The effects of low-level flying military aircraft on the reproductive output of Osprey in Labrador and northeastern Québec

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Abstract

The objective of this study was to determine whether low-level flying military aircraft affected the reproductive success of Osprey (*Pandion haliaetus*), and if so, to determine the optimal avoidance distance to minimize these effects. I studied 49 nests in 1995, and 68 nests in 1996 within the military low-level flying zone. Nest occupancy, clutch size, number of hatchlings, and number of young at 41 days of age were assessed at each nest. GIS flight track records provided frequency of aircraft at given distances and altitudes from the nest. Logistic regression analysis assessed the impact of flight frequency in four distance categories and four altitude categories on Osprey reproduction. The frequency of flights within each category were not accurate predictors of Osprey reproductive output. Nests were then randomly assigned to a buffer-zone radius of either 0, 1.85, 3.7, or to a control of 7.4 km, and reproductive output was compared among treatments, and between years. No significant differences were discovered among the reproductive parameters within either 1995 or 1996, but reproductive output was significantly higher in 1995, likely due to adverse weather conditions experienced in 1996.

Résumé de Thèse

L'objectif de cette recherche était de déterminer si les vols à basse altitude des aéronefs militaires avaient un effet sur le taux de reproduction du Balbuzard pêcheur (*Pandion haliaetus*), et si tel est le cas, d'établir une zone d'évitement afin de minimiser ces effets. Une étude de 49 nids en 1995 et 68 nids en 1996 a été fait à l'intérieur de la zone de vols à basse altitude du Labrador et du Québec nord-est. Les nids étaient contrôlés toute la saison de reproduction afin de déterminer le taux d'occupation, la couvée, la nichée, ainsi que le nombre d'oisillons aptes au vol, 41 jours étant l'âge reconnu à cet effet. Chacun des mouvements d'aéronef était noté et tracé sur un système d'information géographique. Ces routes de vol nous permettaient d'obtenir la fréquence des vols à proximité des nids à certaines altitudes et distances. L'analyse de régression logistique a été utilisé afin d'établir l'impact de la fréquence des vols dans quatre catégories de distance, et quatre catégories d'altitude sur la reproduction du Balbuzard pêcheur pour chacune des années. Les corrélations entre la fréquence des vols de chaque catégorie et le taux de reproduction étaient faible, et aucune des catégories de vol ne s'est avérés être de bons indicateurs du taux de succès de reproduction du Balbuzard pêcheur. De plus, les nids ont été au hasard à une zone tampon d'un radius de 0, 1.85, 3.7, ou à un contrôle de 7.4 km. L'occupation du nid, le couvée, la nichée, et le nombre de jeunes à l'âge de 41 jours étaient comparés entre eux et entre les années. Aucune différence significative n'a été observé entre les paramètres de reproduction de 1995 et 1996. Cependant, les taux de reproduction étaient significativement plus élevés en 1995 mais cette différence est probablement due aux conditions météorologiques défavorables de 1996.

Table of Contents

Method I

METHODS (ctnd.)

Method II

Method I - Treatment Application Experiment

DISCUSSION (ctnd.)

List of Tables

List of Figures

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Preface

Low-level military training flights have been ongoing in Labrador and northeastern Québec since the early 1980s; however it was not until the late 1980s that an environmental impact statement (EIS) was conducted on the low-level flying activities. One of the recommendations was to further the investigation of low-level flying effects on the wildlife of the area. As a result, funding was provided for a study to assess the effects of low-level flying on the reproductive output of Osprey (*Pandion haliaetus*).

The Osprey is the most abundant raptor species within the low-level flying zone in Labrador and northeastern Québec (based on 1993, 1994, and 1995 raptor nest locations) (Jacques-Whitford 1993; Jacques-Whitford 1994; Jacques-Whitford 1995). Thus, both the Department of National Defence (DND), and the Newfoundland and Labrador Wildlife Division (NLWD) have strong interests concerning jet effects on Osprey. Present DND policy stipulates that a 2.5 nautical mile (4.6 km) radius buffer-zone must be applied at all active bird of prey nests of concern discovered within the low-level training zone. With the Osprey being so abundant (more than 180 active nests discovered in 1995), an associated buffer-zone for each nest would greatly jeopardize military training, hence the interest of DND.

The interests of NLWD lie simply in the well-being of the Osprey in the region and maintenance of their population numbers in Labrador. Osprey have long been considered as a good indicator species of environmental change, and have taken on the role of "environmental barometer", indicating environmental contaminant levels of organochlorine pesticides and mercury (Henny 1983).

The results of past work investigating the effects of disturbance on Osprey and other raptor species are mixed (Melo 1975, Fyfe & Olendorff 1976, Windsor 1977, Stalmaster & Newman 1978, Swenson 1979, Poole 1981, Levenson & Koplin 1984, Fraser *et al.* 1985, White & Thurow 1985, Andersen et al. 1989, Ellis et al. 1991, Watson 1993, Grubb & Bowerman 1997, Trimper *et al.* 1998), and many studies are based solely on empirical observations of behaviour.

The following investigation attempted a two-method approach to test the impacts of low-level flying military aircraft on Osprey reproductive output within any one year. The first was an experimental test for the effects of low-level flying on Osprey in an effort to determine what avoidance zone or buffer-zone size, if any, was necessary to minimize any effects. The second approach was to take direct disturbance data in the form of Geographic Information System (GIS) flight track records that provided frequency, distance and altitude information for each flight past a given nest site. Using these data I generated statistical models to search for relationships between flight disturbance and reproductive success.

This thesis is written as a single document in the traditional thesis format.

Literature Review

The effects of disturbance on all forms of wildlife, including humans, has long been discussed and investigated in many scientific circles. Studies have ranged from simple behavioural observations to very complex and detailed scientific investigations. The subjects of these investigations are also just as diverse.

The following literature review will attempt to give a better understanding of the hypothetical impacts of noise on wildlife, with a major focus on the many investigations of the effects of aircraft disturbance.

Definition of Noise Effects

Human-made noise has the potential to alter the behavioural and physiological responses of animals (Bowles 1995). However, before any quantitative analysis can be conducted, it is important to define the meaning of noise, and the potential responses of an animal to such noises (Bowles 1995). Sound is a vibratory disturbance that can be detected by the ear (AHD 1985) and has the potential to fade as it travels farther from its source. How sound is received by an organism is dependent upon the degree of sound attenuation and the ability of the organism to perceive it. Extreme or persistent levels of sound have potential deleterious effects on many forms of wildlife.

The effects of noise on animals can be classified as primary and secondary. Primary effects are experienced physically by the animal, while secondary effects include detrimental impacts on function or performance of the organism (Dufour 1980). Primary effects can involve hindering hearing abilities, masking of intraspecific communication, stress, and physiological responses to noise stimuli. Secondary effects may involve interference with mating, changes in predator-prey relations, and other behavioural activities (Dufour 1980).

For the majority of literature regarding the effects of noise on wildlife populations, secondary effects are the most commonly quantified and discussed. Researchers usually emphasize only the immediate effects upon individual animals, concentrating primarily on reproductive impacts and stress-induced disturbance (R. Larkin *in prep.*). However, caution should be taken when using short-term behavioural responses as indicators of stress in any animal (Bowles *et al.* 1993). Short-term behavioural reactions may not necessarily dictate reproductive outputs in the immediate or long-term future.

Effects of Aircraft Noise on Wildlife

Human-related noise can potentially affect wild animals in a variety of ways that differ significantly from how that same noise stimulus might influence a human, or even a domesticated animal (Bowles 1995). Dufour (1980) has probably best summarized the potential effects of noise, by breaking it down into four key categories:

1) Effects on hearing.

Disturbances can come in many formats, ranging from slight to extremely loud and intrusive. For example, aircraft tend to be very loud disturbances, and dependent upon proximity, may exceed a 100 decibel sound level (Awbrey & Bowles 1991, Trimper *et al.* 1998). Such disturbances may impact the hearing ability of animals temporarily or over the long term. The ear is vulnerable to noise impacts, primarily due to its structure (Zajtchuk & Phillips 1989 as cited in R. Larkin *in prep.*). Severe noise levels can rupture the tympanum, fracture the ossicles, damage the various parts of the cochlea, cause deterioration of auditory nuclei in the brain, and/or distort hearing (see R. Larkin *in prep.*).

2) Masking intraspecific communication.

The ability of some animals to communicate with one another, or to respond to auditory environmental cues, is important. A disturbance may impede or disrupt that communication, resulting in difficulties finding mates, escaping predators and undertaking basic intraspecific communication (Dufour 1980). For example, Narins (1982) determined that the Puerto Rican Coqui (*Eleutherodactylus coqui*) stopped producing a portion of its call when confronted with human-made noise. Other studies conducted on mammalian communication masking have outlined potential effects on Sea Lions (*Zalophus californianus*) (Myberg 1980), and Fin Whales (*Balaenoptera physalus*) (Shaw 1978).

3) Non-auditory physiological effects.

The most commonly investigated physiological impacts induced by disturbance are the "fight or flight response" (Cannon 1929) , otherwise known as "active defence response" (Gabrielsen & Smith 1985), as well as stress, and reproduction. Active defence response is associated with a series of physiological changes in heart rate, respiration, blood flow, body temperature, and blood sugar which prepare an animal to escape the potential danger or fight for its survival. Noise can elicit a similar response (Dufour 1980), but it is not entirely clear how repeated "fight or flight" responses may influence the animal.

The second physiological malady caused by disturbance is stress. Stress is defined as a mentally or emotionally disruptive or disquieting influence (AHD 1985). The effects of stress may not readily be apparent and are difficult to measure. For example, studies of noise effects on humans have often discovered that task performance has been disrupted even after a noise experience has ceased. This disruption was evident even in circumstances when no effects were determined during the noise event itself (Glass & Singer 1972, Cohen 1980, R. Larkin *in prep.*).

Finally, noise can also impact reproductive physiology. Research has linked noise disturbances to possible effects on conception and pregnancy (Bowles 1995). For bird-life, numerous studies have tried to determine if human-made disturbance influences any stage of the breeding season (see Awbrey & Bowles 1990). After reviewing many such investigations Awbrey & Bowles (1990) determined that only marginal impacts were evident as a result of disturbance during the breeding season.

4) Behavioural effects.

Behaviour can be altered due to noise disturbance. These effects can include altered reflexes, aggression, refusal of food, cessation of grooming, and impaired learning and physical performance (see Dufour 1980). Besides Dufour (1980), other literature reviews are available on the subject (Kull & Fisher 1986, Awbrey & Bowles 1990, Bowles 1995, R. Larkin *in prep.*).

Effects of Flying Aircraft on Bird Species

According to Marler *et al.* (1973), noise has been determined to impair the hearing ability of birds to the point where their own vocalizations are significantly altered (Marler *et al.* 1973). However, the birds used in their study were subjected to continuous noise levels over a long period of time. Aircraft noise effects, on the other hand, are brief eruptions of impulse sound (Dufour 1980). The greatest concerns of impulse noise likely include damage to long-term hearing abilities and/or panic flights resulting in abandoned nest sites. The most well known instance of complete nest failure brought on by aircraft disturbance was reported by Austin *et al.* (1972). They suggested that colonially nesting Sooty Terns (*Sterna fuscata*) abandoned their nests due to repeated sonic booms in the area, and most of the 50 000 nests failed to produce young. However, this study made many assumptions (Kull & Fisher 1986), and the results have since been challenged (Bowles 1995). No definitive determination has ever been made as to what actually caused the nest failures. As for ear damage, Marler *et al.* (1973) indicated that continuous noise can affect the hearing abilities of birds, and other studies have determined that impulse noise (e.g. sonic booms) can damage the inner ear (Eames *et al.* 1975, Vertes *et al.* 1984, Ylikoski 1987, Saunders *et al.* 1991, Gao *et al.* 1992). If a bird experienced ear damage, this undoubtedly interferes with many activities, like prey location (Rice 1982) and intraspecific communication (Marler *et al.* 1973). However, birds, unlike mammals, are able to regenerate lost sensory hair cells from such acoustic trauma (Corwin & Cotanche 1988), and may be able to recover from some forms of hearing loss caused by noise.

Few studies have investigated physiological responses of birds to aircraft disturbance. Ellis *et al.* (1991) used a telemetering egg to monitor the heart rate of a Prairie Falcon (*Falco mexicanus*) before and after being subjected to sonic booms and low-level flying aircraft. Unfortunately, the bird was not regularly in close contact with the egg and few data were collected. However, they did find variable heart rate values, differing by 25 - 30 beats per minute for any given 2.5 minute block of time. Heart rates following booms and jet passes were comparable or below heart rates measured for falcons returning from normal flight.

Heart rate levels after a disturbance are not necessarily definitive proof that an animal was startled or stressed (Bowles 1995). Heart rates can vary considerably for a variety of reasons. For example, the sound of biting insects have been known to increase heart rates as much as that from a startle disturbance (Workman & Bunch 1991 as cited in Bowles 1995). However, Ward & Stehn (1989) and Jensen (1990) extrapolated data to conclude that energetic reserves of birds could be reduced by exposure to low-flying aircraft. Metabolic and/or behavioural adjustments on behalf of the birds may have compensated for this loss, and their values were probably not a true projection of long-term effects.

Behavioural studies constitute the majority of the literature on the effects of aircraft on birds and their results have been varied. Observations on seabird colonies along the coast of Scotland indicated little impact of aircraft flying at 100 m above ground level on the attendance of incubating and breeding birds (Dunnet 1977). Similarly, brief observations of a Least Tern (*Sterna antillarum*) colony in Maryland, situated near a Harrier Jet (AV-8B) pad, showed that the birds had a high degree of tolerance to elevated noise levels and aircraft (Altman & Gano 1984). Another study determined that neither fixed-winged aircraft nor helicopters significantly disturbed colonies of wading birds in Florida (Kushlan 1979). However, contrary evidence suggested that Herring Gulls (*Larus argentatus*) exposed to supersonic transport flights, flushed from their nests and engaged in violent behaviours, resulting in both unattended nests and broken eggs (Burger 1981).

For further information on the impact of aircraft and military noise on wildlife species, the reader is referred to other comprehensive literature and research reviews written on the subject (Dufour 1980, Kull & Fisher 1986, Awbrey & Bowles 1990, R. Larkin *in prep*).

Effect of Aircraft on Raptors

The most comprehensive summary of literature investigating the effects of aircraft on raptors is provided by Awbrey & Bowles (1990). Essentially, they broke their discussion into four key categories. The first assessed the effects of aircraft on raptor hearing. The second looked at the effects on raptor reproductive success, which was further broken down into the following sub-categories: nest site abandonment, reduced clutch size or hatchability, panic flights, nest exposure after a panic flight, and overall nest success. The third category was aircraft effects on raptor mortality and distribution, and finally, the fourth category focussed on aircraft affecting raptor populations.

Awbrey & Bowles (1990) formulated seven basic conclusions:

1. Reoccupancy of nests may be affected significantly.
2. A small effect on success rates and young fledged per nest may be observed after exposure to disturbance.
3. Significant effects on nest success and numbers of young fledged are predicted by the number of flight responses of nesting birds.
4. The tendency to flush is most strongly affected by previous experience (habituation) and stage of the breeding season.
5. Sonic booms cannot crack raptor eggs.
6. Adults may kick eggs or young out of the nest, but this effect is likely to be so rare that it cannot be measured.
7. The responses of owls and vultures may not be very different from those of hawks,

eagles, and falcons.

Since the Awbrey & Bowles (1990) review, other studies have continued to investigate the effects of aircraft on raptors. Delaney *et al.* (1997) determined that aircraft overflights had a negligible impact on Spotted Owl (*Strix occidentalis lucida*) reproductive success. Additionally, Watson (1993) found that Bald Eagles (*Haliaeetus leucocephalus*) had lower response rates to fixed-wing aircraft than to helicopters, but observed no direct mortality of young or adults to either disturbance.

More comprehensive studies are needed to better determine the true effects of disturbance on raptors. Awbrey & Bowles (1990) and Bowles (1995) made a series of recommendations toward future research. Future studies on this matter should focus toward these long-term objectives:

1) determine which features of disturbances best predict behavioural responses;
2) better understand animal habituation to noise;
3) quantify the relationship between the magnitude of disturbances and effects, specifically investigating whether numbers of disturbances or raptor responses are the best correlates.

Grubb & Bowerman (1997) attempted to fill one of those gaps investigating the frequency of response of Bald Eagles to three different types of aircraft stimuli (light planes, helicopters, fighter jets). Using a classification tree model, they found that stimuli of different types of aircraft affected Bald Eagle responses in different ways. In fact, jet fighter aircraft elicited the least response. However, they did qualify their results by stating that the sample data were not evenly or randomly distributed across the various parameters, and that eagle habituation to aircraft may cause their models to overestimate or underestimate eagle responses depending upon aircraft flight traffic.

Osprey

Osprey are unique individuals within the raptor world, existing in a family all their own: Pandionidae. However, their distribution is far-reaching. The five subspecies that exist worldwide are found on every continent but Antarctica, and are known to breed in both temperate and tropical climates (Poole 1989). The two subspecies that exist in North America and the West Indies are : *P. h. carolinensis* (Gmelin) found breeding throughout North America, and *P. h. ridgwayi* (Maynard) found primarily in the Caribbean, and along the keys of Belize (Johnsgard 1990).

The Osprey (*P. h. carolinensis*) is a large raptor with an average wing length of 477.4 mm (males), an average weight of 1403 grams (Johnsgard 1990), and an average length of 53 to 65 cm. Osprey are easily recognizable by their large size and distinctive colouration patterns.

The primary food source of the Osprey is fish, although they have been observed returning to their nests with a variety of other animals (Poole 1989). They are adept fishers; hovering over water, they plunge feet-first after their prey, sometimes from heights of 30 m or more (Johnsgard 1990). Well adapted for hunting in an aquatic environment, their feet are zygodactyl, allowing them to rotate one toe from the front to the back to better grip their prey, and their feet pads feature spicules to further secure their grip. Osprey also have large and active uropygial glands, relative to other raptor species (Welty & Baptista 1988), allowing them better water repellency.

