ENVIRONMENTAL CONTAMINANTS, FOOD AVAILABILITY, AND REPRODUCTION OF BALD EAGLES (*HALIAEETUS LEUCOCEPHALUS*) ON VANCOUVER ISLAND, BRITISH COLUMBIA

by

CHRISTOPHER ELLIS GILL

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ABSTRACT

The bald eagle (*Haliaeetus leucocephalus*) is one of the most highly visible wildlife inhabitants of the British Columbia coast. Populations in B.C. have survived relatively intact over most areas of the coast compared to many other parts of its range, possibly due to the limited use of DDT in this area and the relative abundance of suitable nesting habitat. Despite this, productivity is below that necessary to sustain a viable population in several areas of the Georgian Basin such as near Crofton and in Barkley Sound on southern Vancouver Island. In 1996 and 1997, food stress and/or contaminants from pulp mill effluent (PCDDs, PCDFs, and related organochlorine compounds) were investigated as possible causes of the low bald eagle productivity observed near Crofton, the location of a bleached kraft pulp and paper mill. Food abundance measures (prey delivery rates, prey biomass and energy per eaglet, brood size, eaglet activity levels, and adult nest attendance) and adult and eaglet blood contaminant levels were compared between the Crofton population and a population at an uncontaminated control site on the west coast of Vancouver Island. Nests located north and south of the Crofton mill differed significantly in mean 6-year productivity; prey abundance; and eaglet contaminant levels. Productivity and most food abundance measures were low south of the mill suggesting that food stress may be affecting breeding success there. Additionally, highest concentrations of chlorinated hydrocarbons in eaglet blood plasma occurred south of the Crofton mill. However, no correlation was evident between productivity and contaminant levels in eaglets, possibly due to the small sample size. Adult residue levels were generally similar among all study locations. The difference in eaglet contaminant levels north and south of the mill may reflect tidal movement in the Strait of Georgia, which occurs in a north-south direction. It is possible that food stress is acting in conjunction with elevated chlorinated hydrocarbon levels from pulp mill effluent to cause the low bald eagle productivity observed south of the Crofton mill.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICIES

GENERAL INTRODUCTION

Many breeding populations of bald eagles (*Haliaeetus leucocephalus*) have declined dramatically in the last century following the introduction of toxic anthropogenic chemical compounds into the environment, combined with habitat loss and persecution (Hickey and Anderson 1968, Sprunt 1969, Sprunt *et al.* 1973). Bald eagle population declines in the U.S. were first reported by Broley (1958) who postulated that adult sterility, caused by the insecticide dichloro-diphenyl-trichloroethane (DDT) and its metabolite, DDE, were major factors influencing reproductive success. DDT was eventually linked to egg-shell thinning, embryo mortality, and population declines in other raptor species (Newton 1979, Ratcliffe 1970, Hickey and Andersen 1968, Andersen and Hickey 1972, 1976). In the early 1970s, following North American restrictions on DDT usage (Grier 1982), most bald eagle populations began to recover in both numbers and productivity, with recent reports estimating population numbers approaching 70,500 eagles (Blood and Anweiler 1994). In 1995, the United States down listed the bald eagle from endangered to threatened.

Overall, the bald eagle seems to be well on the way to recovery. However, several localized populations in Canada and the U.S. have not recovered to the same degree as populations elsewhere in North America (Dykstra 1995, Elliott *et al.* 1998a, Elliott and Norstrom 1998b, Bowerman 1993, Anthony *et al.* 1993).

In areas of Maine and along the lower Columbia River, high concentrations of DDE and PCB have been correlated to low bald eagle breeding success (Welch 1994, Anthony *et al.* 1993). Reproductive success of eagles nesting along Great Lakes shorelines is lower than that for eagles nesting farther inland (Colborn 1991, Dykstra 1995). Levels of contaminants such as DDE and PCBs in nestlings from shoreline areas are high compared to inland levels leading some researchers to suggest that contaminants are responsible for the reduced reproductive success in this area (Bowerman 1993, Kozie and Anderson 1991, Wiemeyer *et al.* 1984). However, Dykstra (1995) concluded that reduced food availability in the local environment, indicated by low food delivery rates and low adult nest attendance, may be the most important factor influencing productivity in much of the upper Great Lakes.

Eagle populations in the Pacific Northwest and British Columbia have not experienced drastic or widespread reductions in numbers due to the limited use of DDT in this region (Blood and Anweiler 1994). In the southern Strait of Georgia, bald eagle numbers reportedly increased between the mid-1970s and early 1980s (Vermeer *et al.* 1989a). That population growth was tentatively attributed to increasing prey populations, such as the glaucous-wing gull (*Larus glaucacens*), resulting from an increase in food availability in the form of human refuse. However, Elliott *et al.* (1996a) suggested that the population expansion of bald eagles was more closely associated with declining DDE concentrations in common prey species. In the Pacific Northwest and British Columbia, bald eagles are year-round residents (Hancock 1964). The breeding season can last from February to August although nests are maintained year round. Therefore, contaminant levels within breeding territories should largely reflect levels in breeding adults from this area.

Despite this reported increase in numbers, productivity was found to be low in several localized populations in British Columbia, such as areas in the Strait of Georgia, the west coast of Vancouver Island, Johnstone Strait, and the Queen Charlotte Islands (Elliott *et al.* 1998a).

