1410 - 2402 ducks for winter surveys. Most ducks were counted on unoiled transects during the summer (80%) and winter (64%) surveys (Table D1). Few ducks were counted on partially oiled transects during the summer (2%), while 10% of the total ducks were counted on partially oiled transects during the winter.

Comparison of USFWS Data Using Different Trend Analysis Techniques

Using our method of calculating trends and USFWS data, we found no significant change in the density of harlequin ducks during the summer in oiled (slope = 0.0271, S.E. = 0.760, p = 0.973), and unoiled areas (slope = 0.316, S.E. = 0.142, p = 0.113) (Table D2). Slopes were not significantly different (p = 0.723), however, our ability to detect differences was low (power = 5.6%) (Table D3). Using this analysis, and the assumption posed by the USFWS that with the absence of the oil spill, populations in the oiled zone would change at the same rate as those in the unoiled zone, we would conclude that the harlequin population in oiled areas during the summer recovered from the EVOS, but we would have little confidence in this conclusion. In contrast, based on their analysis the USFWS concluded that the harlequin population had not recovered in oiled areas during the summer (Agler and Kendall 1997). For the winter surveys, using our method of analysis, harlequin counts by the USFWS significantly increased in both oiled (slope = 0.393, S.E. = 0.067, p = 0.010) and unoiled areas (slope = 0.415, S.E. = 0.097, p = 0.023) (Table D2). Slopes were not significantly different (p = 0.853), but our ability to detect differences was low (power = 5.2%) (Table D3). Again, we would conclude with little confidence that the harlequin population in oiled areas recovered from the EVOS during the winter, while the USFWS concluded the harlequin population did not recover (Agler and Kendall 1997). These dissimilar conclusions indicate that the type of analysis employed to detect trends can influences the results.

Seasonal Differences in Trends (ADFG and USFWS) Using Identical Trend Analysis Techniques

We detected a significant decrease in the number of harlequin ducks in oiled areas (WPWS), while no significant trend was detected for unoiled areas (EPWS) (Table 13) using data collected during our fall surveys (Table 13). Slopes in oiled and unoiled areas were significantly different and our power to detect differences was relatively high (79.4%) (Table 14). This contrasts with results obtained when we used our method of trend analysis and USFWS data collected during the summer and winter (see above). Consequently, the timing (seasonally) of surveys can influence results of trend analyses. However, the USFWS surveys more shoreline over a broader area, therefore, variation in survey effort is not accounted for and may be reflected in this comparison.

Comparison of Trends During July in Similar Geographic Areas, Using Identical Trend Analysis Techniques

We performed an additional analysis comparing only July survey data (our first fall survey), using only transects surveyed by the USFWS that were in the same general location of our WPWS and EPWS study areas (Fig. 2, Fig. 3), thereby excluding unoiled areas in northern PWS and oiled areas in southwestern PWS. We performed this analysis to determine if trends would be similar during the same time period in the same general area using our method of determining trends. Shoreline coverage overlapped for some transects, but a portion of survey coverage did not. Transects surveyed by the USFWS were partitioned among ten regions in WPWS and five regions in EPWS. Because we only distinguished between oiled and unoiled transects during our surveys, transects considered partially oiled by the USFWS were excluded from the analysis.

During our first fall survey in July, we counted 1210, 1264 and 1338 ducks along 258 km of shoreline in EPWS in 1995, 1996 and 1997, respectively (overall density = 4.91 ducks/km) (Table D4). In comparison, between 298 - 710 harlequin ducks were observed by the USFWS during the summers of 1989, 1990, 1993 and 1996 along 242 km of shoreline (overall density = 2.00 ducks/km) in the same broad geographic area (Table D4). In WPWS, we counted 938, 891 and 808 harlequin ducks along 301 km of shoreline in 1995, 1996 and 1997, respectively (overall density = 2.92 ducks/km) while between 120 - 261 harlequin ducks were observed by the USFWS along 335 km of shoreline (overall density = 0.57 ducks/km) (Table D4). Total shoreline coverage in EPWS and WPWS was similar for ADFG and USFWS surveys, however, harlequin duck densities were much higher on our transects compared to transects surveyed by the USFWS (D4).