Beebe (1974) suggested that Osprey need only three key characteristics for their breeding habitat: the presence of surface-dwelling fish that are relatively slow-moving; an ice-free season long enough to permit reproduction; and a nest site that is elevated and inaccessible to land animals. However, Osprey have been observed nesting successfully in a variety of habitat types across North America (Poole 1989). Active Osprey nests have been reported along the noisy train route from Boston to New York City (Poole 1989), and also in the quiet and remote settings of interior Labrador (Wetmore & Gillespie 1976).

Effects of Aircraft on Osprey

Aside from Trimper *et al.* (1998), very little is known of the overall effect of low-level flying military aircraft on breeding Osprey. However, other research on disturbance effects have been conducted on Osprey (Melo 1975, Fyfe & Olendorff 1976, Swenson 1979, Poole 1981, Levenson & Koplin 1984). With an increase in the number of people at the onset of the summer season in Yellowstone National Park, Osprey fled their nest sites and eventually abandoned them altogether (Swenson 1979). On the other hand, other studies have indicated them to be quite tolerant of disturbance (Melo 1975; Poole 1981, 1989), especially in the early part of the breeding season (Fyfe & Olendorff 1976). Recently, Trimper *et al.* (1998) did not find any detrimental effects of low-level flying military aircraft on the behaviour of Osprey nesting under the same conditions as seen in my study. Trimper *et al.* (1998) measured decibel (dB) levels at the sites, and determined some of them to be in excess of 100 dB, yet the Osprey did not appear agitated or startled.

Trimper *et al.* (1998) investigated the behaviour of Osprey to various intensities of disturbance in an effort to quantify their response. In contrast, my study investigated the impact of low-level flying on the reproductive output of Osprey.

Introduction

The effects of military disturbance have been studied on a variety of wildlife species for many years with mixed results. Research on Mule Deer (*Odocoileus hemionus*) movements in response to military activity in Colorado (Stephenson *et al.* 1996) concluded that their home range tended to increase with increased military activity. Also. work on desert ungulates suggested that animal responses decreased with increased exposure to the activity (Weisenberger *et al.* 1996) and that habituation to low-altitude aircraft possibly occurred. However, a Woodland Caribou (*Rangifer tarandus caribou*) calf survival index was found to be negatively correlated with the exposure of the female to low-level flights (Harrington & Veitch 1991).

Research of avian species has also generated varied results. Observations of bird colonies have indicated high levels of tolerance to disturbance events and aircraft (Dunnet 1977, Kushlan 1979, Altman & Gano 1984). However, contrary evidence has also shown that low-flying aircraft and/or sonic booms can adversely affect behavioural activities and reproduction (Austin *et al.* 1972, Burger 1981).

Tolerance of raptor species to aircraft has also been studied. Behavioural assessments of several raptor species in Arizona that were subjected to regular low-level jet activity indicated no significant responses, and did not appear to limit occupancy or productivity (Ellis *et al.* 1991). Windsor (1977) studied Peregrine Falcons (*Falco peregrinus*) for possible effects of low-level flying activity by fixed-winged aircraft and helicopters, and found no significant differences between the reproductive success of birds exposed to controlled overflights and those that were not exposed. While Bald Eagles (*Haliaeetus leucocephalus*) had a greater response to helicopters than fixed-winged aircraft, no direct mortality of young or adult birds was associated with either disturbance (Watson 1993). According to Andersen *et al.* (1989), Red-Tailed Hawks (*Buteo jamaicensis*) habituated to low-level air traffic over time. This was consistent with Grubb & Bowerman (1997) who found a relationship between an increase in the amount of eagle response to disturbance with a decrease in overall jet activity. However, fixed-wing aircraft flying near Gyrfalcon (*F. rusticolus*) nests have been linked with nest desertions prior to egg-laying (Fyfe & Olendorff 1976).

Low-flying aircraft are sporadic and brief, but highly intense disturbances that may interrupt regular breeding cycles of birds. Sudden noise may cause an incubating adult to panic and rush from the nest, possibly throwing out eggs or young chicks. Prolonged and frequent exits expose the eggs and chicks to increased temperature fluctuations and stress, which may cause direct mortality, increased exposure to predators, as well as a potential decrease in growth.

Osprey (*Pandion haliaetus*) are known to abandon their nests due to the onset of disturbance (Swenson 1979; Levenson & Koplin 1984). Swenson (1979) investigated an Osprey population located in a quiet and remote setting of Yellowstone National Park. With the onset of the summer season, an increase in people caused the Osprey to flee and eventually abandon their nests (Swenson 1979). However, contrary to this, other studies have indicated Osprey as a species tolerant of disturbance (Melo 1975; Poole 1981, 1989), especially in the early part of the breeding season (Fyfe & Olendorff 1976).

Low-level flying military training has been ongoing in Labrador and northeastern Québec since 1981 (Harrington & Veitch 1991, Department of National Defence 1994). Since that time, annual increases in the number of sorties (i.e. flights) has led to growing concerns about the impact of these activities on the growth and survivorship of local wildlife. As a result, an environmental impact statement (EIS) was finalized in 1994 on military flying activities in Labrador and Québec. The EIS report indicated that low-level flying has potential deleterious effects on wildlife behaviour and reproductive success, and recommended monitoring and mitigation programs be implemented for the region with regards to local wildlife (Department of National Defence 1994). In 1991 the Canadian Department of National Defence (DND) implemented a monitoring program for birds of prey within the low-level training area of Labrador and northeastern Québec, concentrating on the traditional Osprey nesting grounds (Wetmore & Gillespie 1976). The criteria of the monitoring program stipulated that a 2.5 nautical mile (nm) avoidance area (i.e. buffer-zone) be established around each active raptor nest of concern, in an effort to reduce and/or eliminate all potential effects of low-level flying activities. However, by 1995, the surveying effort increased and the number of active nests, and subsequently the number of buffer-zones, greatly increased as well. Osprey alone were discovered to have 186 nest sites in this region in 1995 (Trimper *et al.* 1998). As a result, the continuation of regular military operations in the area was in jeopardy.

This study had two key objectives: 1) to determine whether low-level flying military aircraft had any impact on Osprey nest occupancy, egg number, hatchling number, and number of young at 41 days of age within any given year; and 2) if there were impacts, to recommend the necessary mitigation procedures to minimize these disturbance effects.

Study Area

The study area was located in southern Labrador and the northeastern region of Québec (Figure 1). Approximately 45 000 km^2 in size, the study area is characterized by rolling topography, dense boreal forest and numerous lakes and rivers. There are several major watersheds within the study zone and countless lakes and ponds, many of which are unnamed. There are large ravines and river valleys throughout the study area, and these are predominantly vegetated by large, virgin Black Spruce (*Picea mariana*), White Spruce (*P. glauca*), White Birch (*Betula papyrifera*) and Trembling Aspen (*Populus tremuloides*). Osprey nested high atop the large spruce trees in this habitat.

There are also large tracks of open bog and taiga habitat consisting of various vegetation types: stunted Black Spruce, Alder (*Alnus rugosa*), Sheep's Laurel (*Kalmia angustifolia*), Labrador Tea (*Ledum groenlandicum*), Leatherleaf *(Chamaedaphne calyculata)*, Sphagnum Moss (*Sphagnum* spp.), and more. There were no visible nesting sites within the bog habitat type, but several nests were established at the periphery. Osprey nests were also sporadically found in upland dense coniferous forest consisting largely of open tracts of Black Spruce. These spruce trees reach 3 - 6 m in height and are considerably smaller than those found in the river valleys.

Low-Level Training Zone

Military training activities were ongoing within the study area throughout the duration of this project. Experimental and control nests were chosen within the low-level flying zone in the southern region of the low-level training area (LLTA). Low-level training flights have been ongoing in this region since 1981, with upwards of 10 000 - 15 000 annual military sorties within the LLTA.

Osprey Breeding Season

No baseline data are available for Osprey within these areas concerning water quality, prey availability or for overall population demographics, particularly concerning immigration and emigration of individuals, recruitment, survivorship, or dispersal from natal site. Osprey arrive in Labrador beginning in early May. On average, they begin to lay their eggs between 23 May to 1 June. The average incubation time for Osprey in eastern North America is 38-39 days (Poole 1989), making the average hatching date between 1 July to 9 July. The average fledging time for a migratory population of Osprey tends to be between 50 and 55 days (Stotts & Henny 1975; Stinson 1977; Poole 1989), therefore the average fledging time for the Labrador Osprey would be 20 August to 2 September. Virtually nothing is known of the post-fledging time period as well as the onset of migration.

Methods

To have a more complete understanding of the effects of low-level flying on Osprey in 1995 and 1996, two independent methods were utilized. The first procedure established no-fly avoidance zones (i.e. buffer-zones) around nest sites restricting low-level flying activities. The second method assessed actual disturbance levels at a given nest site by analysing the data from Geographic Information System (GIS) flight track records. The coordinates of all known nest sites were overlaid onto the flight track records, and the date, altitude and distance of each flight past a given nest site was determined. These data were analysed to identify if military flight activity affected Osprey reproductive success in this region.

Method I

Treatment Application Experiment

A total of 75 Osprey nest sites were chosen for the study, all located in or near the low-level training zone designated by DND. The nest sites were determined by pooling all known occupied nests from 1993 and 1994, as found during routine raptor surveys conducted by Jacques-Whitford Environment (Jacques-Whitford Environment 1993, 1994). Each nest site was then randomly assigned to one of four buffer-zone treatments. This method of treatment application ensured that nests within treatments were not clumped in space, and that they were truly independent samples of the population.

A buffer-zone was defined as an area restricting all low-level flying military activity within the designated zone and below 1000 feet (305 m) above ground level (AGL). Flights above 305 m AGL may influence a given nest site, however they are not classified as low-level. The experimental treatment buffer-zones were 0, 1.85, and 3.7 km in radius. These treatments were compared to each other, as well as to an interspersed control population with a 7.4 km radius. The kilometre values are equivalent to DND standard distance measurements of 0, 1, 2 and 4 nautical mile radii, respectively. All nests, including control nests, were randomly interspersed within the study area.

One month into the 1995 breeding season, several nest sites with pre-arranged buffer-zones were found to no longer exist. Such nests were eliminated. Newly chosen nests were used for analyses of clutch size, hatchling numbers and number of young at 41 days of age, but not for nest occupancy.

Since new nests were not discovered until after the onset of the breeding season and they had not been assigned a buffer-zone, new randomly-assigned buffer-zones were established at these nests on 13 June, 1995, part way through incubation. Therefore, prior to this date these nests were assigned to the 0 km treatment type (with the exception of the occupancy time period).

Four reproductive variables, as described by Poole (1989), were assessed during four visits to each nest using fixed-wing aircraft and helicopters:

1) *Nest occupancy.* Each potential nest was visited before egg-laying to determine if a pair was present. A nest was selected only if it had an active pair the previous year, and if it was in at least "fair" condition (i.e. the nest needed only minimal repair to be ready for the breeding season). An occupied nest, or breeding territory, was defined as a nest with a pair of birds observed on the nest territory displaying breeding or territorial behaviour.

2) *Clutch size.* Eight to 10 days after the first egg was estimated to have been laid, the nest was visited for an egg count. A nest with ≥ 1 egg was classified as an active nest.

3) *Hatchling number.* The number of hatchlings in each occupied nest was counted approximately 45 days after egg-laying began. This nest check occurred 5 to 10 days after the first egg was scheduled to hatch.

4) *Number of young to reach 41 days of age.* The number of young in an active nest was counted 41 days after the hatching of the last young. Young at 41 days of age and older are considered to have a high probability of surviving to fledge, i.e. an acceptable age to determine nest success (Steenhof 1987). A nest with ≥ 1 young at 41 days of age was classified as successful.

At the completion of the two years, all data were compiled and analysed for differences

among the four buffer-zone treatments in each of four reproductive phases of the breeding season. For each year, the following reproductive phases were established:
1) nest occupancy, when Osprey return to their nest sites and establish themselves (1 May - 20 May); 2) egg-laying and incubation (21 May to 15 July); 3) egg hatch and adult Osprey raise their young (15 July to 25 August); and 4) young Osprey reach the age of 41 days and begin to fledge (25 August to 10 September).

Following the analysis of reproductive differences among buffer-zone treatment types, three other reproductive factors were assessed. First was the nest failure rate over time. Each stage of the breeding season was analysed independently, i.e. the number of failed nests from phase 1 to phase 2, phase 2 to phase 3, and phase 3 to phase 4. Also, the overall nest failures of occupied nests and active nests were assessed and compared among the buffer-zone treatments, as well as between years. The second factor being analysed was the success of nests within each treatment type. The mean number of young that reached 41 days of age in occupied, active and successful nests for each buffer-zone treatment type were compared within 1995 and 1996, as well as between years. Third, nest reutilization in 1996 was assessed with regard to occupied, active and successful nests from 1995.

Weather variables were not collected for individual nest sites throughout the breeding season; however daily temperature, rainfall and snowfall values were collected for the Happy Valley-Goose Bay region for May, June, July and August of 1995 and 1996.

Method II

GIS Flight Track Records

Each military flight based out of Canadian Forces Base - Goose Bay in 1995 and 1996 had an associated GIS flight track record. These records provide the date of each flight. the altitude AGL of that flight, and the linear distance of the flight from the nest site.

The goal of the second part of the study was to search for a relationship between the frequency of flights at various distance and altitude categories and Osprey reproductive output at any given nest. If a significant relationship was determined with one or several flight variables, they could be used as predictors of Osprey reproductive output. To accomplish this, all flight track records were compiled for 1995 between 28 April and 31 August, and for 1996 between 8 May and 31 August.

The distance of each flight from an Osprey nest was categorized:

1. 0 - 0.5 nautical miles (i.e. 0 - 0.93 km)
2. 0.5 - 1.0 nautical miles (i.e. 0.93 - 1.85 km)
3. 1.0 - 2.0 nautical miles (i.e. 1.85 - 3.7 km)
4. 2.0 - 3.0 nautical miles (i.e. 3.7 - 5.56 km)

The altitude AGL of each flight past a nest was also categorized:

1. <100 feet AGL (i.e. <30.5 m AGL)
2. 100 - 249 feet AGL (i.e. 30.5 - 75.5 m AGL)
3. 250 - 499 feet AGL (i.e. 76 - 152 m AGL)

4. 500 - 999 feet AGL (i.e. 152.5 - 304.5 m AGL)

Trend Surface Analysis

Although the experimental design of this project attempted to control for any spatial autocorrelation, the survey methods used to initially discover these nests did not. Therefore, to ensure the lack of spatial autocorrelation, a trend surface analysis procedure was conducted to search for geographic trends in the reproductive output data (Legendre 1993). Geographic proximity of Osprey nests to each other may influence the reproductive output of these nest sites (Wartenberg 1985), independent from any affect of low-level flying or any other environmental variable. Organisms interact not only with the environment but also with their neighbours. The degree of that interaction is dependent upon proximity (Wartenberg 1985). Geographic information can be used to better understand variation among populations (Wartenberg 1985), or within any one given population.

Trend surface analysis employs multiple linear regression analysis of the variables of interest using the geographic coordinates as the independent variables (Diniz-Filho & Malaspina 1995). For this study the latitudinal and longitudinal coordinates, and their polynomial expansions (i.e. latitude^2, longitude^2, and latitude*longitude) were used as the independent variables, while the dependent variables were nest occupancy and the number of young at 41 days of age (Davis 1986). Occupancy and the number of young at 41 days of age were the only two dependent variables being investigated for geographical surface trends because this analysis was attempting to determine spatial connections for overall reproductive output within a given breeding season. The most significant variables to consider for long-term productivity were nest occupancy and the number of young that reach the age of fledging (Steenhof 1987). Thus, the number of eggs and the number of hatchlings are incidental to the success of a given nest to produce ≥ 1 fledgling.

Field Techniques

Nest Surveying

Fixed-wing aircraft were used to assess nest occupancy, while helicopters were used to assess all remaining reproductive phases. These methods were the most efficient and economical for this study area. According to Poole (1989) ground surveys take longer than aerial surveys and are potentially more disturbing to the birds. During aerial surveys, a nest could be approached and assessed very quickly; the whole procedure could be conducted in approximately one minute.

Helicopters have been used for many years to conduct raptor surveys with minimal effects on the birds. Watson (1993) found no direct mortality of young or adult Bald Eagles during their helicopter surveys, and Andersen *et al.* (1989) also determined that helicopter surveys did not significantly affect the behaviour of Red-Tailed Hawks. Additionally, Fraser *et al.* (1985) concluded that incubating and brooding Bald Eagles appeared indifferent to fixed-wing aircraft near their nests, and they attributed no nest failures or egg/hatchling mortalities to the use of aircraft.

Using helicopters for surveying Osprey nest sites is considered to be an accurate method to determine reproductive output (Ewins & Miller 1995). Ewins & Miller (1995) found no significant differences between aerial surveys and ground surveys in determining Osprey reproductive success.

Estimating Age

Ages of hatchlings were estimated by considering their size, plumage and colour (Poole 1989). These characteristics were compared to photographs of young Osprey from hatching to fledging. The egg hatch date was determined by back-dating. However, there were often difficulties in aging young due to several factors. First, at some nest sites adult Osprey were very aggressive, forcing the helicopter to keep its distance, and therefore decreasing visual clarity. Second, when confronted with danger the chicks often huddled close together and crouched into the nest (Poole 1989), impairing the view. Finally, debris in Osprey nests can cover part of or even entire chicks. For example, a large piece of birch bark may entirely conceal a 2-day old chick.

Statistical Analysis

Treatment Application Experiment

A normal distribution could not be attained for the reproductive data. Log transformation, square-root transformation, and arcsin transformation (Sokal & Rohlf

1995) techniques were performed on the raw data, as well as their residuals to attempt to attain normality. None was successful, so non-parametric statistics were used. As a result, testing for a 'year-by-treatment' interaction was not possible with rank transformed non-parametric analysis (Thompson 1991; Jorgensen *et al.* 1998). Kruskal-Wallis and Mann-Whitney U tests were performed on raw data comparing all buffer-zone treatment types (i.e. 0 km, 1.85 km, 3.7 km, and 7.4 km radius no-fly zones) within both 1995 and 1996, as well as between years.