It is possible that the low productivity observed in certain areas may be associated with industrial activities there. The Strait of Georgia receives industrial waste from numerous forest products industries (Waldichuk 1957) and is of particular importance due to the abundance of marine and aquatic wildlife which attracts many migratory and non-migratory bird species to that area (Butler and Campbell 1987). Since the late 1970's, the Canadian Wildlife Service has used colonial fish-eating birds such as the great blue heron (*Ardea herodias*) and the double-crested cormorant (*Phalacrocorax auritis*) as indicators of chemical contamination of coastal and estuarine habits on the Strait of Georgia (Whitehead 1989). Local populations of herons and cormorants on the Strait do not migrate, therefore, contaminants found in the tissues or eggs of these species reflect those found in the local environment.

Nine large kraft pulp and paper mills discharge effluent into the Strait of Georgia, which, until the early 1990s, contained high levels of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) produced in the chlorine pulp bleaching process (Elliott *et al.* 1996). Those contaminants are highly lipophylic, readily stored in fatty tissues, and can cause various toxic effects in fish, birds, and mammals even at very low exposure concentrations (low parts per trillion) (Peterson *et al* 1993). The most toxic and extensively studied PCDD and PCDF isomer is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). Effects of TCDD and its isoteres are species-specific but include weight loss, edema, hepatotoxicity, thymic atrophy, hyperkeratosis (mammals only), mortality, and reproductive impairment (Goldstein 1980, Safe 1987, 1990). TCDD is often used as a model for studying the effects of PCDDs and PCDFs. Several of the toxic effects caused by these compounds are thought to be mediated by the aryl hydrocarbon (*Ah*) receptor, a cytosolic receptor found in many tissues, but mainly in the liver (Landers and Bunce 1991). Dioxins such as TCDD enter cells by passive diffusion and bind with the *Ah*-receptor. This complex then interacts with the nuclear translocating protein (Arnt) and moves into the nucleus. Here the receptor-ligand complex interacts with dioxin responsive elements (AhREs) on the genome causing an alteration in the transcription of specific mRNAs. Proteins produced by this alteration mediate the biochemical and toxic responses observed with TCDD exposure (Okey *et al.* 1994).

Chlorinated hydrocarbon compounds normally exist in environmental and biological samples as complex mixtures of congeners. In order to provide a practical method of assessing the effects of multiple contaminants, the study of *Ah*-receptor mediated structure-activity relationships has produced an additive scheme for assessing the toxicity of complex mixtures. After the relative toxicities of each individual compound in relation to 2,3,7,8-TCDD is determined, a "TCDD Toxic Equivalence Factor" (TEF) is assigned. Residue levels determined analytically are then multiplied by the corresponding TEF and the results summed to produce the "TCDD Toxic Equivalents" (TEQs, Safe 1990).

A four year study on bald eagle productivity and contaminant levels along the coast of British Columbia by Elliott *et al.* (1998a) and Elliott and Norstrom (1998b) reported a difference in reproductive rates for eagles breeding near two bleached pulp and paper mills on Vancouver Island. In order for a bald eagle population to remain stable, Sprunt *et al.* (1973) estimated that a reproductive rate of at least 0.7 chicks per occupied nest site was required whereas 1.0 chicks per occupied nest site is thought to reflect a healthy population (Wiemeyer *et al.* 1984). Near Crofton, the location of a Fletcher Challenge/ TimberWest Ltd. bleached kraft pulp and paper mill, mean 4-year productivity of nests within the dioxin fishery closure area surrounding the mill was 0.23 chicks per active territory compared to 1.0 at nests outside the closure area (Elliott and Norstrom 1998b). They concluded that a toxicological explanation for the reduced productivity within the dioxin fishery closure area could not be ruled out. The highly lipophylic nature of PCDDs, PCDFs, and PCBs allows accumulation of these contaminants in top predators such as the eagle. Previous studies have shown that fish-eating birds such as great blue herons, double-crested cormorants, western grebes (*Aechmophorus occidentalis*), and common mergansers (*Mergus merganser*), all of which are potential food of eagles, were contaminated with high levels of PCDDs and PCDFs in the mid-1980s (Elliott *et al.*, 1989a). In 1990, levels of PCDDs and PCDFs in western grebes and surf scoters collected near coastal mills were high enough to warrant advisories against human consumption (Whitehead *et al.* 1990).

Bald eagle eggs collected from the Crofton population in 1990 and 1991 by Elliott *et al.* (1989, 1996b) contained PCDD and PCDF levels similar to those found in great blue heron eggs collected in 1986 and 1987 from the same area. Elevated levels of PCDDs and PCDFs in heron eggs were affecting the health of heron chicks (Sanderson *et al.* 1994) and may have contributed to the colony failure observed in 1987 and 1988 at Crofton. Acute toxicological effects of 2,3,7,8-TCDD on the heron embryo were ruled out as a possible cause of nesting failure since levels in some eggs collected from Crofton in 1987 were within the range (<200 ng/kg) which produced young in 1986. Elliott *et al.* (1989) suggested that 2,3,7,8-TCDD may have influenced heron productivity through extrinsic effects such as reduced parental attentiveness. This is supported by behavioral observations conducted at this colony in 1988 by Moul (1990). At contaminated colonies near Crofton, incubation times were lower and more variable among nests compared to that reported for control colonies.