Using our survey data for July, we found no significant trend (slope = 0.2868, S.E. = 0.113, p = 0.086) in the number of harlequin ducks in EPWS (Table D2). Survey data from the USFWS generated a similar slope (slope = 0.2753, S.E. = 0.084), however, a significant increasing trend was detected ($p = 0.046$) (Table D4). For WPWS, our survey data (slope = -1.10035, S.E. = 0.593, $p = 0.123$) and the USFWS' survey data (slope = 0.1325, S.E. = 0.0698, $p = 0.094$) indicate no significant trend in the number of harlequin ducks, however, unlike results for EPWS, slopes and standard errors were substantially different between data sets (Table D4).

Based on a two-sample t-statistic, slopes generated from our July survey data for WPWS and EPWS were not significantly different ($p = 0.058$) with an observed power of our test of 46.0%. For USFWS' data, we found no significant difference between slopes in WPWS and EPWS (p = 0.238) with an observed power of only 18.9% (Table D3).

Overall Comparison

The trend in harlequin duck numbers was similar when using survey data collected by ADF&G and the USFWS for unoiled areas of EPWS. Regardless of time period, the general trend was always positive with slight variation in slopes (range: 0.2476 - 0.4155 ducks/km/year). In contrast, substantial differences in slopes exist for oiled areas. Slopes generated from data collected by the USFWS were always positive, whereas, slopes generated from our data were always negative (range: -1.1004 - 0.3930 ducks/km/year).

We believe the disparity in results between ours and the USFWS' survey data is related to differences in the allocation of survey effort among oiled and unoiled areas, and, at least for harlequin ducks in WPWS, the failure of randomly selected transects, used by multi-species surveys, to incorporate high density areas for species that exhibit a patchy rather than uniform distribution.

We calculated that ca. 580 km and 1111 km of shoreline are surveyed by the USFWS during the winter (March) and summer (July), respectively (Table D1). Approximately 62% of total shoreline is surveyed in unoiled areas, while 31% are surveyed in oiled areas; the remaining 7% is located on transects that were considered partially oiled. In comparison, our surveys cover less shoreline (559 km), but we survey the same transects during spring, fall and winter surveys. Our first fall survey (late July) is conducted at approximately the same time as the USFWS' summer survey. Compared to the USFWS surveys, our shoreline coverage is divided more evenly between oiled (54%) and unoiled (46%) areas.

A larger proportion of the total number of harlequin ducks are counted by the USFWS on unoiled transects in the winter (64%) and summer (80%) than on oiled transects, while our counts are more evenly distributed between oiled (42.5%) and unoiled transects (57.5%) (Table D1).

For July surveys only, and only in the general location of our WPWS and EPWS study areas, shoreline coverage was similar between ours (559 km) and the USFWS (577 km) and allocated in similar proportions between WPWS and EPWS (Table D4). Of the 6,449 harlequin ducks counted during our surveys in 1995, 1996, and 1997, 41% were counted in WPWS (overall density = 2.92 ducks/km) and 59% were counted in EPWS (overall density = 4.91 ducks/km). In contrast, substantially fewer ducks were counted on transects surveyed by the USFWS during 5 years of surveys in the same general areas (3,383 ducks), while a much larger proportion were counted on unoiled transects (72%) (Table D4), indicating that low density areas are being surveyed by the USFWS, especially in oiled areas. The difference between slopes in EPWS and WPWS is much larger for our survey data and based on a substantially larger number of ducks. The relatively larger difference between slopes is, for the most part, why we have greater power to detect differences between locations. We believe that the number of harlequin ducks sampled by the USFWS in oiled areas of WPWS are insufficient to predict population trends and explains why variability during their surveys is lower. A species-specific survey conducted in high density areas over consecutive years is more likely to generate meaningful trend data for harlequin ducks.