Orthogonalized values of the number of hatchlings and the number of young at 41 days of age were also statistically compared among the buffer-zone treatments. There is a temporal connection among each reproductive phase assessed during the breeding season, and therefore, an inherent bias is carried over from one reproductive phase to the next. Orthogonalization is a procedure that mathematically removes the effects of past phases from the raw data, allowing testing to resume on residual data that were free from that temporal bias (Eaton *et al.* 1986). By comparing the reproductive output for each phase of the breeding season independent of the previous phase, there was a more complete understanding of the effects of low-level flying on each individual reproductive phase of the breeding season. This process can be completed with a statistical method called two-dimensional partitioning (Eaton *et al.* 1986, Spaner *et al.* 1996). Once the temporal correlation was removed, log transformation, square-root transformation and arcsin transformation techniques (Sokal & Rohlf 1995) failed to normalize the data. Thus, a Kruskal-Wallis test was conducted to compare the two reproductive phases within 1995 and 1996.

The differences in overall nest failure rates, as well as those within each reproductive phase, were also statistically compared among the four buffer-zone treatments and between the two years. To accomplish this, a Kruskal-Wallis test was conducted to compare nest failure rates among treatments within years, and Mann-Whitney U tests were used to compare the treatments between the two years. Similarly, a Kruskal-Wallis test was used to determine differences among the four buffer-zone treatments for nest reutilization from 1995 to 1996, as well as nest success relative to the amount of occupied, active and successful nests in both 1995 and 1996.

Weather Data

Daily mean temperature values, rainfall values, and snowfall values were obtained from the Environment Canada weather station in Happy Valley-Goose Bay. A 1-way analysis of variance (ANOVA) was conducted on log-transformed temperature, snowfall and rainfall weather variables to compare each month between 1995 and 1996. A Mann-Whitney U test compared the number of days per month that rain and snow was present between 1995 and 1996 for each month.

GIS Flight Track Record Analysis

Since the reproductive data were not normally distributed, a stepwise logistic regression procedure (Hosmer & Lemeshow 1989) was used to determine which distance and altitude flight categories best explained Osprey reproductive output. The significance of the regression model was based on a log-likelihood chi-square probability statistic, a prediction accuracy table, and the Hosmer-Lemeshow lack-of-fit test (Hosmer & Lemeshow 1989).

Within the model the ability of a nest to succeed was represented as a binary value: 0 = failed; 1 = fledged ≥ 1 young. This holds true for both models in this section of the analysis. A stepwise logistic model was generated to predict the following:

1) nest occupancy in 1996 using the cumulative values of all flight variables for 1995;
2) the success of all occupied nest sites to fledge ≥ 1 young, using the cumulative values of all flight variables.

To increase the number of nest sites available for the second model, both 1995 and 1996 nest sites were grouped together. To control for any potential year effects, the *Year* variable was entered into the model as a dummy variable. By doing this, the model could determine if the year influenced the overall significance of the model (Zar 1984). If in fact *Year* does have an influence, including it as a dummy variable would increase the accuracy of the model to predict Osprey reproductive output using the distance and altitude flight categories.

Corresponding to the logistic regression models, univariate analyses using Mann-Whitney

U tests were conducted to determine any significant differences in the number of flights in each distance and altitude category. This was compared between occupied and unoccupied nests in 1996 for model 1, and successful and unsuccessful occupied nests for model 2.

Trend Surface Analysis

To test for the presence of spatial autocorrelation, a univariate multiple stepwise regression test was conducted on the residuals of the orthogonalized *occupancy* and *young at 41 days of age* data, with five independent variables: 1) latitude; 2) longitude; 3) latitude*longitude; 4) latitude^2; and 5) longitude^2 (Davis 1986).

If spatial autocorrelation is discovered within the geographic situation of the Osprey nest sites being investigated, the independence of the chosen nest sites is compromised (Legendre & Fortin 1989). All ensuing statistical analysis has to remove or control for the autocorrelated data.

All tests (unless otherwise indicated) were performed at the $P < 0.05$ significance level.

RESULTS

METHOD 1 - Treatment Application Experiment

Reproductive Output Among Treatments

A summary of all reproductive parameters for each buffer-zone treatment as well as the overall values for 1995 and 1996 are found in Table 1. No significant differences were detected in the number of occupied nests among the four buffer-zone treatment types in either 1995 ($n = 53$, $KW = 2.56$, $df=3$, $P = 0.46$; Fig. 2) or 1996 ($n = 45$, $KW = 0.19$, $df = 3$, $P = 0.98$; Fig. 2). However, while a trend toward significance was indicated in 1995 for the difference in the number of eggs per occupied nest among the four treatments ($n = 42$, $KW = 6.7$, $df=3$, $P=0.08$; Fig. 3), the same was not true for 1996 ($n = 26$, $KW = 1.67$, $df = 3$, $P = 0.64$; Fig. 3). There were no statistical differences found for the number of hatchlings per active nest (hatchlings 1995: $n = 43$, $KW = 0.48$, $df=3$, $P=0.92$; Fig.4; hatchlings 1996: $n = 24$, $KW = 3.9$, $P = 0.27$; Fig. 4), and the number of young at 41 days of age per the number of hatchlings for either year (number of young at 41 days of age 1995: $n = 31$, $KW = 3.28$, $df=3$, $P=0.35$; Fig. 5; the number of young at 41 days of age 1996: $n = 16$, $KW = 0.48$, $df = 3$, $P = 0.92$; Fig. 5).

Reproductive output among all treatment types was also compared between 1995 and 1996. Table 2 outlines the differences among the four buffer-zone treatments between the two years for the number of occupied nests, the number of eggs, the number of hatchlings, and the number of young to reach 41 days of age. The results are mixed. In addition, all treatments were grouped for each phase of the breeding season, and differences between the two years were determined for the four reproductive phases. The number of occupied nests (*n* = 118, *U* = 2204.5, *df* = 1, *P* = 0.001; Fig. 2), the number of hatchlings per active nest (*n* = 76, *U* = 908.0, *df* = 1, *P* = 0.029; Fig. 4) and the number of young to reach 41 days of age per the number of hatchlings (*n* = 54, *U* = 521.0, *df* = 1, *P* = 0.002; Fig. 5) were all significantly different between the two years. Only the differences in the number of eggs per occupied nest was not significant (*n* = 78, *U* = 862.0, *df* = 1, *P* = 0.21; Fig. 3).

Orthogonalized Data

After orthogonalizing the data, further analysis was conducted on the residuals for the number of hatchlings and for the number of young to reach 41 days of age. There were no significant differences among the treatments at either the hatchling time period (*n* = 40, *F* = 0.49, *P* = 0.69) or the fledgling time period (*n* = 36, *F* = 1.26, *P* = 0.30) for 1995. The 1996 values were also not significantly different among the four buffer-zone treatments during the hatchling time period (*n* = 36, *F* = 1.95, *P* > 0.10), as well as for chicks that reached 41 days of age (*n* = 34, *F* = 1.16, *P* > 0.10).

Nest failures

Nest failure rates were compared among the four buffer-zone treatments within each year, as well as between years. The first comparison was on the failure rate of occupied nests to lay ≥ 1 egg. This was not significant among the four buffer-zones in 1995 (*n* = 45, *KW* = 3.50, *df* = 3, *P* = 0.32; Fig. 6), and 1996 (*n* = 37, *KW* = 3.61, *df* = 3, *P* = 0.31; Fig. 6).

There were no differences between 1995 and 1996 for occupied nests in which the female failed to lay ≥ 1 egg (Table 3). Overall, when all treatments were grouped there were no differences between the two years (Table 3).

The second comparison examined nests that had ≥ 1 egg but failed to have any hatchlings. There were no significant differences among the four buffer-zone treatments for both 1995 ($n = 43$, $KW = 6.86$, $df = 3$, $P = 0.08$; Fig. 7) and 1996 ($n = 33$, $KW = 2.57$, $df = 3$, $P = 0.46$; Fig. 7). While there was a trend toward significance in 1995, it was not supported in 1996. Thus, the 1995 value was either influenced by another environmental variable or was a statistical anomaly. Comparing hatching failures for each buffer-zone treatment between years showed a significant difference in the 0 km treatment group and a trend toward significance in the 7.4 km buffer-zone group (Table 3), with 1996 being lower than 1995. When grouping the values for all buffer-zone treatments for each year, there were no differences between the two years, although a trend toward significance was evident with a *p-value* < 0.10 (Table 3).

The third comparison investigated the nests that had ≥ 1 hatchling but failed to fledge any young. In 1995 no significant differences among the four buffer-zones were evident ($n = 31$, $KW = 3.28$, $df = 3$, $P = 0.35$; Fig. 8). The 1996 values were also not significantly different ($n = 23$, $KW = 1.58$, $df = 3$, $P = 0.66$; Fig. 8). However, when each treatment type was compared between 1995 and 1996, the 1.85 km and the 3.7 km buffer-zone treatments were significantly different and the 7.4 km treatment was near significant

(Table 3), with 1996 having a higher failure rate than 1995. There was also a significant difference between the two years when all treatments, within each year, were grouped and compared (Table 3). Again, the failure rate was higher in 1996.

The fourth comparison searched for significant differences among the four treatments of occupied nests that failed to have ≥ 1 young to reach 41 days of age. No differences were indicated for either 1995 ($n = 39$, $KW = 1.42$, $df = 3$, $P = 0.70$; Fig. 9) or 1996 ($n = 37$, $KW = 1.84$, $df = 3$, $P = 0.61$; Fig. 9). However, differences were found for the 0 km and 7.4 km buffer-zone treatment between the two years (Table 3), and a strong trend toward significance was indicated for the 1.85 km and 3.7 km treatments (Table 3). When all treatments were grouped and the overall values for both years were compared, there was a significant difference between the two years (Table 3). Like the previous comparison, 1996 had a higher failure rate than 1995.

A fifth and final comparison assessed the failure rate of active nests to have ≥ 1 young to reach 41 days of age. Like the other phases, no significant differences were found in 1995 ($n = 38$, $KW = 1.93$, $df = 3$, $P = 0.59$; Fig. 10), and 1996 ($n = 31$, $KW = 2.26$, $df = 3$, $P = 0.52$; Fig. 10). Table 3, however does indicate significant differences between the two years for the 0 km and the 7.4 km treatments. When all the treatment types were grouped, significant differences were again detected with 1996 having more failed nests than 1995 (Table 3).

Nest success

A similar analysis was conducted to compare the number of young to reach 41 days of age among occupied, active and successful nests. In 1995 there were no significant differences among the buffer-zone treatments for occupied ($n = 38$, $KW = 0.45$, $df = 3$, $P = 0.93$; Fig. 11), active ($n = 38$, $KW = 0.45$, $df = 3$, $P = 0.93$; Fig. 11), and successful nests ($n = 31$, $KW = 3.28$, $df = 3$, $P = 0.35$; Fig.11). The same was also found in 1996 for occupied ($n = 36$, $KW = 1.82$, $df = 3$, $P = 0.61$; Fig. 12), active ($n = 33$, $KW = 1.78$, $df = 3$, $P = 0.62$; Fig. 12) and successful nests ($n = 23$, $KW = 1.28$, $df = 3$, $P = 0.73$; Fig.12). Table 4 shows the comparisons among the treatments between years, and the results are mixed. However, when all treatments were grouped and an overall analysis was done between years, all three categories were significantly different (Table 4).

Nest reutilization

No significant differences were found among the four buffer-zone treatments for the return rate of Osprey to nest sites in 1996 that were occupied ($n = 37$, $KW = 1.05$, $P = 0.78$; Fig.13), active ($n = 33$, $KW = 1.55$, $P = 0.67$; Fig.13), and/or successful ($n = 29$, $KW = 3.43$, $P = 0.33$; Fig.13) in 1995.

Weather Effects

Daily mean temperature values for May (1995 = 6.6°C; 1996 = 4.0°C) were significantly different between years ($n = 62$, $df = 1$, $F = 12.6$, $P = 0.001$) with 1996 being cooler. July mean daily temperature values (1995 =16.1°C; 1996 = 13.6°C) were also significantly different between years ($n = 62$, $df = 1$, $F = 6.11$, $P = 0.016$), again with 1996 being cooler. The number of days in May that received snow (1995 = 5; 1996 = 11) indicated a trend toward significance ($n = 62$, $U = 387.5$, $df = 1$, $P = 0.08$) with a p-value < 0.10, suggesting that the month of May had significantly more days of snowfall in 1996 than in 1995. Rainfall values were not significantly different between years.

METHOD II - GIS Data

Impact of Jet Activity

Both Spearman and Pearson correlation analysis indicated that the altitude class 4 (500 - 999 feet AGL) and altitude class 1 (<100 feet AGL) variables had a significant relationship that differed from other altitude and distance flight variables. This relationship was believed to be spurious, suggesting impacts of low-level flying on Osprey reproduction that were not substantiated biologically nor supported by other analysis procedures. As a result of this spurious relationship, altitude class 4 was eliminated from further analyses.

Occupied nests in 1996 experienced more jet activity in 1995 for five of the seven flight variables than unoccupied nests in 1996 (Table 5). The subsequent logistic regression model correctly classified 86% of all occupied nests and 68% of non-occupied nests (Table 6). Distance class 1 (0 - 0.5 nm) and distance class 3 (1.0 - 2.0 nm) had a significant impact on nest occupancy. However, within distance class 1 there was no significant difference for the number of flights encountered by either occupied or unoccupied nests (Table 5). In fact, within distance classes 1 and 3, the reoccupied nest sites in 1996 received more flight activity than the non-occupied sites. Therefore, these values contradicted the logical assumption that increased low-level flying activity impacted negatively on Osprey reproductive output.

A second model was generated to predict fledging success of all occupied nest sites. After completing the stepwise analysis, no flight variable met the 0.15 tolerance level set by the model (Table 7). The univariate data reflects the model well, with *P-values* >0.30 for all flight categories (Table 8).

Trend surface analysis

No variable met the 0.15 significance level established for either nest occupancy or young at 41 days of age in both 1995 and 1996. Therefore, no spatial autocorrelation existed.

Discussion

Treatment Application Experiment

Nest Occupancy

Osprey nest occupancy in 1995 and 1996 did not differ significantly among the four buffer-zone treatment types. Many bird species are more prone to disturbance during the early part of the breeding season (Bunnel *et al.* 1981, Safina & Burger 1983, Awbrey & Bowles 1990), and therefore, more prone to nest abandonment. In addition, nest site tenacity during the early part of the breeding season is minimal (Fyfe & Olendorff 1976), but some species are known to be more tolerant than others. Dependent upon location, both Ferruginous Hawks (*Buteo regalis*) and Gyrfalcons readily abandon their nests early in the breeding season when subjected to disturbance, while Osprey are often considered to be tolerant of disturbance early in the breeding season (Fyfe & Olendorff 1976).

The ability of raptors to maintain their primary nest location is important, as a natural delay in nest initiation may compromise the long-term viability of that nest. A late nest initiation date is known to negatively affect clutch size, brood size, and number of young fledged per nest (Steeger & Ydenberg 1993). This decline in reproductive output for late nesting pairs is not associated with reduced food availability (Poole 1982, Steeger & Ydenberg 1993).

While there were no significant differences in reproductive output among the four buffer-zone treatments within any given year, there was a significant difference between 1995 and 1996, the latter being lower. Weather appeared to be largely responsible for this yearly difference. Weather is an important consideration when assessing the impacts of human disturbance on raptors (Schueck & Marzluff 1995). While pertinent weather data was not collected at each individual nest site throughout the study area, Environment Canada rainfall, snowfall and temperature values for May, June, July and August of 1995 and 1996 were analysed for the Happy Valley-Goose Bay region of Labrador. The analysis suggested that the Osprey nest initiation date in 1996 was delayed by adverse weather conditions in the month of May, with cooler temperatures and more days of snowfall. As a result, the weather may have affected reproductive output throughout the breeding season. Unfortunately, the exact initiation date was not determined for any nest within either year.

If unusual weather patterns are consistently bad in the early stages of the nesting season, it may delay nest initiation (Steeger & Ydenberg 1993). Cool temperatures and an abundance of ice may also keep the pair from establishing its nest (Wetmore & Gillespie 1976). Confounding these factors, Osprey are known to have a relatively high limit of thermoneutrality (Wasser 1986), defined as the temperature at which a bird must burn energy to stay warm. Poole (1989) reported observing Ospreys fleeing their nests to seek shelter inland during a freak April snowstorm in New England.

Inclement weather has also been linked to a decline in the foraging success of Osprey (Grubb 1977, Stinson *et al.* 1987, Machmer and Ydenberg 1990), which can indirectly affect reproductive success. If weather patterns are not suitable for obtaining prey at the beginning of the season, the pair may have diminished fitness, thus affecting productivity (Steeger & Ydenberg 1993). Also, unsuitable weather for hunting during the hatchling time period can adversely affect prey delivery rates to developing young. Poole (1982) observed slowed growth and decreased survival at nests during heavy storms. On Sanibel Island, Florida, in 1983, extremely high levels of rain resulted in high mortality of hatchlings yielding productivity rates which were half the average (Phillips *et al.* 1984).

Osprey nest occupancy was not significantly different among treatments within any one year, or between years. Therefore, low-level flying military aircraft appeared to have no influence on nest occupation. However, I cannot conclusively state that nest initiation was delayed in 1996. Nonetheless, it can be assumed that Osprey have no predilection to nests with larger buffer-zone treatments. Therefore, the remaining variables were analysed without nest-selection bias.

Reproductive Output

There were no indications that low-level flying aircraft had an impact on Osprey reproductive output. Correspondingly, Poole (1981) found no significant negative correlations between nest disturbance and any measure of nest production, despite a ten-fold increase in the number of visits by researchers. These two studies contradict other research by Swenson (1979) and Levenson & Koplin (1984) that link disturbance to reduced reproductive success . However, in these studies the disturbance was initiated after the Osprey had established themselves at their nests, which contrasts with this study. Within the low-level training area (LLTA) of Labrador and northeastern Québec, the training flights began in April, prior to the usual return of Osprey to their breeding grounds in the beginning of May. Thus, the disturbance of low-level flying occurred prior to Osprey arrival.