Reduced parental attentiveness can also be attributed to other chlorinated hydrocarbons such as PCBs and DDE. A study by McArthur *et al.* (1983) on reproductive behavior and performance in ringed turtle doves (*Streptopelia risoria*) reported that treatment of an organochlorine mixture (DDE, PCBs, and photomirex) reduced androgen and estrogen levels while increasing thyroxine concentrations. McArthur *et al.* (1983) observed deficient early courtship behavior (delays in nest building, ovulation, and incubation) in birds treated with the organochlorine mixture. The authors concluded that the organochlorine mixture altered the nature and duration of courtship behavior in a dose-related fashion. At high concentrations, (28.03 ppm Aroclor, 4.61 ppm DDE, 0.897 ppm mirex, and 0.324 ppm photomirex), the organochlorine mixture caused thyroxine-induced hyperactivity. Hyperactivity was associated with reduced attentiveness to incubation and brooding which, in turn, resulted in increased chick mortality and nest abandonment (McArthur *et al.* 1983).

A study of the reproductive failure of Forster's terns (*Sterna fosteri*) on Lake Michigan, based on an inter-colony egg swap experiment, suggested that PCBs caused a decrease in nest attendance and defense resulting in higher frequencies of egg disappearance and chick mortality (Kubiak *et al.* 1989). Similar results were found with organochlorine contamination in herring gulls (*Larus argentatus*) in the Great Lakes (Fox *et al.* 1978). In both studies, pollutant-induced endocrine dysfunction was suggested as the cause of aberrant parental behavior and decreased attentiveness to brooding.

It is possible that the adult eagles attempting to breed at Crofton were hatched and raised prior to the reduction in chlorinated hydrocarbon output in the late 1980s. While appearing externally normal, these birds may have damaged reproductive systems resulting from exposure to compounds such as TCDD *in ovo* or during early development. Studies by

Mably *et al.* (1992 I, II) on the *in utero* effects of TCDD on male rats reported that maternal exposure to a single low dose of TCDD (0.064-1.0 ug/kg) caused feminization in male fetuses possibly through a decrease in plasma testosterone concentration so that levels were intermediate between control male and female fetuses. Additional effects included reduced spermatogenesis, demasculinized adult sexual behavior, and feminization of the regulation of LH secretion (cycling of LH secretion which only occurs in females was observed in the male test animals). The effects of TCDD on the male reproductive system were thought to be due in part to an androgenic deficiency caused by decreased testicular response to LH and an increase in pituitary responsiveness to feedback inhibition by androgens and estrogens (Mably *et al.* 1992 I, II, III). Other studies reported that rats and monkeys exposed to < 1 ug/kg of TCDD had impaired reproductive capability, but showed no other apparent health problems (Peterson *et al.* 1993, Bowman *et al.* 1989).

In the late 1980s the Crofton pulp and paper mill terminated the use of pentachlorophenol-treated wood chips and made several changes to the chlorine pulp bleaching process. Following these changes, PCDD and PCDF levels in the heron colony have decreased substantially and productivity has generally improved (Elliott *et al.* 1996a). For example, mean 2,3,7,8-TCDD levels in heron eggs collected from the Crofton colony averaged 209 ppt in 1987 but declined rapidly to 3.7 ppt by 1994. The rapid decline of chlorinated hydrocarbons in the eggs reflects the swift decrease of contaminant levels in heron prey following control measures. A corresponding increase in bald eagle productivity near Crofton, however, had not been observed (Elliott, 1995).

Although contaminants are an obvious potential cause of reduced productivity near Crofton, natural factors such as food stress may be causing the reproductive impairment observed in this area. Food availability has been reported as one of the most important factors regulating raptor productivity in natural ecosystems (Newton 1976, 1979) and has been shown to influence reproductive rates in bald eagles (Dykstra 1995, Hansen 1984), white-tailed sea eagles (Helander 1985), ospreys (Clum 1986), and several other species (Newton 1979). A study by Dykstra (1995) on food availability, contaminants and productivity for bald eagles breeding near Lake Superior concluded that the low nesting success was due in part to low food delivery rates reflecting prey abundance in the local environment. Productivity studies on ospreys (*Pandion haliaeetus*) by Clum (1986) suggested that the abundance of prey at the pre-laying stage significantly affected egg hatchability. Similar results were found by Keith and Mitchell (1993) when food restrictions were imposed on ring turtle doves (*Streptopelia risoria*). Food restrictions at or before breeding had a greater effect than restrictions at the time of egg laying and were observed to influence egg production and the ability of birds with eggs to fledge young. Results suggested that reduced parental attentiveness, especially by the female, was the main factor affecting egg hatchability and survival of young.

The apparent pattern of nest failure at Crofton may thus reflect that of a population experiencing food stress during incubation with nest initiation occurring in late March or April followed by abandonment in May or June (Elliott *et al.* 1998b). Although marine productivity at Crofton is high and may not be limiting bald eagle productivity, food stress may occur if the eagles in this area are feeding primarily on transient food sources such as spawning fish species or migrating waterfowl that are abundant during nest initiation in early spring but in limited numbers later in the season. As the season progresses, the eagles would be forced to rely on less abundant food sources. Foraging time would increase causing a reduction in nest attendance possibly leading to higher chick mortality and nest abandonment.