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Appendix D1. Summary table comparing USF&WS and ADF&G surveys of harlequin ducks in oiled and unoiled areas of Prince William Sound, Alaska.

	USFWS[a]		ADFG[b]
Prince William Sound	Winter survey	Summer survey	Fall surveys[c]
Total shoreline surveyed	580 km	1111 km	559 km
Shoreline oiled	31 %	31 %	54 %
Shoreline unoiled	62 %	62 %	46 %
Number of harlequin ducks	9621	10213	22469
Density of harlequin ducks	3.32	1.84	4.50
Annual range in duck numbers	1410-2402	982-2707	n/a[d]
Harlequin ducks on oiled transects	26 %	18 %	43 %
Harlequin ducks on unoiled transects	64 %	80 %	57 %

[a] United States Fish and Wildlife Service surveys conducted in 1989, 1990, 1991, 1993, 1994 and 1996. Does not include partially oiled transects.
[b] Alaska Department of Fish and Game surveys conducted in 1995, 1996, and 1997.
[c] Three fall surveys per year (July - September).
[d] Not applicable.

Appendix D2. Trend analysis for harlequin duck populations in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska comparing USF&WS and ADF&G surveys using ADF&G method of trend analysis.

Study Area	Agency	Season	Number of slopes	Total ducks	Weighted mean slope	Standard error	P[a]
Oiled	USFWS	summer	6	1843	0.0271	0.7596	0.973
Unoiled	USFWS	summer	5	8167	0.3157	0.1419	0.113
Oiled	USFWS	winter	5	2567	0.3930	0.0674	0.010
Unoiled	USFWS	winter	5	6133	0.4155	0.0967	0.023
WPWS	USFWS	summer	10	959	0.1325	0.0698	0.094
EPWS	USFWS	summer	5	2424	0.2753	0.0835	0.046
WPWS	USFWS	winter	9	1416	0.2619	0.1984	0.228
EPWS	USFWS	winter	5	3622	0.5672	0.2105	0.074
WPWS	ADFG	summer	7	2637	-1.1004	0.5928	0.123
EPWS	ADFG	summer	5	3812	0.2868	0.1135	0.086

[a] Probability of slope being significantly different than 0 (t test).

Appendix D3. Power to detect differences in population trends for harlequin ducks in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound comparing USF&WS and ADF&G surveys using ADF&G method of trend analysis. Only the ADF&G July survey is included in this comparison.

Agency	Comparison	Month	Standard error	P[a]	Power[b]
USFWS	oiled/unoiled	July	0.7728	0.723	0.056
USFWS	oiled/unoiled	March	0.1178*	0.853	0.052
USFWS	WPWS/EPWS	July	0.1154*	0.238	0.189
USFWS	WPWS/EPWS	March	0.3106*	0.345	0.132
ADFG	WPWS/EPWS	July	0.6036	0.058	0.460

[a] Probability of slopes being significantly different.

[b] Power at alpha = .05.

* pooled variance

Appendix D4. Length of shoreline and number of harlequin ducks counted during surveys conducted in July by USF&WS and ADF&G in oiled areas of western (WPWS) and unoiled areas of eastern (EPWS) Prince William Sound, Alaska. USF&WS surveys were conducted in 1989, 1990, 1991, 1993, and 1996. ADF&G surveys were conducted in 1995, 1996, and 1997.

Survey characteristics	USF&WS	ADF&G
Shoreline in EPWS	242 km	258 km
Shoreline in WPWS	335 km	301 km
Number of harlequin ducks	3383	6449
Harlequin ducks in WPWS	28 %	41 %
Harlequin ducks in EPWS	72 %	59 %
Density of harlequin ducks in WPWS[a]	0.6	2.9
Density of harlequin ducks in EPWS[a]	2.0	4.9

[a] all years combined (ducks/km).