The effect of low-level flying jets on clutch size and hatchability was also assessed by this study. The data indicated a slight trend towards significance for the number of eggs in 1995. However, a series of Mann-Whitney U tests investigated the differences among the four buffer-zone treatment types. These tests indicated the difference to be between the 3.7 km treatment and the 7.4 km treatment and no others. Since this does not seem logical, this difference must be a function of small sample size and a statistical anomaly. Thus, it should not be attributed to low-level flying. This conclusion was substantiated by the 1996 data where no such trend was found. Little information is available on this aspect in the literature, but Fraser *et al.* (1985) attributed no embryo or hatchling mortalities to the use of fixed-wing aircraft for surveying Bald Eagle nests in Minnesota. However, other studies have linked disturbance with decreased hatching success (Safina & Burger 1983; Awbrey & Bowles 1990). Safina & Burger (1983) reported that the most likely cause of egg mortality in their colony of Black Skimmers (*Rynchops niger*) was heat stress and altered parental behaviour. Awbrey & Bowles (1990) extrapolated information from marine and shorebird literature to conclude that raptor eggs on a warm day would have to be exposed for 30 - 60 minutes to reach lethal temperatures, yet disturbance-induced flushes of raptors rarely result in prolonged absences from nests (Awbrey & Bowles 1990; Ellis *et al.* 1991; Trimper *et al.* 1998). Ellis *et al.* (1991) determined that of 279 adult responses due to military jet disturbance, only 23 were considered significant, and none were classified as severe. A disturbance response was classified as 'significant' if the disturbance (i.e. military jet) interrupted high priority behaviours (i.e. incubation), and 'severe' when the disturbance threatened the success of the reproductive effort. In fact, Trimper *et al.* (1998) did not witness any startle response or rapid nest departures during 240 hours of nest observation on Ospreys nesting in the same region as this study during military flights in Labrador.

Overall reproductive output for this region was comparable to other Osprey studies (Poole 1981, Levenson & Koplin 1984, Hagan & Walters 1990, Steeger *et al.* 1992). Poole (1981) determined the number of young fledged per active nest while subjecting the Osprey to increased levels of disturbance. There were obvious annual fluctuations within his study. Output ranged from approximately 0.7 young per active nest to as high as 1.9 young per active nest in different years. These values are consistent with the data from this study. During 1995, 38 nests averaged 1.7 young per active nest, but during 1996 the value dropped to 0.8 young per active nest for 33 nests (see Table 1). However, the reduced reproductive output in 1996 may not detrimentally impact population levels. Spitzer *et al.* (1983) calculated the "break-even" value to be 0.8 young per active nest for an Osprey population in New York state. The output for my study was at or above this level even when subjected to adverse weather conditions and increased military jet activity.

For both nest failure and nest success rates, the sample sizes within the buffer-zone treatments varied, but were relatively high compared to other studies of aircraft effects on raptors (Windsor 1977, Ellis 1981). However, Awbrey & Bowles (1990) assessed the Windsor (1977) and Ellis (1981) studies, recognizing the small sample size, and re-examined the data for both of them. In both studies Awbrey & Bowles determined a weak negative correlation between nest success and disturbance, and that the tendency of the raptor to flush due to disturbance was the best predictor of reproductive loss. My data indicated no direct connection between nest success and disturbance, which is further supported by the lack of behavioural response by Labrador Osprey when subjected to controlled low-level flying aircraft (Trimper *et al.* 1998).

Nest Reoccupancy

Birds in this study were not marked and/nor identified in any way. Nest site reutilization was determined under the assumption that Osprey are strongly philopatric and fidelic (Newton 1979, Poole 1989). Although Osprey often have secondary or even tertiary nests on their nesting territories (Poole 1989), they are usually located within a few hundred metres of each other (P. Thomas, *pers. obs.*). If either of these nests were occupied in the 1996 season, the nest site was classified as reoccupied.

Nest reutilization was similar among the four buffer-zone treatment types in 1996 for occupied, active and successful 1995 nests, consistent with Ellis *et al.* (1991) who examined nest site reoccupancy by the same species the year after being subjected to low-level jet activity. They studied eight raptor species whose range of disturbances during the previous year was from one to 32 jet flights past a nest. Of the 20 nest sites, 19 were reoccupied the following year. This is exceedingly high for any population and an argument can be made that some of these birds could be young individuals returning to their natal site to breed (Ellis *et al.* 1991). However, in some raptor species, nest site fidelity is stronger than natal site fidelity (Newton 1979). The Osprey data for my study were consistent with fidelity values for Richardson's Merlins (*F. columbarius richardsonii*). Of 12 marked adult male Merlins captured in Alberta, nine of them were established on territories where they had bred previously (Newton 1979). Consequently, the majority of Osprey nests in 1996 were likely reoccupied by the same pair from the previous year.

GIS Flight Track Record Analysis

In the flight track records provided by DND, there is a degree of error associated with determining the exact coordinates that correspond to the true route followed by each military jet (Department of National Defence 1994). The source of error is dependent upon nest location, topography, type of aircraft, GIS flight track plotting, and the pilot/navigator of the jet. However, due to the number of records provided and the number of nests sampled, these flight track records should be representative of the influence of low-level flying on any given Osprey nest.

The logistic regression models indicated no discernible relationship between the frequency of flights at any distance or altitude category past a nest with the reproductive output of that nest. However, two distance flight variables from 1995 were determined to influence nest occupancy in 1996 (Table 6), but the mean number of flights was much higher for occupied nests than for unoccupied nests for both distance variables (Table 5). Therefore, it would be difficult to conclude that low-level flying adversely affected reproduction. The disparity between the number of flights for occupied and unoccupied nest sites may be influenced by habitat choice. The better Osprey habitat of the region is located in river valleys with higher trees, protection from adverse weather conditions, and long stretches of open water that becomes ice-free faster than lakes and ponds. Correspondingly, river valleys are more frequently utilized by military jet aircraft to practice low-level flying manoeuvres. As a result, further investigation may be warranted to pursue an Osprey habitat selection study and to assess the impacts of jet aircraft within these various habitat types.

The results of this study are consistent with recent research by Trimper *et al.* (1998), who concluded that little significant impact on Osprey behaviour could be attributed to low-level flying. Grubb & Bowerman (1997) also found that low-level jet aircraft within 200 m of a Bald Eagle nest caused relatively low eagle response and was in fact less disturbing than other aircraft types. Finally, Smith *et al.* (1988) (as cited in Grubb & Bowerman 1997) determined that the responses of 14 raptor species to low-level military jets was brief and insignificant.

Conclusions and Management Implications

No significant impacts of low-level flying military aircraft on Osprey reproductive output were detected within any one given year. However, since no power analyses were conducted on the data, I cannot dispense with the possibility of Type II error. Nonetheless, it was evident that this population of Osprey was prone to annual fluctuations in reproductive success. This yearly variation may have been related to adverse weather affects.

The noted disparity between the number of flights for occupied/unoccupied and successful/unsuccessful nests may indicate a need for further study of Osprey habitat choice in Labrador. The region of the LLTA with the majority of low-level flying activity may also correspond with the optimal Osprey habitat type. Assessing the impact of low-level jet flights on Osprey habitat selection would add to our understanding of how low-level flying may affect this species.

Habituation of birds to disturbance has been demonstrated in several studies, with a decrease in avian response to disturbance over time as the frequency of the disturbance increases (Knight & Temple 1986; Awbrey & Bowles 1990; Grubb & Bowerman 1997; Conomy *et al.* 1998). The ability of raptors to habituate to disturbance has also been documented in several studies (Andersen *et al.* 1989; Poole 1989; Awbrey & Bowles 1990; Grubb & Bowerman 1997) and considering the disturbance-tolerant nature of Osprey (Fyfe & Olendorff 1976, Poole 1989) it is logical to assume that some level of habituation may be occurring. Low-level aircraft have been flying in this region of Labrador since 1981, and therefore Osprey have had ample opportunity to adapt to the high level of activity. With this in mind, caution should be taken when applying these findings to general management plans, mitigation procedures and to other raptor species. A similar study conducted on Labrador Osprey subjected to low-level flying for the first time, comparing their reproductive rates to those that have been exposed over the long term, would be useful.

Literature Cited

AHD. 1985. *The American Heritage Dictionary*. Houghton Mifflin Company, Boston. 1568pp.

Altman, R. L. & R.D. Gano, Jr. 1984. Least Terns nest alongside Harrier Jet pad. *J. Field Ornith.* 55: 108-109

Andersen, D.E., O.J. Rongstad & W.R. Mytton. 1989. Response of nesting Red-Tailed Hawks to helicopter overflights. *Condor* 91:296-299

Austin, Jr., O.L., W.B. Robertson, Jr. & G.E. Woolfenden. 1972. Mass hatching failure in Dry Tortugas Sooty Terns (*Sterna fuscata*). Abstract. pp.627. In: *Proceedings of the XVth International Ornithological Congress*, The Hague, Netherlands, 30 August - 5 September, E.J. Brill, Leiden, Netherlands.

Awbrey, F.T. & A.E. Bowles. 1990. *The effects of aircraft noise and sonic booms on raptors: A preliminary model and a synthesis of the literature on disturbance* . (NSBIT Technical Operating Report #12): Noise and Sonic Boom Impact Technology, Advanced Development Program Office, Wright-Patterson AFB, Ohio. 158pp.

Beebe, F.J. 1974. Falconiformes of British Columbia. *Brit. Col. Proc. Mus. Occ. Papers* 69: 1176-1187

Bowles, A.E. 1995. Responses of Wildlife to Noise. pp.109-156. In: R.L. Knight & K.J. Gutzwiller (*eds.*) *Wildlife and Recreationists: Coexistence Through Management and Research*. Island Press, Washington, D.C.

Bowles, A.E., L. McClenaghan, J.K. Francine, S. Wisely, R. Golightly & R. Kull. 1993. Effects of aircraft noise on the predator-prey ecology of the Kit Fox (*Vulpes macrotis*) and its small prey. *Proceedings of the 6th Annual International Congress on Noise as a Public Health Problem. Actes INRETS* 34: 462-469m

Bunnel, F.L., D. Dunbar, L. Koza & G. Ryder. 1981. Effects of disturbance on the productivity and survivorship of White Pelicans in British Columbia. *Colonial Waterbirds* 4: 2-11

Burger, J. 1981. Behavioural responses of Herring Gulls (*Larus argentatus*) to aircraft noise. *Envir. Pollut.* 24: 177-184

Cannon, W.B. 1929. *Bodily Changes in Pain, Hunger, Fear, and Rage*. Appleton Press, New York. 404pp.

Cohen, S. 1980. After effects of stress on human performance and social behaviour: a review of research and theory. *Psychol. Bull.* 88: 82-108

Conomy, J.T., J.A. Collaza, J.A. Dubovsky & W.J. Fleming. 1998. Dabbling duck behaviour and activity in coastal North Carolina. *J. Wildl. Manage.* 62: 1127-1134

Corwin, J.T. & D.A. Cotanche. 1988. Regeneration of sensory hair cells after acoustic trauma. *Science* 240: 1772-1774

Davis, J.C. 1986. *Statistics and Data Analysis in Geology*. John Wiley & Sons, New York. 646pp.

Delaney, D.K., T.G. Grubb & L.L. Pater. 1997. *Effects of helicopter noise on nesting Mexican Spotted Owls*. Report to U.S. Air Force 49 CES/CEV, Holloman AFB, Project Order No. CE P.O. 95-4. 49pp.

Department of National Defence (DND). 1994. *EIS: Military Flight Training - an Environmental Impact Statement on Military Flying Activities in Labrador and Quebec*. Project management Office Goose Bay, National Defence Headquarters, Ottawa, Ontario

Diniz-Filho, J.A.F. & O. Malaspina. 1995. Evolution and population structure of Africanized honey bees in Brazil: evidence from spatial analysis of morphometric data. *Evolution* 49: 1172-1179

Dufour, P.A. 1980. *Effects of Noise on Wildlife and Other Animals: Review of Research Since 1971*. Report for the U.S. Environmental Protection Agency. Report # EPA-550/9-80-10. 97pp.

Dunnet, G.M. 1977. Observations on the effects of low-flying aircraft at seabird colonies on the coast of Aberdeenshire, Scotland. *Biol. Conserv.* 12: 55-63

Eames, B.L., R.P. Hamernik, D. Henderson & A. Feldman. 1975. The role of the middle ear in acoustic trauma from impulses. *Laryngoscope* 85: 1582-1592

Eaton, G.W., P.A. Bowen & P.A. Jolliffe. 1986. Two-dimensional partitioning of yield variation. *HortScience* 21: 1052-1053

Ellis, D.H. 1981. *Responses of raptorial birds to low-level military jets and sonic booms*. Results of the 1980-1981 Joint USAF-USFWS Study. NTIS #ADA108-778. 59pp.

Ellis, D.H., C.H. Ellis & D.P. Mindell. 1991. Raptor responses to low-level jet aircraft and sonic booms. *Envir. Pollut.* 74: 53-83

Ewins, P.J. & M.J.R. Miller. 1995. Measurement error in aerial surveys of Osprey productivity. *J. Wildl. Manage.* 59: 333-338

Fraser J. D., L.D. Frenzel & J.E. Mathisen. 1985. The impact of human activities on breeding Bald Eagles in north-central Minnesota. *J. Wild. Manage.* 49: 585-592

Fyfe, R.W. & R.R. Olendorff. 1976. *Minimizing the dangers of nesting studies to raptors and other sensitive species*. Occas.Paper. No.23. Can. Wildl. Serv. Ottawa, Ontario. 16pp.

Gabrielsen, G.W. & E.N. Smith. 1985. Physiological responses associated with feigned death in the American Opossum. *Acta Physiologica Scandinavia* 123: 393-398

Gao, W.Y., D.L. Ding, X.Y. Zheng, F.M. Ruan & Y.J. Liu. 1992. A comparison of changes in the stereocilia between temporary and permanent hearing losses in acoustic trauma. *Hearing Research* 62: 27-41

Glass, D.C. & J.E. Singer 1972. *Urban stress: experiments on noise and social stressors*. Academic Press, New York. 182pp.

Grubb, Jr, T.G. 1977. Weather-dependent foraging in Ospreys. *Auk* 94: 146-149

Grubb, T.G. & W.W. Bowerman. 1997. Variations in breeding Bald Eagle responses to jets, light planes and helicopters. *J. Raptor Res.* 31: 213-222

Hagan III, J.M. & J.R. Walters. 1990. Foraging behaviour, reproductive success, and colonial nesting in Ospreys. *Auk* 107: 506-521

Harrington, F.H. & A.M. Veitch. 1992. Calving success of Woodland Caribou exposed to low-level jet fighter overflights. *Arctic* 45: 213-218

Henny, C.J. 1983. Distribution and Abundance of Nesting Ospreys in the United States. pp.175-185. In: D.M. Bird (*ed.*) *Biology and management of bald eagles and ospreys*. Harpell Press, Ste-Anne-de-Bellevue, Québec.

Hosmer, Jr, D.W. & S. Lemeshow. 1989. *Applied Logistic Regression*. John Wiley & Sons, New York. 307pp.

Jacques-Whitford Environment. 1993. *1993 Raptor Monitoring Program Goose Bay EIS.* Jacques-Whitford Environment, St.John's, NF. 45pp. + Appendices

Jacques-Whitford Environment. 1994. *1994 Avoidance monitoring program: raptor/Harlequin Duck.* Goose Bay EIS. Jacques-Whitford Environment, St. John's, NF. 36pp. + Appendices.

Jacques-Whitford Environment. 1995. *1995 Avoidance monitoring program: raptor/Harlequin Duck.* Goose Bay EIS. Jacques-Whitford Environment, St. John's, NF.

Jensen, K.C. 1990. Responses of molting Pacific black brant to experimental aircraft disturbance in the Tekshupek Lake special area, Alaska. Ph.D. Diss., Texas A&M University. 72pp.

Johnsgard, P.A. 1990. *Hawks, Eagles & Falcons of North America: Biology and Natural History*. Smithsonian Institution Press, Washington, D.C. 403pp.

Jorgensen, E.E., S. Demarais, S.M. Sell & S. P. Lerich. 1998. Modeling habitat suitability for small mammals in Chihuahuan Desert foothills of New Mexico. *J. Wildl. Manage.* 62: 989-996

Knight, R.L. & S.A. Temple. 1986. Why does intensity of avian nest defense increase during the nesting cycle? *Auk* 103: 318-327

Kull, R.C. & A.D. Fisher. 1986. *Supersonic and subsonic aircraft noise effects on animals: a literature survey; final report. 15 Oct 1985 - 15 October 1986* (AAMRL-TR-87-032): Harry G. Armstrong Aerospace Medical Research Lab., Wright-Patterson AFB, Ohio. 51pp.

Kushlan, J.A. 1979. Effects of helicopter censuses on wading bird colonies. *J. Wildl. Manage.* 43: 756-760

Larkin, R.P. In prep. *Effects of military noise on wildlife: a literature review*. Center for Wildlife Ecology, Illinois Natural History Survey. 83pp.

Legendre, P. 1993. Spatial autocorrelation: trouble or new paradigm? *Ecology* 74: 1659-1673

Legendre, P. & M.J. Fortin. 1989. Spatial pattern and ecological analysis. *Vegetatio* 80: 107-138

Levenson, H. & J.R. Koplin. 1984. Effects of human activity on productivity of nesting Ospreys. *J. Wildl. Manage.* 48: 1374-1377

Machmer, M.M. & R.C. Ydenberg. 1990. Weather and Osprey foraging energetics. *Can. J. Zool.* 68: 40-43

Marler, P., M. Konishi, A. Lutjin & M.S. Wasser. 1973. Effects of continuous noise on avian hearing and development. *Proc. Nat. Acad. Sci.* 70: 1393-1396

Melo, J. 1975. Logging around an osprey nest site. *J. Forest.* 73: 724-725

Myberg, Jr., A.A. 1980. Ocean noise and the behavior or marine animals relationships and implications. pp. 461-491. In: F.P. Diemer, F.J. Vernberg & D.Z. Mirkes (*eds.*) *Advanced Concepts in Ocean Measurements for Marine Biology*. University of South Carolina Press, Columbia, South Carolina

Narins, P.M. 1982. Effects of masking noise on evoked calling in the Puerto Rican coqui (*Anura: Leptodactylidae*). *J. Comp. Physiol.* (Series A) 147: 439-446

Newton, I. 1979. *Population Ecology of Raptors*. Buteo Books, Vermillion, South Dakota. 399 pp.