It is also possible that contaminants are acting in conjunction with food stress to cause the reproductive impairment observed near Crofton. A study by Keith and Mitchell (1993) on the reproductive effects of DDE and food stress on ring turtle doves reported that the combined effects of these two factors severely reduced productivity. Food restrictions imposed during pairing caused a drastic reduction in productivity in clean birds (no DDE) and total failure in DDE-treated birds. DDE alone did not influence breeding success. However, when combined with food restriction, this contaminant compounded the effects of food stress. Keith and Mitchell (1993) concluded that food restrictions and DDE adversely influenced reproduction by reducing levels of circulating gonadotropins and sex steroids. Gonadotropins such as luteinizing hormone (LH) and follicle stimulating hormone (FSH) are necessary for gonad maturation which, in turn, produces estrogens and other sex steroids necessary for egg production.

Breeding success of bald eagles nesting near Crofton may be influenced by one or more factors. Low productivity near Crofton may be due to natural factors such as low prey abundance in the local environment. Prey abundance may be high during nest initiation in early March but decline as the breeding season progresses resulting in high eaglet mortality. Alternatively, high levels of persistent chlorinated hydrocarbons released in pulp mill effluent prior to changes in the pulp bleaching process may have damaged adult reproductive systems possibly reducing egg hatchability. Contaminants may also be influencing breeding success near Crofton through embryo toxicity or reduced survival of nestlings. Finally, a combination of factors such as these may be the cause of the low bald eagle productivity near Crofton.

OBJECTIVES

The objective of this study is to determine the cause of the low breeding success near Crofton. Productivity was determined for Crofton and Barkley Sound (control site). Food availability in the local environment was assessed at both study areas using prey delivery rates to nests; prey biomass and energy each eaglet received on a daily basis; brood size; eaglet activity; and adult nest attendance. Concentrations of chlorinated hydrocarbons in adult and eaglet blood plasma from both study areas were measured along with lipid plasma levels and comparisons made to breeding success.

HYPOTHESES

Food availability study

Hypothesis: Low food availability near Crofton and in Barkley Sound is impairing breeding success of bald eagles in these areas.

Contaminants study

Hypothesis: The accumulation of persistent chlorinated hydrocarbons in bald eagles breeding near Crofton is affecting reproductive success in this area.

STUDY AREAS

Study areas were located on Vancouver Island in southwestern British Columbia (Figures 1.1, 1.2). Crofton, my primary study area, was located on southeast Vancouver Island approximately 50 km north of Victoria. This area included 11 breeding pairs of bald eagles nesting within 4 nautical miles of the Fletcher Challenge/ TimberWest Ltd. bleached kraft pulp and paper mill. Nests under observation were located near Chemainus, on several small islands north of the mill, on the northwest coast of Saltspring Island, and south of the mill near Maple Bay. All nest trees were Douglas fir *(Pseudolsuga menziesii)* located less than 100 m from the shoreline. Most nests were located approximately 30 m above the ground and 5 m below the top of the tree.

Barkley Sound, located on southwest Vancouver Island, served as a contaminant free control site. This area included 6 nesting pairs located within 6 nautical miles of Poett Nook. Nest trees were either Douglas fir *(Pseudolsuga menziesii)* or western red cedar (*Thuja plicata*) located within 50 m of the shoreline. Nests height and location on the tree were similar to that found near Crofton and also to measurements reported by Vermeer and Morgan (1989) for bald eagle nests surveyed in Barkley Sound.