Phillips, S.R., M.A. Westall & P.W. Zajicek. 1984. The winter of 1983: poor productivity for Ospreys on Sanibel Island, Florida. pp.61-66. In: M.A. Westall, *(ed.) Proc. Southeastern U.S. and Caribbean Osprey symposium*. Int. Osprey Foundation, Sanibel Island, Florida

Poole, A.F. 1981. The effects of human disturbance on Osprey reproductive success. *Colonial Waterbirds* 4: 20-27

Poole, A.F. 1982. Brood reduction in temperate and sub-tropical Ospreys. *Oecologia* 53: 111-119

Poole, A.F. 1989. *Ospreys: A Natural and Unnatural History*. Cambridge University Press, Cambridge. 246 pp.

Rice, W.R. 1982. Acoustical location of prey by the Marsh Hawk: adaptation to concealed prey. *Auk* 99: 403-413

Safina, C. & J. Burger. 1983. Effects of human disturbance on reproductive success in the Black Skimmer. *Condor* 85: 164-171

Saunders, J.C., Y.E. Cohen & Y.M. Szymko. 1991. The structural and functional consequences of acoustic injury in the cochlea and the peripheral auditory system: a five year update. *J. Acoust. Soc. Amer.* 90: 136-146

Schueck, L.S. & J.M. Marzluff. 1995. Influence of weather on conclusions about effects of human activities on raptors. *J. Wildl. Manage.* 59: 674-682

Shaw, E.A.G. 1978. Symposium on the effects of noise on wildlife. pp. 1-5. In: J.L. Fletcher & R.G. Busnel (*eds.*) *Effects of Noise on Wildlife*. Academic Press, New York

Smith, D.G., D.H. Ellis & T.H. Johnson. 1988. Raptors and aircraft. pp. 360-367. In: R.L. Glinski, B. Giron-Pendleton, M.B. Moss, M.N. LeFranc, Jr., B.A. Millsap & S.W. Hoffman (*eds.*) *Proceedings of the southwest raptor management symposium and workshop*. Nat. Wildl. Fed., Washington, DC USA

Sokal, R.R. & F.J. Rohlf. 1995. *Biometry. Third Edition*. W.H. Freeman and Company, New York. 887pp.

Spaner, D., D.E. Mather & R.A.I. Brathwaite. 1996. Yield and Quality Attributes of Rainfed Green Immature Corn in Trinidad. *HortTechnology* 6: 131-134

Spitzer, P.R., A.F. Poole & M.S. Schiebel. 1983. Initial population recovery of breeding ospreys in the region between New York City and Boston. pp.231-241 In: D.M. Bird (*ed.*) *Biology and management of bald eagles and ospreys*. Harpell Press, Ste-Anne-de-Bellevue, Québec

Stalmaster, M.V. & J.R. Newman. 1978. Behavioral responses of wintering Bald Eagles to human activity. *J. Wildl. Manage.* 42: 506-513

Steeger, C. & R.C. Ydenberg. 1993. Clutch size and initiation date of ospreys: natural patterns and the effect of a natural delay. *Can. J. Zool.* 71: 2141-2146

Steeger, C., H. Esselink & R.C. Ydenberg. 1992. Comparative feeding ecology and reproductive performance of ospreys in different habitats of southeastern British Columbia. *Can. J. Zool.* 70: 470-475

Steenhof, K. 1987. Assessing raptor reproductive success and productivity. pp.157-170. In: B.A. Giron Pendleton, B.A. Millsap, K.W. Cline and D.M. Bird (*eds.*) *Raptor Management Techniques Manual.* National Wildlife Federation, Washington, D.C.

Stephenson, T.R., M.R. Vaughn & D.E. Andersen. 1996. Mule Deer movements in response to military activity in southeast Colorado. *J. Wildl. Manage.* 60: 777-787

Stinson, C.H. 1977. Familial longevity in Ospreys. *Bird-Banding* 48: 72-73

Stinson, C.H., J. Lauthner & R.T. Ray. 1987. The effect of weather conditions on the behavior of Ospreys in northwestern Washington. *Can. J. Zool.* 65: 2116-2118

Stotts, V.D. & C.J. Henny. 1975. The age at first flight for young American Osprey. *Wilson Bull.* 87: 277-278

Swenson, J.E. 1979. Factors affecting status and reproduction of Ospreys in Yellowstone National Park. *J.Wildl.Manage.* 43:595-601

Thompson, G.L. 1991. A note on the rank transform for interactions. *Biometrika* 78: 697-701

Trimper, P.G., N.M. Standen, L.M. Nye, D. Lemon, T.E. Chubbs & G.W. Humphries. 1998. Effects of low-level jet aircraft on the behaviour of nesting osprey. *J. Appl. Ecol.* 35: 122-130

Vertes, D., A. Axelsson, C. Hornstrand & P. Nilsson. 1984. The effect of impulse noise on cochlear vessels. *Arch. Otolaryngol.* 110: 111-115

Ward, D.H. & R.A. Stehn. 1989. *Response of brant and other geese to aircraft disturbance at Izembek Lagoon, Alaska.* Final Report by U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center for the U.S. Minerals Management Service. 241 pp.

Wartenberg, Daniel. 1985. Canonical trend surface analysis: a method for describing geographic patterns. *Syst. Zool.* 34: 259-279

Wasser, J.S. 1986. The relationship of energetics of falconiform birds to body mass and climate. *Condor* 88: 57-62

Watson, J.W. 1993. Responses of nesting Bald Eagles to helicopter surveys. *Wildl. Soc. Bull.* 21: 171-178

Weisenberger, M.E., P.R. Krausman & M.C. Wallace. 1996. Effects of simulated aircraft noise on heart rate and behavior of desert ungulates. *J. Wildl. Manage.* 60: 52-61

Welty, J.C. & L. Baptista. 1988. *The Life of Birds. 4th Edition.* Saunders College Publishing, New York. 581pp.

Wetmore, S.T. & D.I. Gillespie. 1976. Osprey and Bald Eagle populations in Labrador and northeastern Quebec, 1969-1973. *Can. Field-Nat.* 90: 330-337

White, C.M. & T.L. Thurow. 1985. Reproduction of Ferruginous Hawks exposed to controlled disturbance. *Condor* 87: 14-22

Windsor, J. 1977. *The response of Peregrine Falcons (Falco peregrinus) to aircraft and human disturbance.* Canadian Wildlife Service MacKenzie Valley Pipeline Investigations. Report by Canadian Wildlife Service for the Environmental Social Program, Ottawa, Government of Canada. 87pp.

Workman, G.W. & T.D. Bunch. 1991. *Sonic boom/animal stress project report on elk (Cervus canadensis).* Report by Utah State University for U.S. Air Force. 87pp.

Ylikoski, J. 1987. Impulse noise induced damage in the vestibular end organs of the guinea pig: a light microscopic study. *Acta Otolaryngol.* 103: 415-421

Zajtchuk, J.T. & Y.Y. Phillips. 1989. *Effects of blast overpressure on the ear.* Paper presented to Walter Reed Army Institute, Washington, DC.

Zar, J.H. 1984. *Biostatistical Analysis. Second Edition.* Prentice-Hall, Inc., Englewood Cliffs. 718 pp.

Table 1. Mean ± SE, and sample total (n) for occupied nests (%), number of eggs, number of hatchlings, and number of young to reach 41 days of age per occupied, active, and successful Osprey nests in Labrador among the four buffer-zone treatment types, as well as an overall value for all treatments combined.

Reproductive Output	**Treatment 1 0 km**		**Treatment 2 1.85 km**		**Treatment 3 3.7 km**		**Treatment 4 7.4 km**		**All Treatments Combined**	
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Nest Occupancy (%)	85% (20)	55.9% (34)	80% (10)	60% (10)	76.9% (13)	58.3% (12)	100% (10)	55.6% (9)	84.9% (53)	56.9% (65)
Number of Eggs	2.7±0.13 (14)	2.3±0.20 (19)	2.9±0.13 (8)	2.3±0.49 (6)	2.1±0.31 (10)	1.8±0.60 (6)	2.8±0.13 (10)	2.8±0.2 (5)	2.6±0.1 (42)	2.3±0.17 (36)
Number of Hatchlings	2.2±0.18 (17)	1.4±0.26 (18)	1.8±0.53 (8)	1.8±0.58 (5)	1.9±0.39 (9)	1.8±0.49 (5)	1.9±0.31 (9)	0.6±0.4 (5)	2.0±0.15 (43)	1.4±0.2 (33)
Young at 41 Days per Occupied Nests [1]	1.8±0.30 (12)	0.9±0.26 (19)	1.6±0.50 (8)	0.6±0.60 (6)	1.5±0.37 (10)	0.7±0.42 (6)	1.8±0.31 (8)	0.2±0.20 (5)	1.7±0.18 (38)	0.7±0.18 (36)
Young at 41 Days per Active Nests [2]	1.8±0.30 (12)	0.9±0.27 (18)	1.6±0.50 (8)	0.6±0.60 (5)	1.5±0.37 (10)	0.8±0.49 (5)	1.8±0.31 (8)	0.2±0.20 (5)	1.7±0.18 (38)	0.8±0.19 (33)
Young at 41 Days per Successful Nests [3]	1.8±0.30 (12)	1.3±0.33 (13)	2.6±0.25 (5)	0.8±0.75 (4)	2.1±0.26 (7)	1.0±0.58 (4)	2.0±0.22 (7)	0.5±0.50 (2)	2.1±0.15 (31)	1.1±0.24 (23)

1 - Occupied nest is defined as having two adult birds observed demonstrating territorial or breeding behaviours

2 - Active nest is defined as having ≥ 1 egg

3 - Successful nest is defined as having ≥ 1 young to reach 41 days of age

Table 2. Sample total, Mann-Whitney U statistic (with 1 degree of freedom), and probability for the differences in reproductive success for occupied nests, and for the number of eggs, hatchlings, and young to reach 41 days of age among the four treatment types applied to the Labrador Osprey. Comparisons are made between 1995 and 1996.

Comparisons Between 1995 & 1996	**Treatment 1 0 km**			**Treatment 2 1.85 km**			**Treatment 3 3.7 km**			**Treatment 4 7.4 km**		
	n	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*
Occupied Nest	54	439.0	0.03	20	60.0	0.34	25	92.5	0.33	19	65.0	0.02
Egg Number	33	164.0	0.19	14	29.5	0.32	16	31.0	0.91	15	25.0	1.00
Hatchling Number	35	210.5	0.045	13	20.0	1.00	14	24.5	0.77	14	37.5	0.035
Young at 41 Days	25	97.5	0.26	9	16.5	0.09	11	22.0	0.097	9	13.5	0.036

Table 3. Sample total, Mann-Whitney U statistic (with 1 degree of freedom), and probability for the differences in Osprey nest failure rates in Labrador for each of the four time periods in the breeding season, as well as for occupied and active nest sites. Comparisons are made between 1995 and 1996 for each treatment type, and all treatments combined.

Comparisons Between 1995 & 1996	Treatment 1 0 km			Treatment 2 1.85 km			Treatment 3 3.7 km			Treatment 4 7.4 km			All Treatments Combined		
	n	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*
Reproductive Phase 1[a]	36	153.0	0.34	14	20.0	0.25	17	28.5	0.34	15	25.0	1.0	82	761.0	0.11
Reproductive Phase 2[b]	35	110.5	0.02	13	23.5	0.52	14	23.0	0.93	14	11.5	0.06	76	593.5	0.09
Reproductive Phase 3[c]	25	61.0	0.24	9	2.5	0.03	11	7.0	0.05	9	3.5	0.06	54	209.0	<0.01
Reproductive Phase 4[d]	32	80.5	0.06	14	13.0	0.10	17	20.5	0.10	13	6.5	0.02	76	419.0	<0.01
Reproductive Phase 5[e]	28	64.0	0.07	13	11.5	0.15	14	14.0	0.17	14	7.0	0.01	69	352.0	0.001

a - The failure of occupied nests to lay ≥ 1 egg

b - The failure of nests with ≥ 1 egg to have ≥ 1 hatchling

c - The failure of nests with ≥ 1 hatchling to have ≥ 1 young to reach 41 days of age

d - The failure of occupied nests to have ≥ 1 young to reach 41 days of age

e - The failure of nests with ≥ 1 egg to have ≥ 1 young to reach 41 days of age

Table 4. Sample total (*n*), Mann-Whitney U statistic (with 1 degree of freedom), and probability for the differences in the number of Osprey young to reach 41 days of age in occupied, active, and successful nests in Labrador. Differences are compared among four buffer-zone treatment types, as well as an overall difference between 1995 and 1996 nests.

Comparisons of Treatments Between 1995 & 1996	**Occupied Nests**			**Active Nests**			**Successful Nests**		
	n	*U*	*p*	*n*	*U*	*p*	*n*	*U*	*p*
Treatment - 0 km	31	163.5	0.032	30	152.5	0.045	25	97.5	0.26
Treatment - 1.85 km	14	34	0.147	13	27.5	0.224	9	16.5	0.089
Treatment - 3.7 km	16	42.0	0.162	15	33.5	0.265	11	22.0	0.097
Treatment - 7.4 km	13	36.5	0.010	13	36.5	0.010	9	13.5	0.036
All Treatment Types Combined	74	995.0	< 0.001	71	894.5	0.001	54	521.0	< 0.002

Table 5. Means, SE, minimum values, maximum values, and test statistics (Mann Whitney U-test with 1 degree of freedom) for the meristic values of the cumulative totals of all jet flights at all distance and altitude categories in 1995 and the effect on Osprey nest occupancy in 1996 in Labrador.

Jet Flight Category	Occupied Nests - 1996					Non-Occupied Nests - 1996					Test Statistic	
1995 Values	n	$\bar{x}$	SE	Min	Max	n	$\bar{x}$	SE	Min	Max	*U*	*P*
Distance Category[1]												
0 - 0.5 nm	21	39.3	13.5	0	195	9	10.9	5.0	0	47	70.0	0.27
0.5 - 1.0 nm	21	30.2	11.2	0	234	9	7.3	2.1	0	16	62.5	0.15
1.0 - 2.0 nm	21	78.1	27.4	1	564	9	13.2	3.8	1	38	45.5	0.03
2.0 - 3.0 nm	21	82.1	2602	3	521	9	25.2	5.4	1	59	57.5	0.09
Altitude Category[2]												
<100 ft	21	169	57.1	1	1029	9	30.6	12.0	1	90	42.5	0.02
100 - 249 ft	21	186.2	57.2	11	867	9	35.8	11.1	2	106	47.0	0.03
250 - 499 ft	21	109.7	42.5	0	644	9	13.7	4.9	0	40	46.5	0.03

1 - Horizontal distance of flights from a nest given in nautical miles (nm). Imperial units of measurement are used to coincide with standard military measurement of distance (0 - 0.93 km; 0.93 - 1.85 km; 1.85 - 3.7 km; and 3.7 - 5.56 km, respectively)

2 - Vertical distance above ground level (AGL) of flights past a nest given in feet (ft). Imperial units of measurement are used to coincide with standard military measurement of altitude (< 30.5 m; 30.5 - 75.5 m; 76 - 152 m; and 152.5 - 304.5 m, respectively)

Table 6. Logistic regression parameter estimates for predicting Osprey nest occupancy in Labrador for 1996 using the cumulative totals of all distance and altitude flight categories in 1995.

Categorical Model Variables	**Complete Model**[a]				**Subset Model**			
	Coeff.	SE	Odds Ratio	P	Coeff.	SE	Odds Ratio	P
Constant	-1.15	0.99	--	0.25	-1.04	0.83	--	0.21
Dist. 0 - 0.5 nm[b]	-0.47	0.17	0.62	0.006	-0.32	0.17	0.72	0.05
Dist. 0.5 - 1.0 nm[b]	0.27	0.20	1.30	0.18	--	--	--	--
Dist. 1.0 - 2.0 nm[b]	0.33	0.14	1.39	0.02	0.24	0.12	1.28	0.04
Dist. 2.0 - 3.0 nm[b]	-0.21	0.10	0.81	0.03	-0.07	0.05	0.93	0.14
Alt. <100 ft[c]	0.06	0.05	1.06	0.25	--	--	--	--
Alt. 100 - 249 ft[c]	-0.13	0.08	0.88	0.10	--	--	--	--
Alt. 250 - 499 ft[c]	0.50	0.23	1.64	0.03	0.164	0.11	1.18	0.13

a - n = 30; Log-Likelihood = 19.73; Hosmer-Lemeshow lack-of-fit Test (χ^2_8 = 3.29, P = 0.65)

b - Horizontal distance of flights from a nest given in nautical miles (nm). Imperial units of measurement are used to coincide with standard military measurements of distance (0 - 0.93 km; 0.93 - 1.85 km; 1.85 - 3.7 km; and 3.7 - 5.56 km, respectively).

c - Vertical distance above ground level (AGL) of flights past a nest given in feet (ft). Imperial units of measurement are used to coincide with standard military measurement of altitude (< 30.5 m; 30.5 - 75.5 m; 76 - 152 m; and 152.5 - 304.5 m, respectively)

Table 7. Logistic regression parameter estimates for predicting the success of occupied Osprey nests in Labrador to fledge ≥ 1 young using the cumulative totals of all distance and altitude flight categories.

Categorical Model Variables	Complete Model[a]				Subset Model			
	Coeff.	SE	Odds Ratio	P	Coeff.	SE	Odds Ratio	P
Constant	-1.1	0.55	--	0.05	-0.82	0.36	--	0.02
Dist. 0 - 0.5 nm[b]	-0.01	0.02	0.99	0.59	--	--	--	--
Dist. 0.5 - 1.0 nm[b]	0.02	0.01	1.02	0.14	--	--	--	--
Dist. 1.0 - 2.0 nm[b]	<0.001	0.01	1.0	0.97	--	--	--	--
Dist. 2.0 - 3.0 nm[b]	-0.008	0.004	0.99	0.04	--	--	--	--
Alt. <100 ft[c]	-0.001	0.003	0.99	0.86	--	--	--	--
Alt. 100 - 249 ft[c]	0.02	0.01	1.02	0.09	--	--	--	--
Alt. 250 - 499 ft[c]	-0.02	0.01	0.98	0.14	--	--	--	--
Year[d]	1.2	0.59	3.3	0.04	1.47	0.51	4.36	0.004

a - n = 71; Log-Likelihood = 18.0; Hosmer-Lemeshow lack-of-fit Test (χ^2_8= 9.90, P = 0.27)

b - Horizontal distance of flights from a nest given in nautical miles (nm). Imperial units of measurement are used to coincide with standard military measurements of distance (0 - 0.93 km; 0.93 - 1.85 km; 1.85 - 3.7 km; and 3.7 - 5.56 km, respectively).

c - Vertical distance above ground level (AGL) of flights past a nest given in feet (ft). Imperial units of measurement are used to coincide with standard military measurement of altitude (< 30.5 m; 30.5 - 75.5 m; 76 - 152 m; and 152.5 - 304.5 m, respectively)

d - The year variable is classified as a dummy variable, not an effect variable

Table 8. Means, SE, minimum values, maximum values, and test statistics (Mann Whitney U-test with 1 degree of freedom) for the meristic values of the cumulative totals of all jet flights at all distance and altitude categories for both 1995 and 1996, and the effect of a pair's ability to have ≥ 1 Osprey young to reach 41 days of age for occupied nest sites in Labrador.

Jet Flight Category	**≥1 Young at 41 Days of Age**					**No Young**					**Test Statistic**	
	n	$\bar{x}$	SE	Min	Max	n	$\bar{x}$	SE	Min	Max	*U*	*P*
Distance Variables[1]												
0 - 0.5 nm	34	41.6	11.9	0	300	30	23.2	6.2	0	145	484.0	0.73
0.5 - 1.0 nm	34	37.3	11.3	0	284	30	23.1	4.9	0	95	494.5	0.83
1.0 - 2.0 nm	34	69.2	18.3	0	564	30	54.8	12.1	1	291	509.5	0.99
2.0 - 3.0 nm	34	88.2	33.4	0	1161	30	91.4	22.3	2	521	512.0	0.98
Altitude Variables[2]												
<100 ft	34	139.6	36.5	0	1029	30	130.5	20.4	1	482	588.0	0.29
100 - 249 ft	34	150.6	40.7	0	867	30	75.9	12.0	4	301	487.5	0.76
250 - 499 ft	34	74.7	26.8	0	644	30	41.7	8.9	1	226	528.0	0.81

1 - Horizontal distance of flights from a nest given in nautical miles (nm). Imperial units of measurement are used to coincide with standard military measurement of distance (0 - 0.93 km; 0.93 - 1.85 km; 1.85 - 3.7 km; and 3.7 - 5.56 km, respectively)

2 - Vertical distance above ground level (AGL) of flights past a nest given in feet (ft). Imperial units of measurement are used to coincide with standard military measurement of altitude (< 30.5 m; 30.5 - 75.5 m; 76 - 152 m; and 152.5 - 304.5 m, respectively)

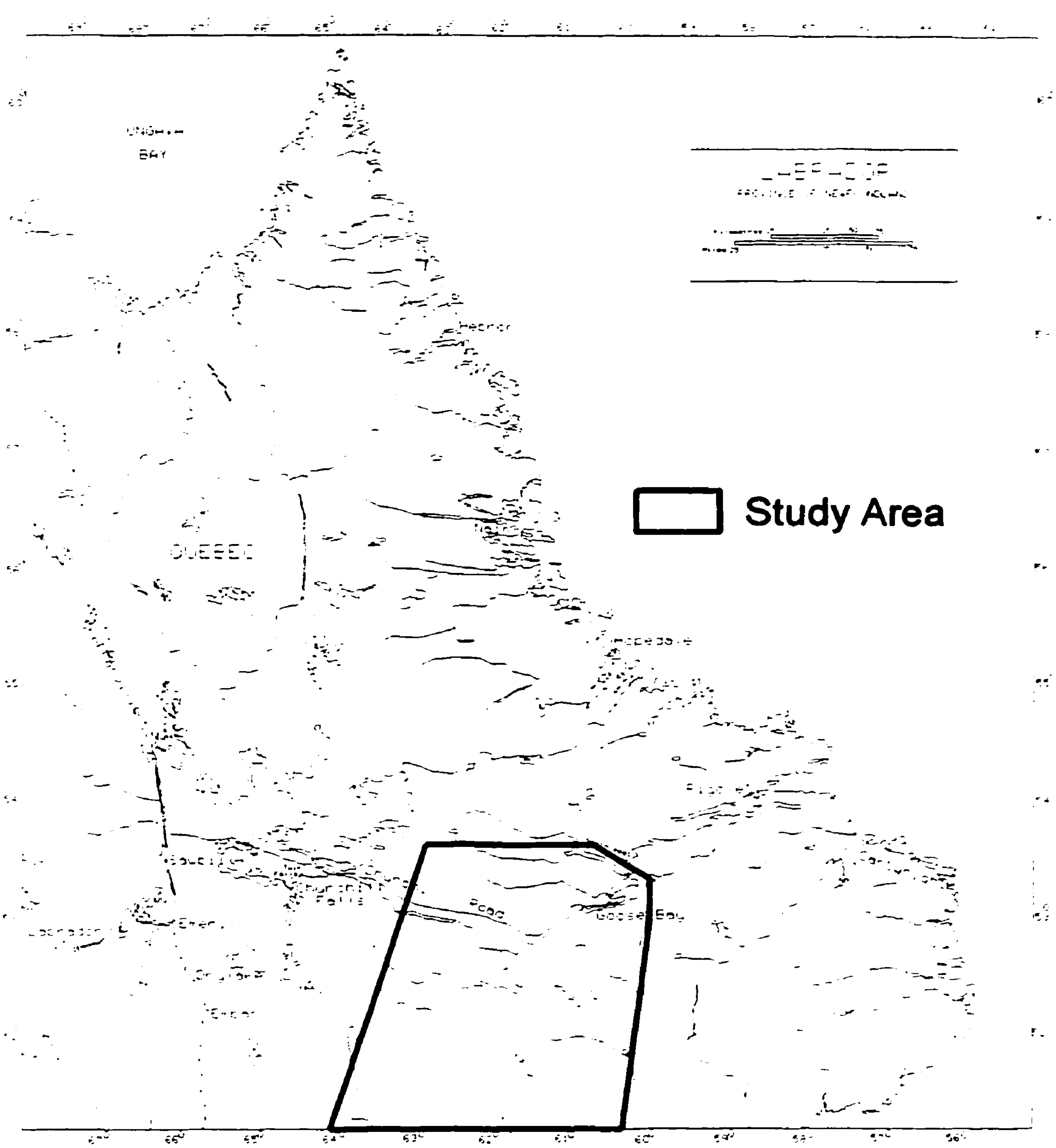

Figure 1. The study area comprising approximately 45 000 km^2 located in the southern region of Labrador and northeastern Quebec.

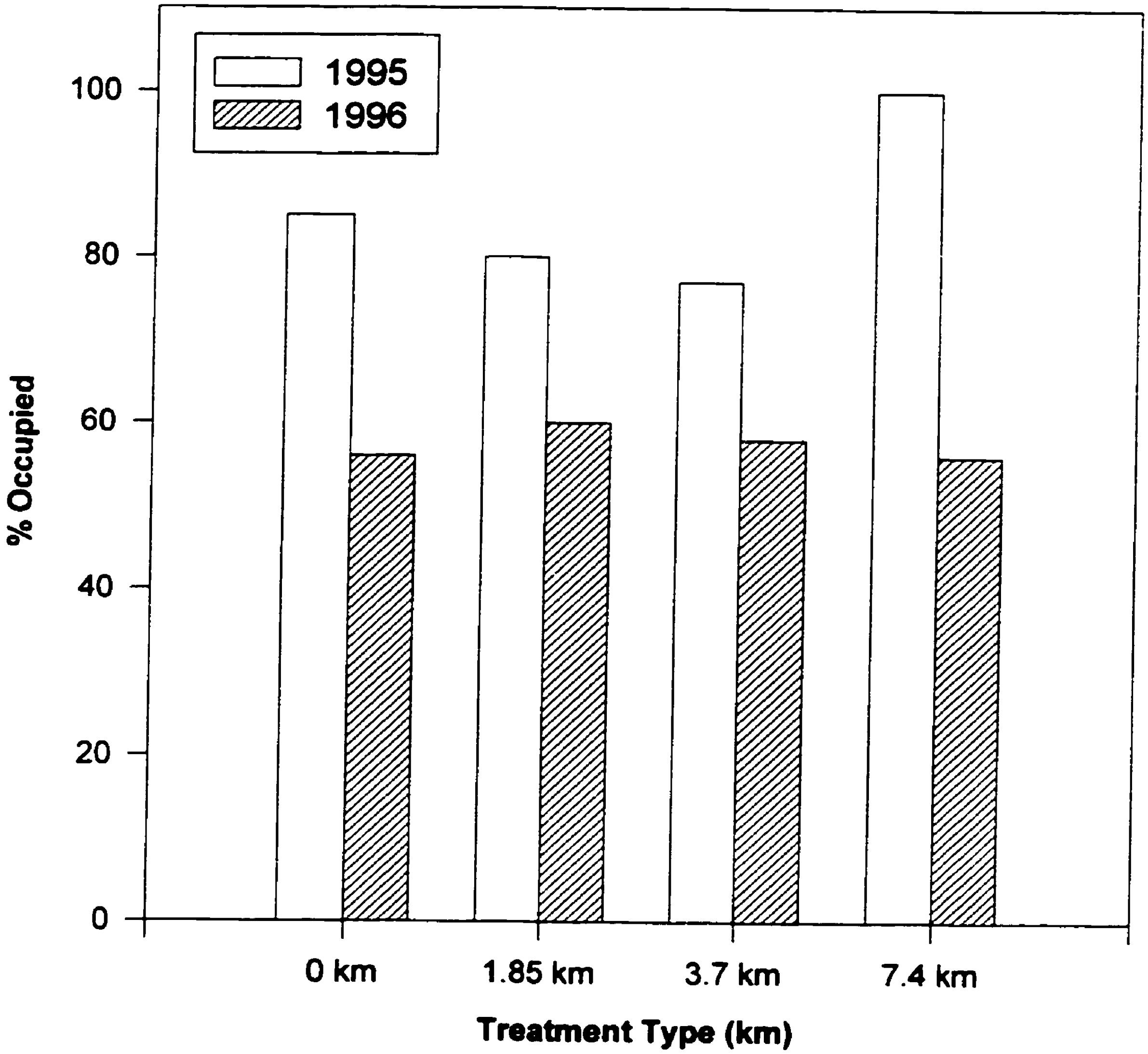

Figure 2. Mean number of occupied Osprey nests in each treatment type for 1995 and 1996.

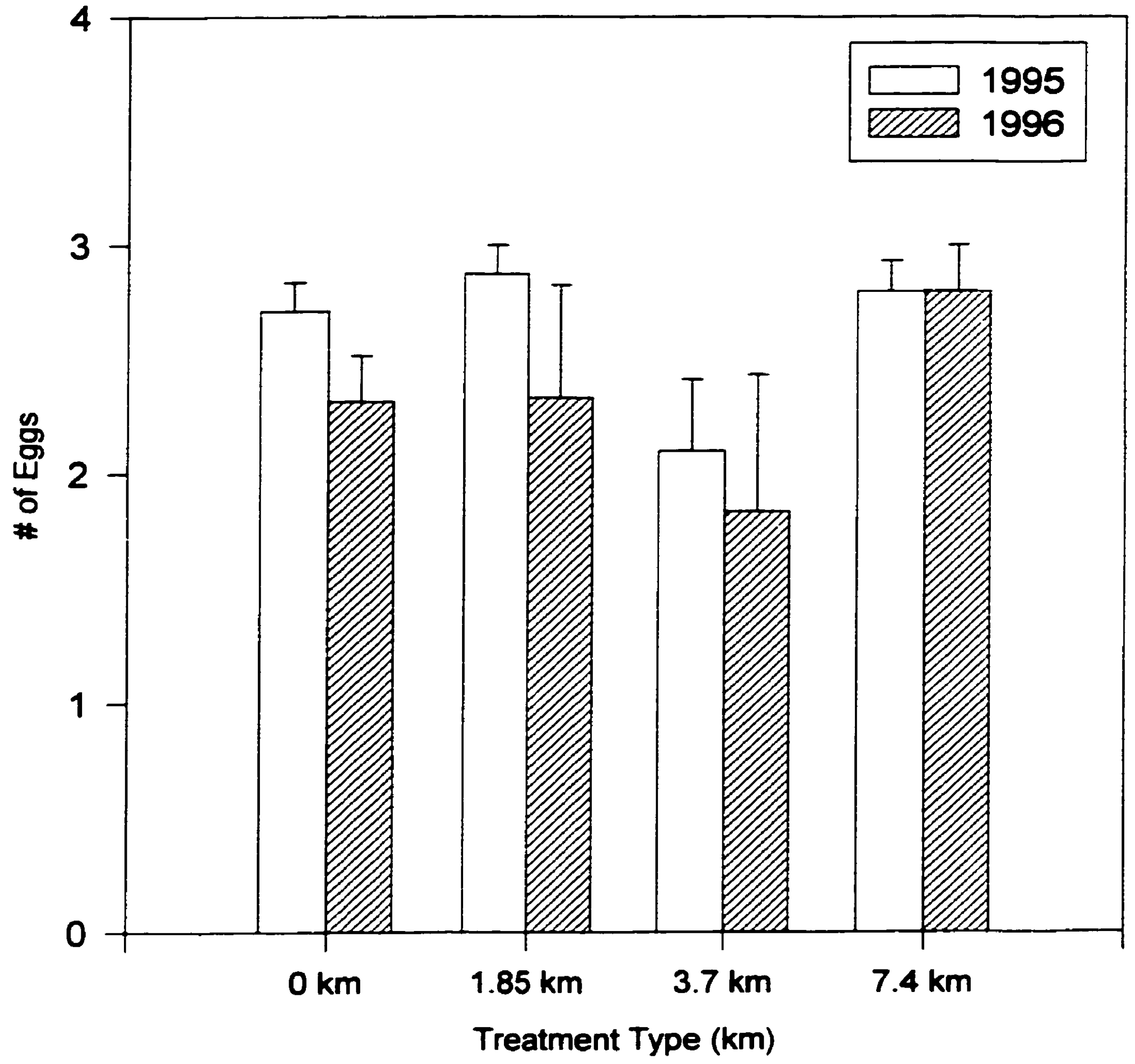

Figure 3. Mean ± 1 SE of the number of Osprey eggs per occupied nest in each treatment type for 1995 and 1996.

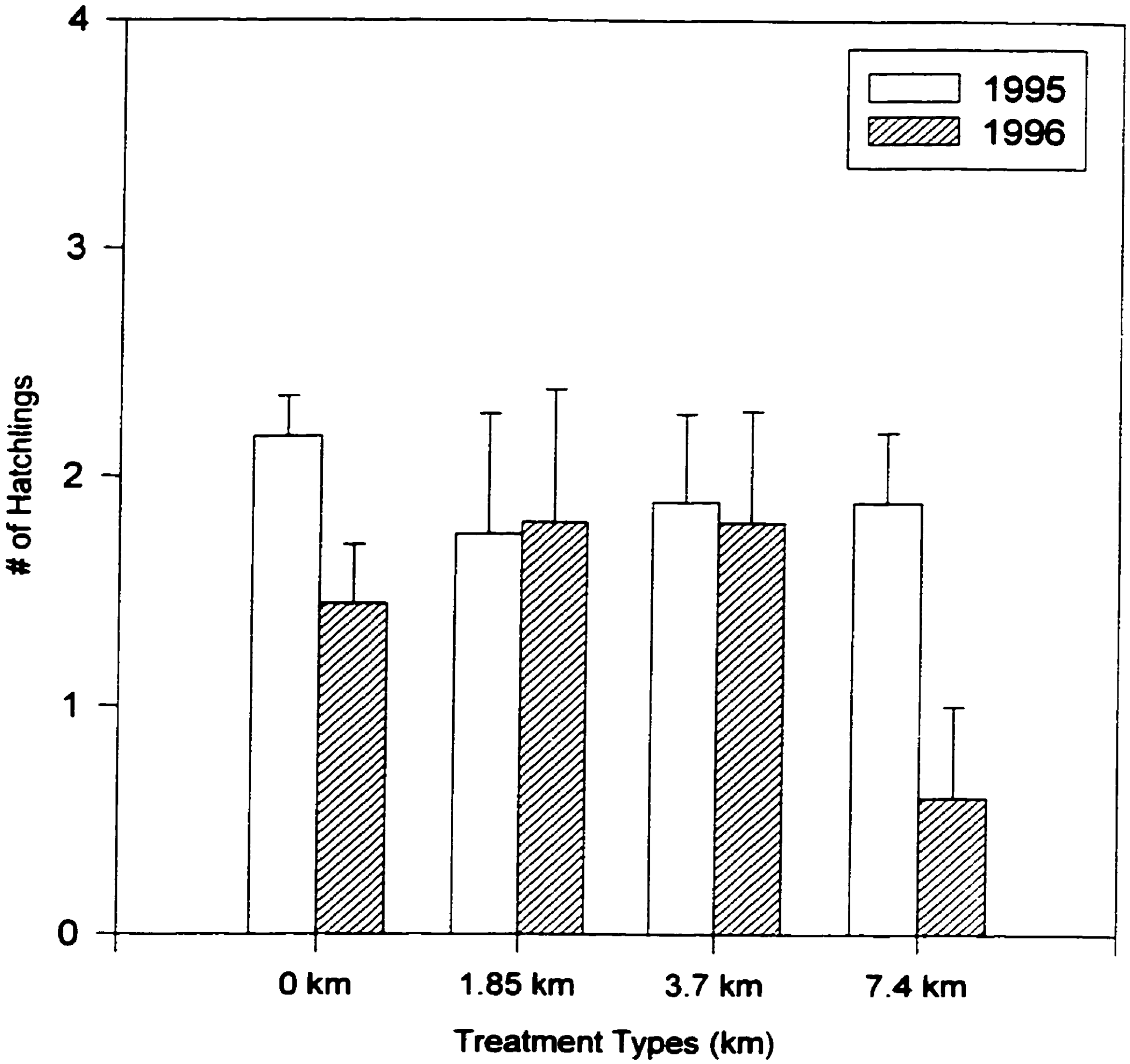

Figure 4. Mean ± 1 SE for the number of Osprey hatchlings per active nest in each treatment type for 1995 and 1996.