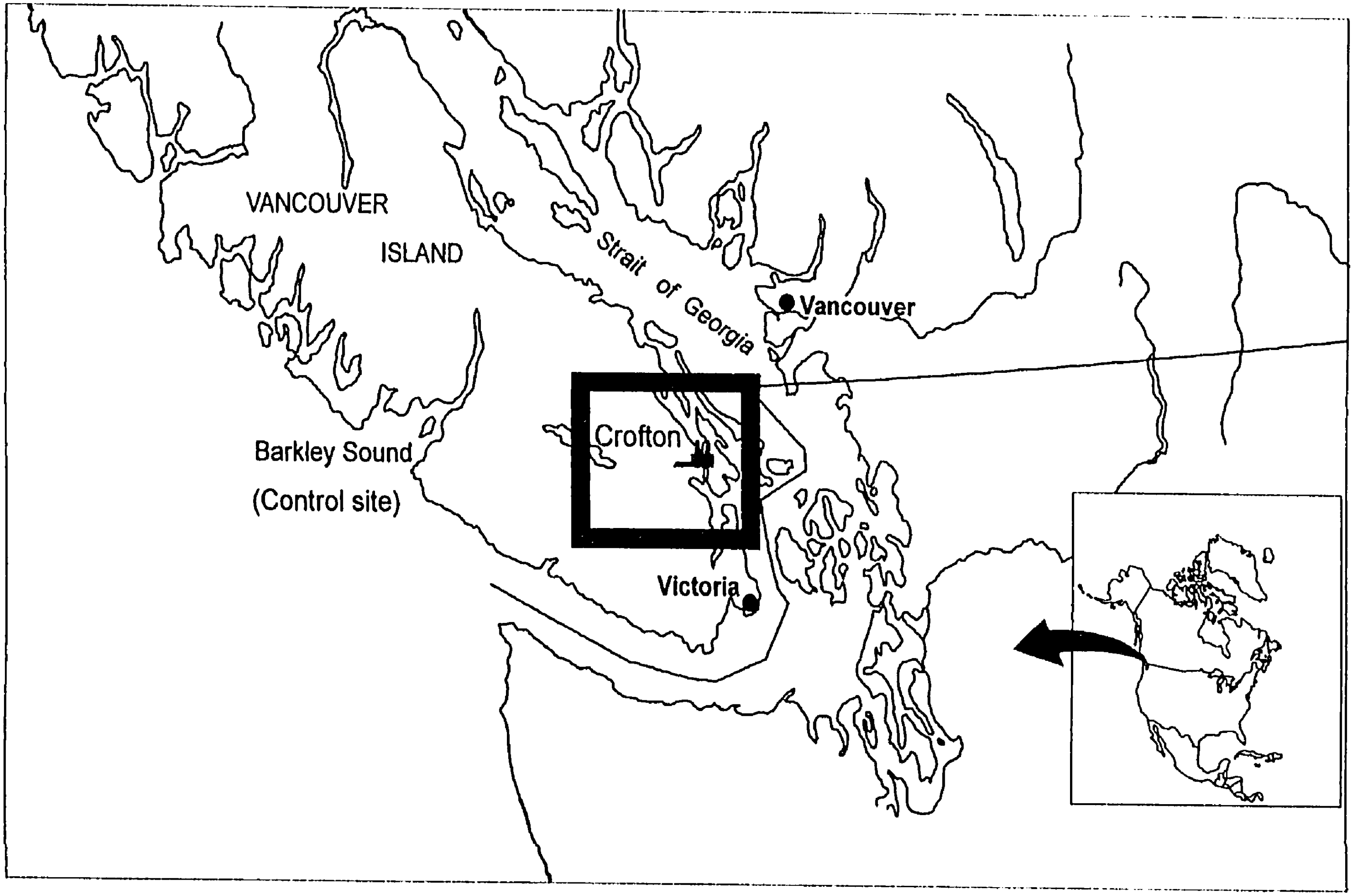

Figure 1.1 Location of study areas on Vancouver Island.