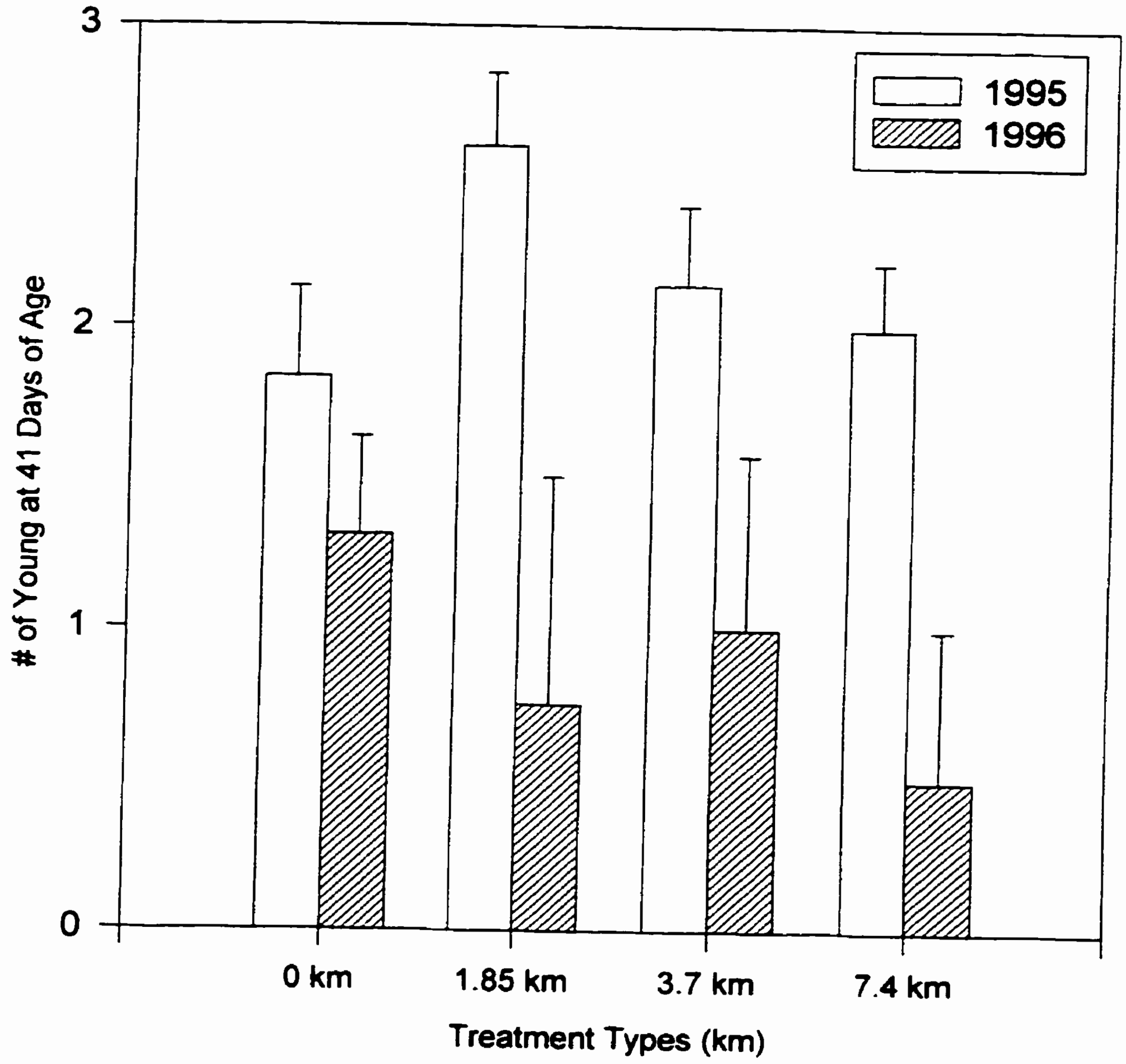

Figure 5. Mean ± 1 SE for the number of Osprey young to reach 41 days of age per the number of hatchlings in each treatment type for 1995 and 1996.

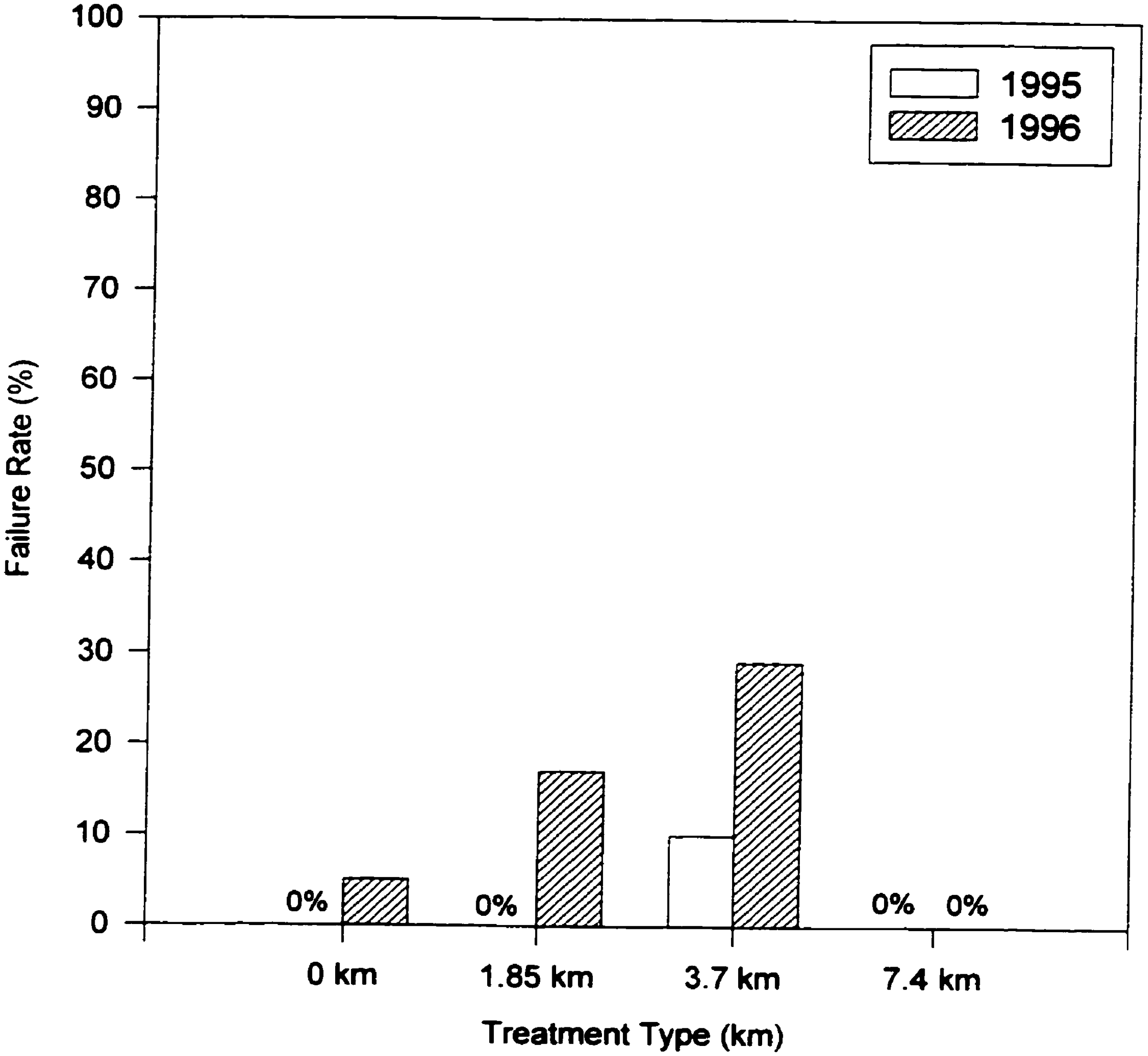

Figure 6. The failure rate of occupied Osprey nests to lay at least 1 egg for all treatment types in both 1995 and 1996.

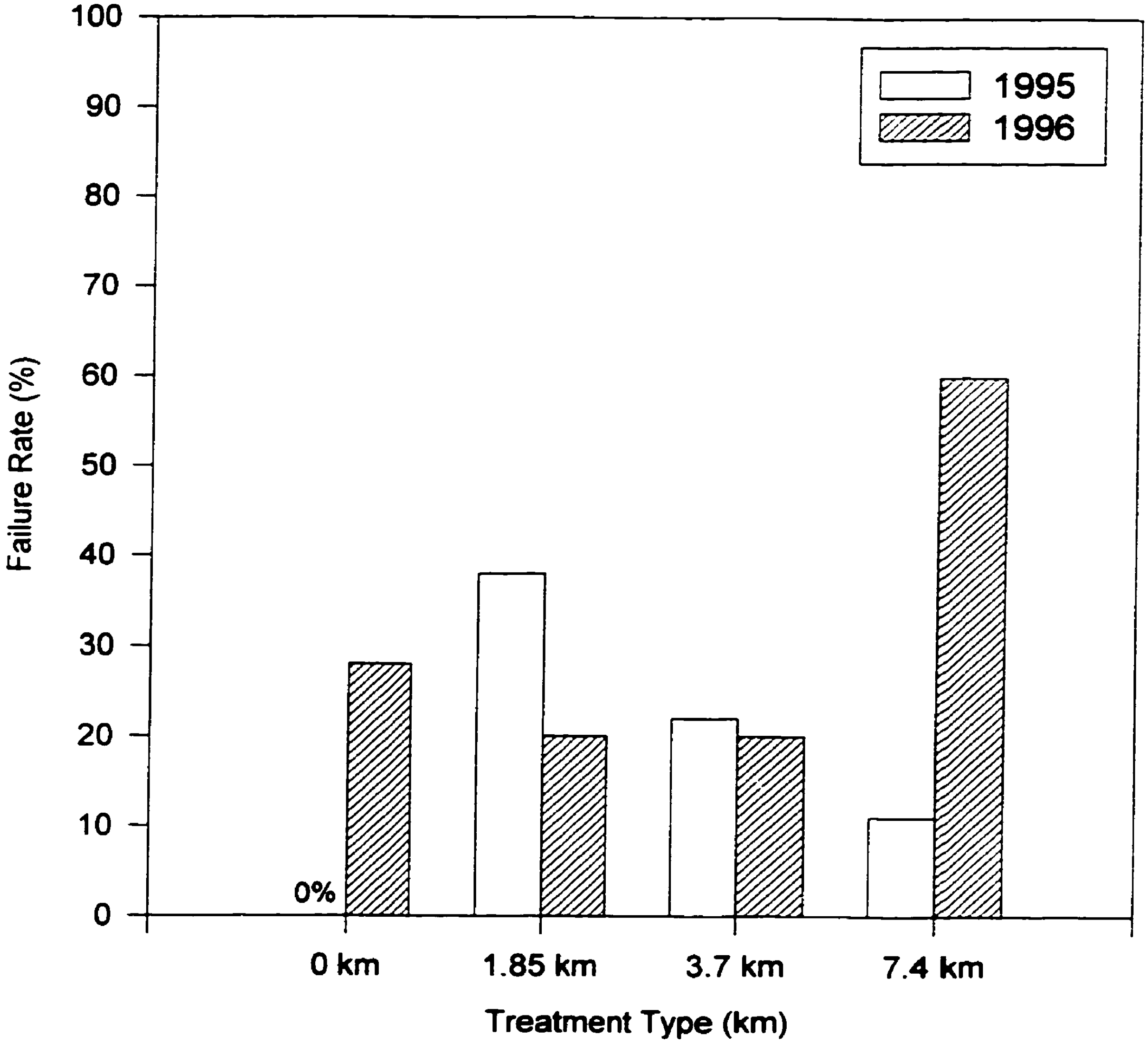

Figure 7. The failure rate of active Osprey nests to have at least 1 hatchling for all treatment types in both 1995 and 1996.

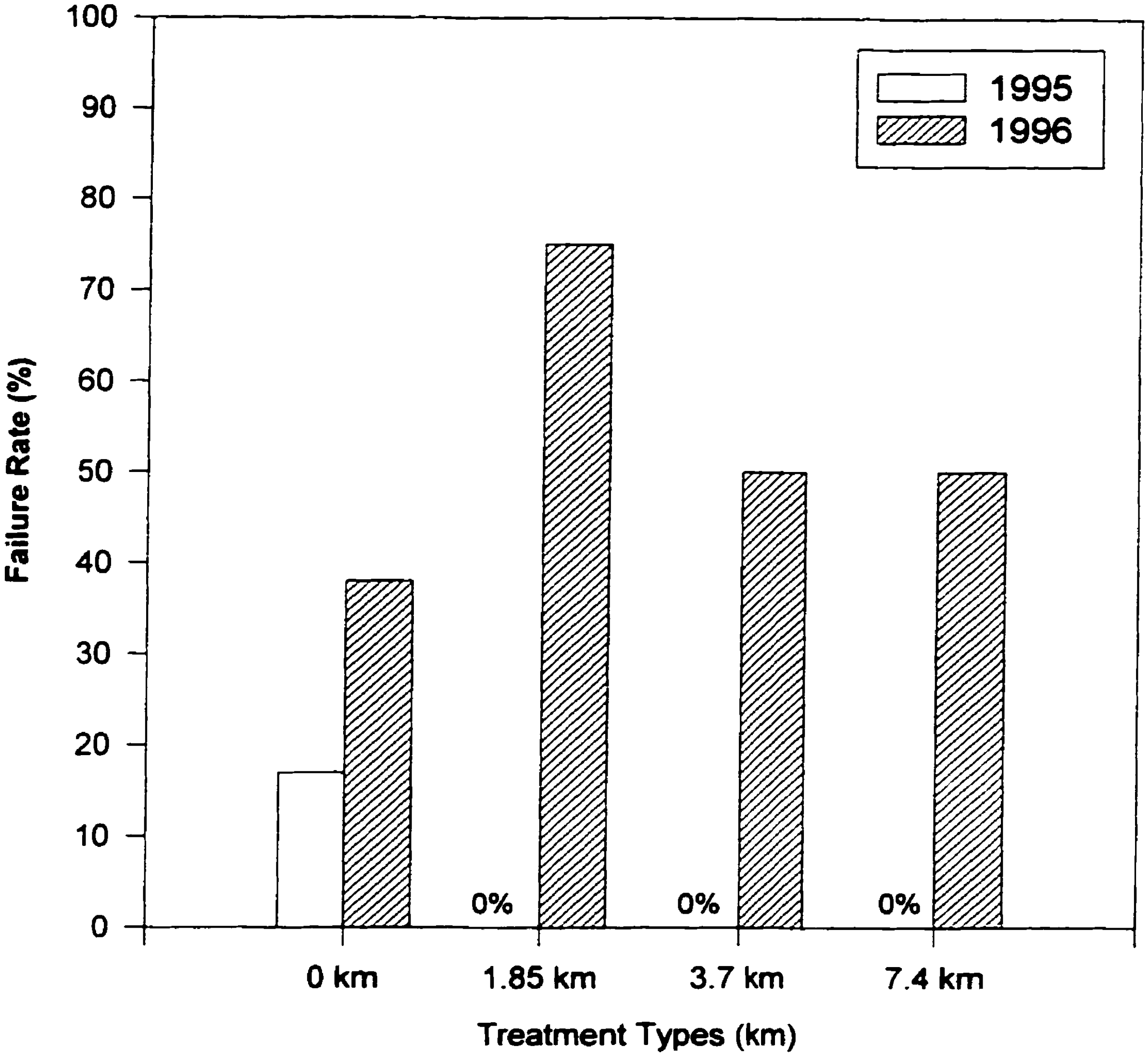

Figure 8. The failure rate of Osprey nests with at least 1 hatchling to have at least 1 young reach 41 days of age for all treatment types in both 1995 and 1996.