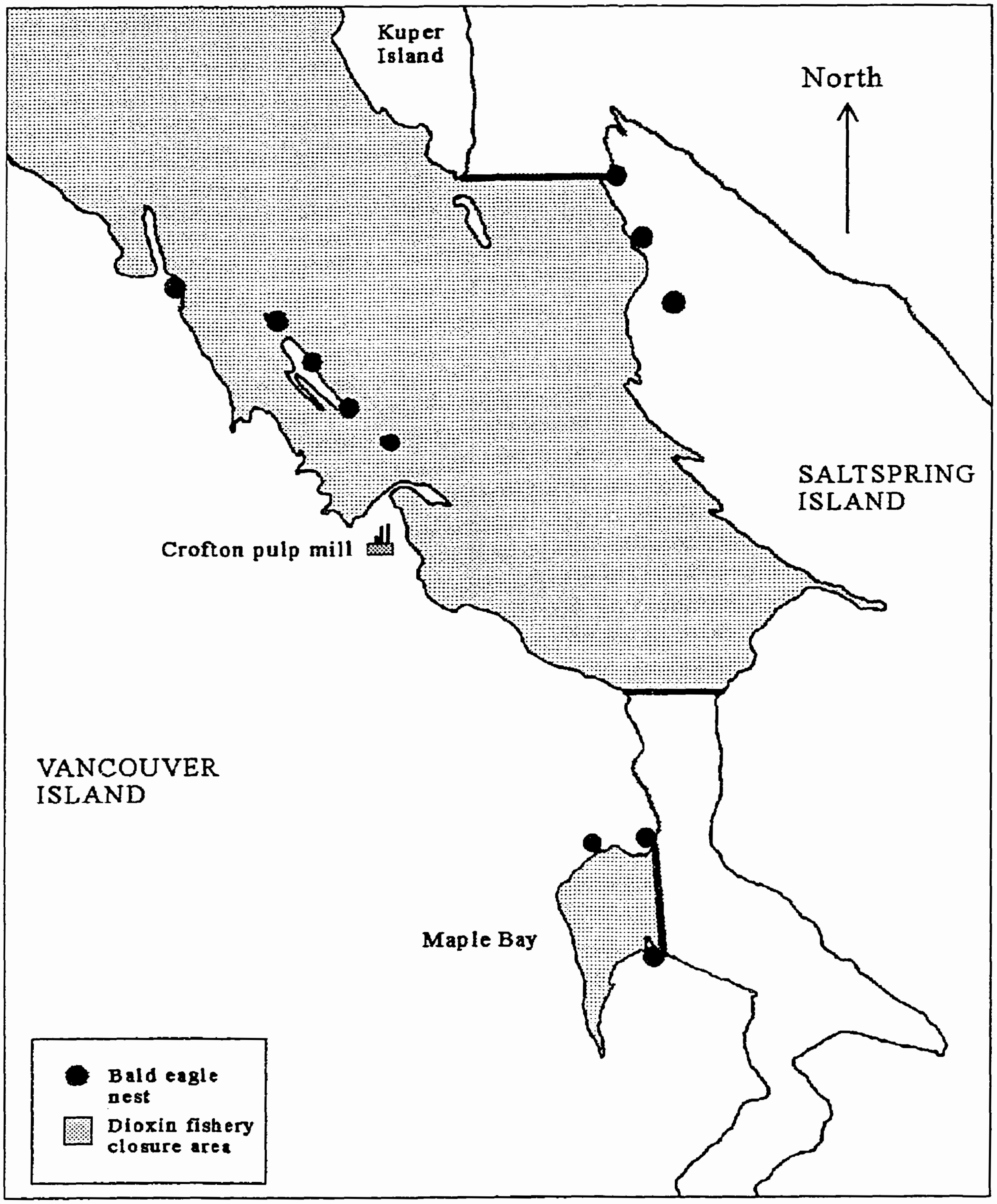

Figure 1.2 Location of bald eagle nests near Crofton.

CHAPTER 1

PREY TYPES, FEEDING RATES, AND PRODUCTIVITY OF TWO BALD EAGLE POPULATIONS ON VANCOUVER ISLAND, BRITISH COLUMBIA.

In this study, we investigated the possibility that the low bald eagle productivity near Crofton is due to low prey abundance in the local environment. Breeding success near Crofton and in Barkley Sound was measured from 1992-1997 and compared to lipid plasma levels, prey delivery rates, prey biomass and energy per eaglet, and relevant behavior of both adults and eaglets recorded using two observational techniques.

METHODS

Productivity

Nesting success was determined for the Crofton and Barkley Sound areas by a standard two flight method (Fraser *et al.* 1983) using helicopters and a minimum of two observers. The preliminary flight took place during incubation, (first week of April for Crofton and the end of April for Barkley Sound) to determined the number of occupied breeding territories. An occupied territory was considered one in which an adult was present either on or within 200 metres of the nest. The second flight occurred when eaglets were approximately 5-8 weeks of age (the first week of June for Crofton and mid-June for Barkley Sound) to count the number of nestlings produced. Mean productivity was considered the total number of young produced divided by the number of occupied breeding territories (Postupalsky 1974). Productivity was compared among nests located inside the dioxin fishery closure surrounding the Crofton mill, to those adjacent to this closure area, and to nests in Barkley Sound.

Data is presented as the number of chicks per occupied territory and as percent nesting success. Nests within the dioxin closure surrounding the Crofton mill were divided into nests north of the Crofton pulp mill outflow pipe and those adjacent to or south of this point due to differences in nest success rates between the two areas. Percent nest success was then compared among nests north of the mill, south of the mill, and Barkley Sound. Data presented here includes productivity surveys conducted from 1992-1994 at the same nests as reported by Elliott *et al.* (1998a).

Food availability

Two observational methods were employed to determine adult and eaglet behaviour and food delivery rates for nests near Crofton and in Barkley Sound. Dawn to dusk observations were conducted at 4 nests in the Crofton area and 3 nests in Barkley Sound (≥ 6 observations per nest, each approximately 16 continuous hours) using a 20-60X spotting scope and two observers. Observations were conducted approximately 100-300 m from the nest in order to minimize disturbance. To avoid fatigue, observers were switched every two hours.

Four additional nests in the Crofton area and 3 nests in Barkley Sound were observed using video cameras (Sony model V-1205 miniature CCD camera) and time lapse VCRs (Panasonic AG-1070DC) set to record for a maximum of 12 hours per day. Cameras were housed in waterproof compartments, camouflaged using paint and vegetation and placed approximately 2 metres above the nest by a professional tree climber when the nestlings were 4-6 weeks of age. Power and video lines (RG-8UM type) from the camera were secured to the nest tree and connected to a time lapse VCR (recording 1 frame/second) located on the ground. VCRs were housed in waterproof compartments and programmed to record for a maximum of 12 hours per day on 120 minute video tapes (3M T-120 Professional HG

Videocassette). Recording of nest activity occurred during estimated peak periods of prey deliveries (5-11am, and 2:30-8:30pm) to record a maximum number of prey deliveries within the 12 hour recording period. Power was supplied to the video unit by two 12 volt deep cycle marine batteries in protective housings. Batteries were replaced after 8 days of recording while video tapes were changed every three days.

The distance from the VCR to the nest tree averaged 20 m. This distance was determined by the length of power and video cable left over after the camera was mounted and also by the location of the nest. Dykstra (1995) placed VCRs farther from the nest tree, however, nests in my study either occurred within human settlements or on small islands, limiting the distance between the nest tree and the VCR. Maintenance of VCRs (tape and battery exchanges) probably caused only minor disturbance to breeding eagles: nests were normally located more than 30 m above the ground and isolated from view by the lower branches of the nest tree and dense ground cover (e.g. Salal); during visits to the nest tree, adults rarely vocalized and were observed feeding young or perched beside the nest on numerous occasions.

Observations conducted using both video and dawn to dusk observation methods simultaneously indicated good compatibility for determining the number of prey deliveries. These methods have also been shown to be compatible in other studies of nesting behavior of bald eagles (Dykstra 1995).

Data was collected from weeks 2-10 in the nestling stage. Dawn to dusk observations totaled 616 hours while video observations totaled 812 hours. Adult behaviors recorded using both methods included nest attendance time and number of prey items delivered to the nest. Eaglet behavior was classified as inactive, active or standing, according to the type of activity. These classifications were also used by Dykstra (1995) for comparisons of bald eaglet activity in several areas of the Great Lakes. Active behavior included standing, feeding, preening, fighting with siblings, exercising wings, playing with nest material, and walking around the nest. Inactive behaviour included lying down and sitting.

Prey items delivered to nests under observation were classified into four size categories: 7-15 cm, 15.1-23 cm, and 23.1-30, and 30.1-40 cm. This was accomplished by estimating the size of the prey item in relation to bill or foot pad length of the adult.

When possible, prey deliveries were identified to class (fish, bird, mammal) and species. Information on prey species and length was used to estimate prey biomass which was then converted to the appropriate energy content for each prey species using equations and data from the literature (Carlander 1969, Thompson and King 1994, Hislop *et al.* 1991, Bailey 1942, Hart *et al.* 1939, Ann 1973, Chatwin 1956, Bilton 1985, Gamboa 1991, Craigie 1927, Food composition and nutrition tables 1989). Energy content was estimated for some species when not available from the literature.

For fish deliveries where prey length and species was determined, energetic content was estimated using appropriate mass and energy equations for that species. Methods of estimating biomass and energy content for those fish not identified to species or where length was unknown were similar to that reported by Dykstra (1995). Distribution curves were generated from all prey deliveries for which prey species and size was available. The species and size distribution of unidentified fish was assumed to be similar to the distribution of all fish deliveries identified to species and where length was known. This same method was applied to all bird and mammal deliveries where species and/or length was unknown. Birds identified to species were assigned masses (Dunning 1992) and energetic content was assumed to be similar to that measured for mallards (*Anas platyrhynchos*) (Stalmaster and Gessaman 1982). Mammal deliveries were either European rabbits (*Oryctolagus cuniculus*) or small rodents. Mass and energy content was available for rabbits but had to be estimated for rodents by averaging these values for three rodent species (Kirkley and Gessaman 1990, Whitaker 1980). Those prey items for which species and size were unknown were assumed to have the same species and size distribution as all known prey in this study.

The prey biomass and energy eaglets received at nests in this study may be somewhat over estimated as adults commonly eat a certain amount of the prey when feeding the eaglets. Additionally, not all prey is completely edible (for example, the skulls of larger animals and the wings of birds) or in many cases, is not completely consumed. In other studies of prey delivery rates to eagle nests, certain prey items were said to be not completely edible. Dykstra (1995) estimated that fish over 305 mm were 90% edible, while birds and mammals were 85% edible. The main fish species taken by the eagles in Dykstra's study were very different from the species in this study, most of which were completely edible from personal observations and video analysis. Therefore, percent edibility was only applied to those species with large bony skulls such as ling cod. Similarly, the amount of mammal and bird biomass was adjusted for the larger species (such as the European rabbit (*Oryctolagus cuniculus*) and pigeon guillemot (*Cepphus columba*) but not for the smaller species which were eaten whole.

Lipid Plasma Levels

Between 1995 and 1996, blood samples were collected from 14 eaglets at 6 nests near Crofton and 4 eaglets from 4 nests in Barkley Sound for determination of lipid plasma levels and contaminant analysis (see Chapter 2).

When the eaglets were approximately 5-8 weeks of age, a professional tree climber was hired to climb nest trees near Crofton and in Barkley Sound. Not all nests in this study could be accessed for sample collection due to unsuitable climbing conditions or private land access problems.

Eaglets were lowered to the ground in a soft canvas bag, weighed, aged by the length of the eighth primary feather (Bortolotti 1984) and a CWS band attached to the left tarsus. Up to 24 ml of blood was taken from the brachial vein using a 12 ml sterile syringe and a 21 gauge needle. Blood was transferred to heparinized vacutainers and stored upright on ice. Samples were centrifuged within 6 hours of collection and plasma drawn off, transferred to chemically cleaned (acetone/hexane) glass vials and then frozen.

Frozen plasma samples were shipped to the Canadian Wildlife Service National Wildlife Research Center (NWRC) for lipid analysis. Lipid was determined by 2 methods: 1) a gravimetric approach whereby 1-2 ml of plasma was combined with 4 ml of hexane in a centrifuge tube. The mixture was extracted with an Ultra-Turrax homogenizer for 2 minutes then centrifuged to separate the hexane and plasma layers. The hexane was then passed through sodium sulphate to remove any moisture. This procedure was repeated three times. The sodium sulphate was then washed with hexane after the final extract. The three hexane extracts were combined on a pre-weighed aluminum dish and the hexane evaporated. The dish was re-weighed to determine the amount of lipid. Lipid was then calculated on the basis of grams per ml plasma.