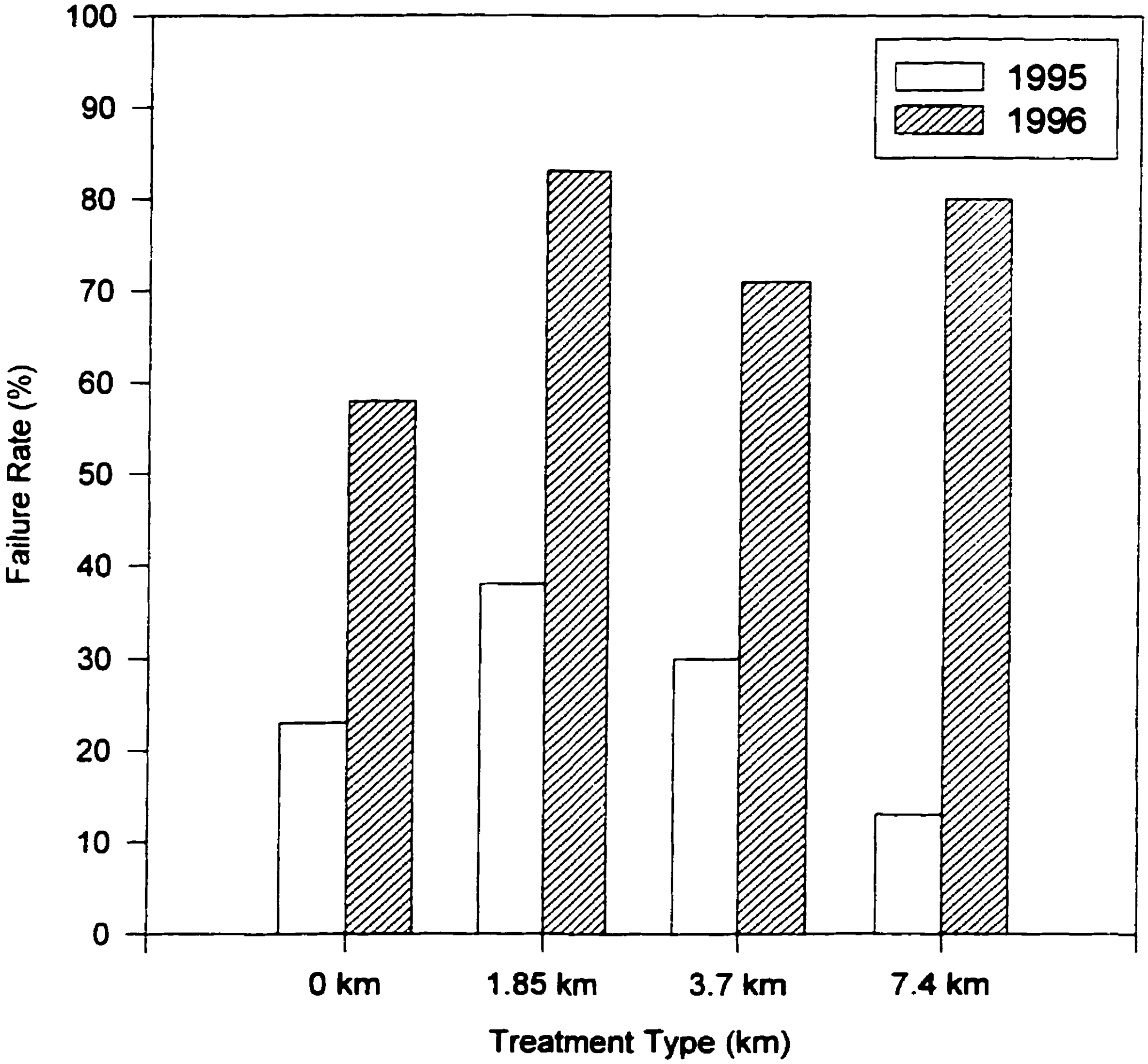

Figure 9. The failure rate of occupied Osprey nests to have at least 1 young reach 41 days of age for all treatment types in both 1995 and 1996.

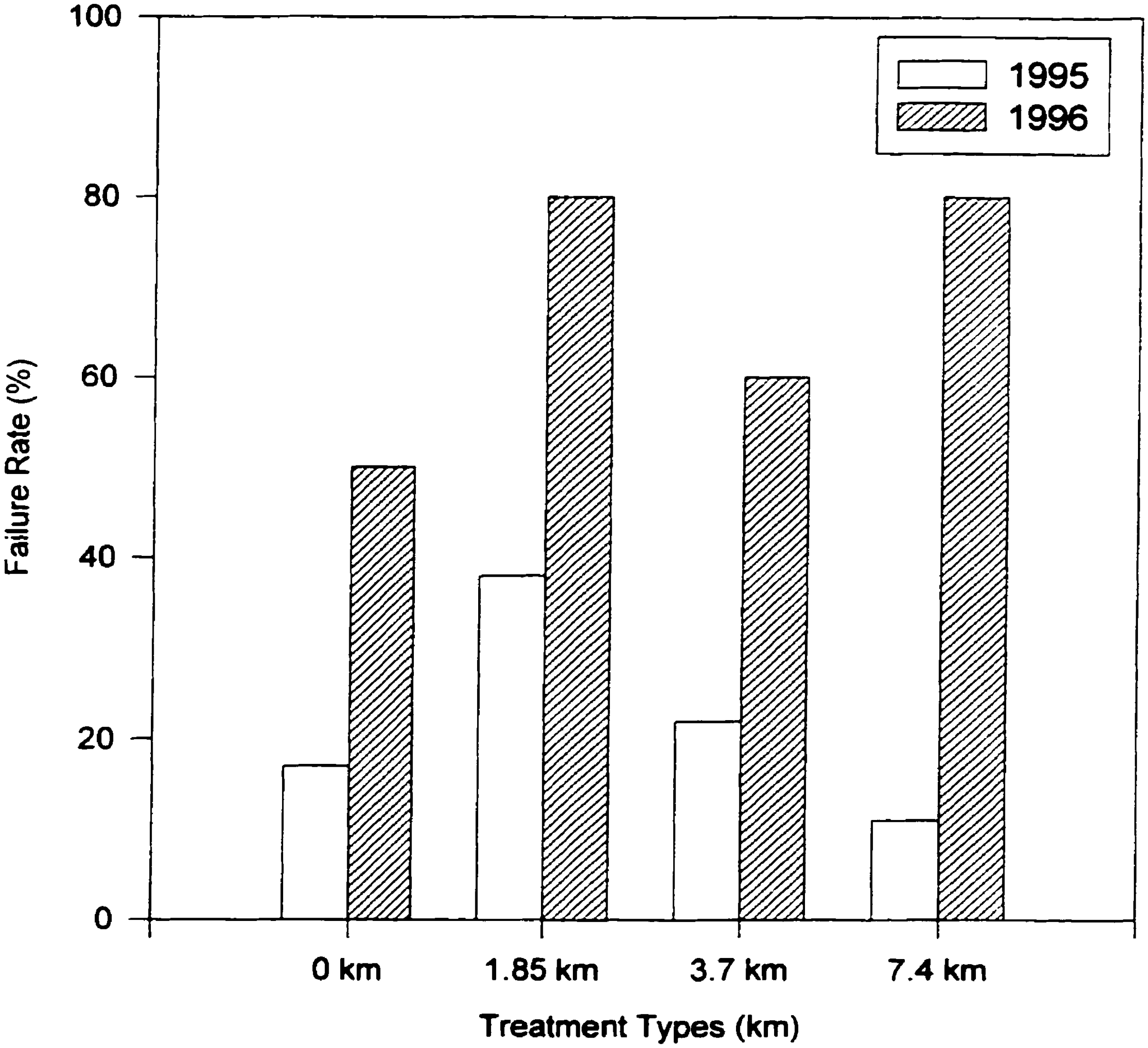

Figure 10. The failure rate of active Osprey nests to have at least 1 young reach 41 days of age for all treatment types in both 1995 and 1996.

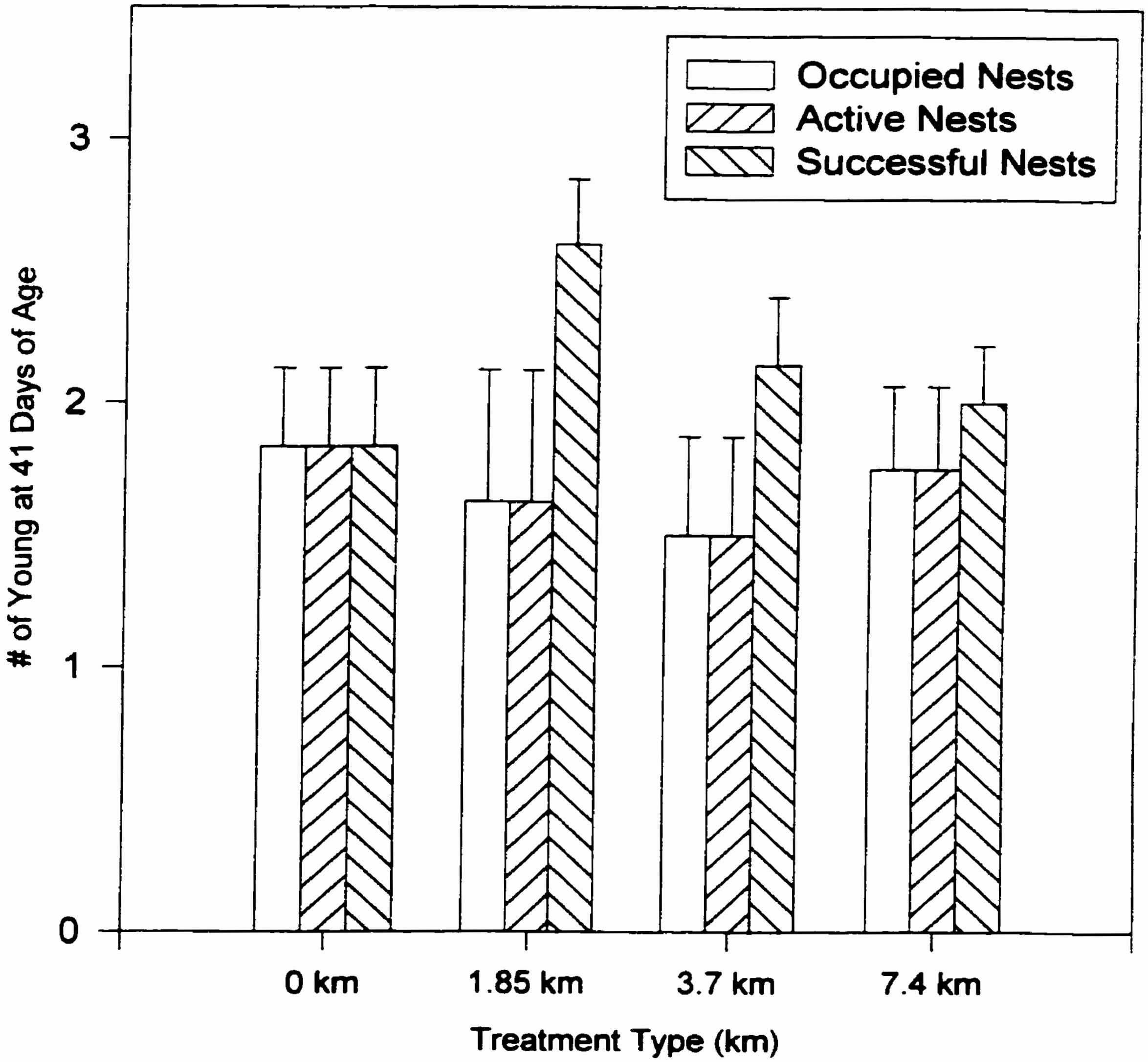

Figure 11. Mean number of Osprey young ± 1 SE to reach 41 days of age for all occupied, active, and successful nests in 1995.

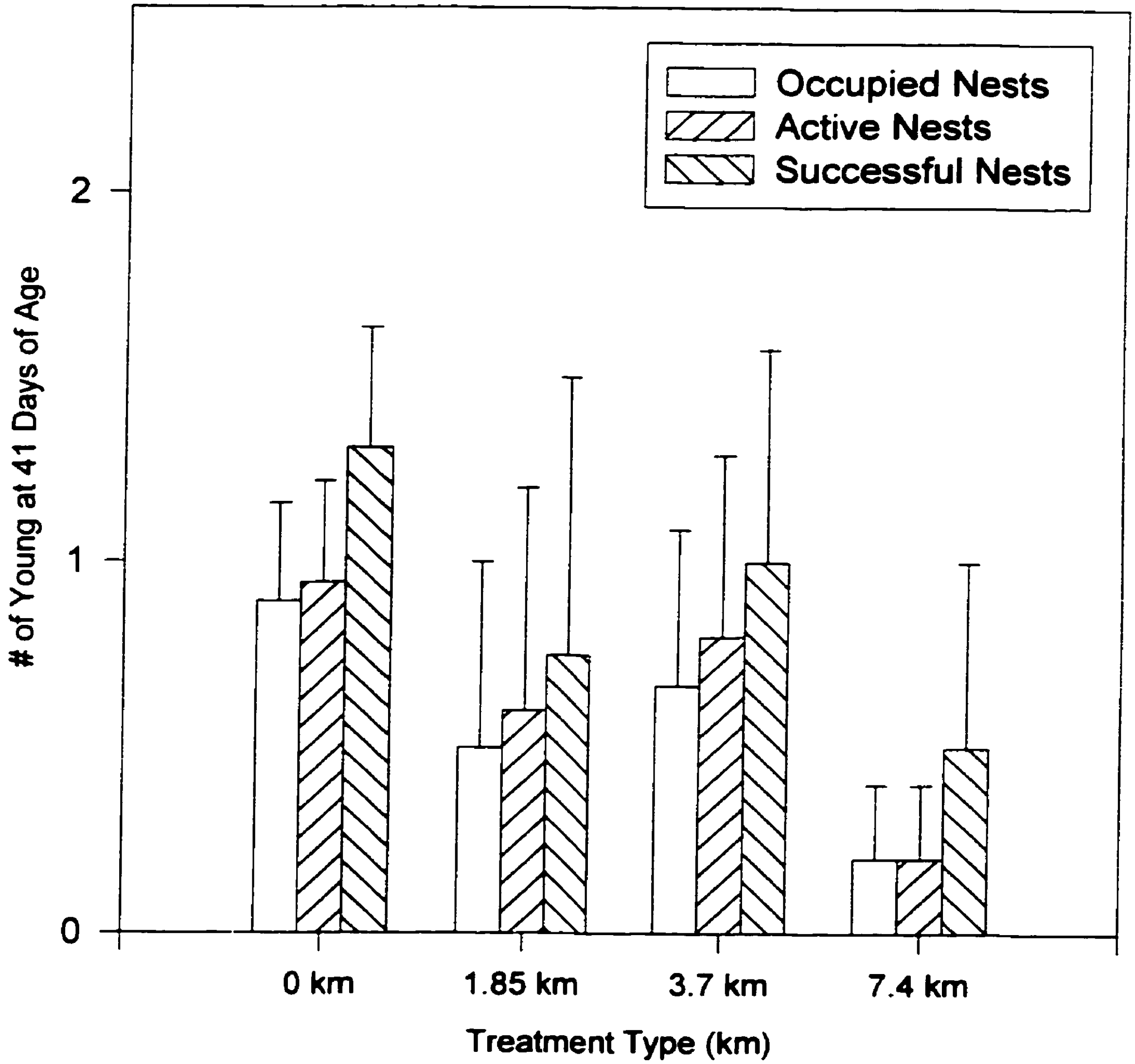

Figure 12. Mean number of Osprey young ± 1 SE to reach 41 days of age for all occupied, active, and successful nests in 1996.

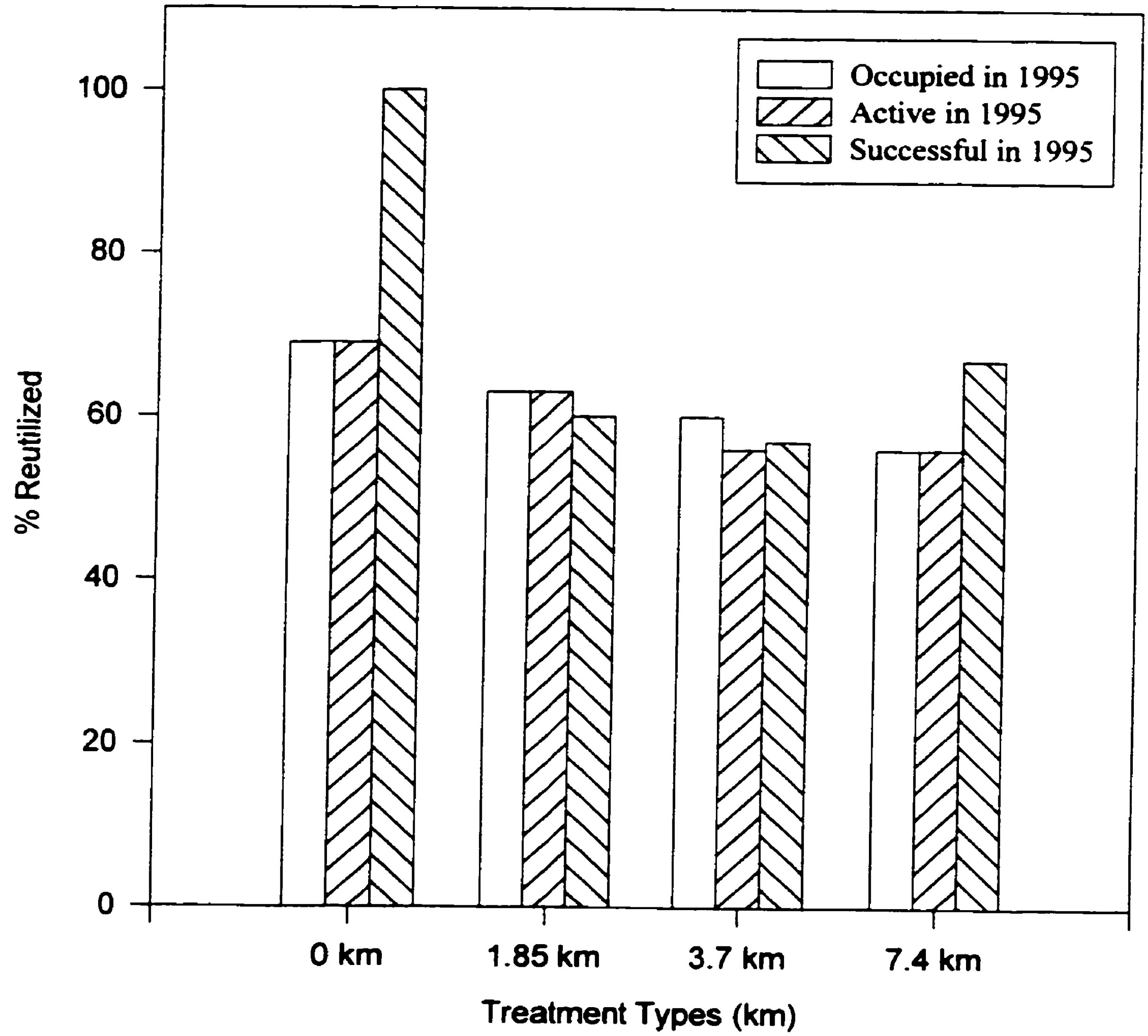

Figure 13. The percentage of reutilized Osprey nest sites in 1996 for each treatment type. Reutilization is assessed for occupied, active, and successful nest sites in 1995.