The gravimetric method of lipid determination measures only tryglyceride levels in blood plasma which comprise approximately 59.7 % of the total lipid volume (Christie and Moore 1972). Phospholipids, which comprise 31.8 % of the total lipid volume are not measured by this test. Samples were therefore re-analyzed using 2) a colorimetric approach (Frings *et al.* 1972) which is used to determine the levels of both triglycerides and phospholipids circulating in the plasma. Samples (20 ul) were combined with 0.20 ml of concentrated sulfuric acid in a cuvet and mixed thoroughly on a vortex mixer. Cuvets were then placed in boiling water for 10 minutes then cooled in cold water for 5 minutes. Approximately 10 ml of phospho-vanillin reagent, made by combining 350 ml of vanillin reagent, 50 ml of water, and 600 ml of concentrated phosphoric acid, is added to each cuvet. Samples are mixed well on a vortex mixer and placed in a 37 ^{0}C water bath for 15 minutes. Cuvets are then cooled for 5 minutes and absorbance measured within 30 minutes at 540 mu on a Spectronic 70 (Bausch & Lomb).

Statistics

All statistical analyses was performed using SAS v.6.11 software package (1988). Due to the unbalanced nature of the sample design, a general linear model (GLM) was used for comparisons of productivity; prey delivery rates; prey biomass and energy delivered per day; eaglet activity; adult nest attendance; and eaglet lipid plasma levels. In cases where differences were detected, Tukey's multiple comparison procedure (MCP) was carried out on the main factors in the analysis. For Tukey's MCP, the p-value was set at 0.05. Correlation analyses were performed using Pearson Product Moment Correlation Coefficients (PPCC) with the experiment wise probability level of 0.05. Unless stated otherwise, results were considered significant if $p < 0.05$ and possibly significant when $p < 0.10$. Geometric means and 95% confidence intervals were calculated with the data grouped by study area.

RESULTS

Productivity

Productivity surveys conducted for nests near Crofton and in Barkley Sound from 1996-1997 were combined with surveys conducted at the same nests from 1992-1995 as reported by Elliott *et al.* (1998a).

Mean 6-year productivity was highest outside the dioxin fishery closure that surrounds the Crofton mill (Table 1.1). Productivity was similar between those nests within the closure area and nests in Barkley Sound (0.74 ± 0.28 and 0.58 ± 0.12 chicks/occupied territory, respectively). Productivity was more variable among nests within the dioxin fishery closure area surrounding the Crofton mill compared to those adjacent to this closure area. When nests inside the dioxin fishery closure area were divided into those adjacent to, or south of the Crofton mill outflow pipe (n=5) and nests north of this point (n=6), significant differences in productivity were noted. South of the Crofton mill, productivity was similar to that found for nests in Barkley Sound (south of mill = 0.48 ± 0.31, Barkley Sound = 0.58 ± 0.12) but significantly lower than that found for nests north of the mill (1.06 ± 0.50, Table 1.2).

Brood size

Brood size per successful nest (1992-1997, all years pooled) was significantly greater for nests north of the Crofton mill (1.63 ± 0.50 eaglets nest^{-1}) compared to those in Barkley Sound (1.25 ± 0.12 eaglets nest^{-1}, Table 1.3). Brood size south of the mill did not differ from the latter two study areas. There was a significant interaction between brood size and nest

Table 1.1. Nest success and number of young per occupied territory (including 95% confidence intervals) for nests near Crofton and in Barkley Sound (1992-1997).

Study area	Year	No. of occupied territories	Successful nests	% nest success	No. of young produced	Young/occupied nest
Crofton						
Inside closure area (n=11)	1992	3	1	33	1	0.33
	1993	2	0	0	0	0.00
	1994	4	2	50	2	0.50
	1995	4	2	50	4	1.00
	1996	5	4	80	9	1.80
	1997	4	2	50	3	0.75
	Mean*	**3.7**	**1.8**	**53**	**3.2**	**$0.74^{b} \pm 0.28$**
Outside closure area (n=11)	1992	5	5	100	7	1.40
	1993	8	7	88	9	1.10
	1994	9	5	55	7	0.78
	1995	8	6	75	8	1.00
	1996	8	7	88	12	1.50
	1997	6	6	100	8	1.33
	Mean*	**7.3**	**6.0**	**82**	**8.5**	**$1.13^{a} \pm 0.22$**
Barkley Sound (n=47)	1992	36	16	44	21	0.58
	1993	35	20	57	26	0.74
	1994	30	8	27	12	0.40
	1995	30	11	37	21	0.7
	1996	26	16	61	19	0.73
	1997	21	7	33	8	0.38
	Mean*	**29.7**	**13.0**	**44**	**17.8**	**$0.58^{b} \pm 0.12$**

a,b = data not sharing the same letter are significantly different ($p<0.05$)
* = all years pooled

Table 1.2. Nest success and number of young per occupied territory (including 95% confidence intervals) for nests north and southof the Crofton mill and in Barkley Sound (1992-1997).

Study area	Year	No. of occupied territories	Successful nests	% nest success	No. of young produced	Young/occupied nest
Crofton						
North of mill (n=6)	1992	2	1	50	1	0.50
	1993	1	0	0	0	0.00
	1994	3	2	67	2	0.67
	1995	3	2	67	4	1.33
	1996	4	4	100	9	2.25
	1997	4	2	50	2	0.50
	Mean*	**2.8**	**1.8**	**65**	**3.0**	**1.06[a] ± 0.50**
South of mill (n=5)	1992	3	0	0	0	0
	1993	4	3	75	3	0.75
	1994	4	0	0	0	0.00
	1995	2	1	50	1	0.50
	1996	4	2	50	3	0.75
	1997	3	2	67	3	1.00
	Mean*	**3.3**	**1.3**	**38**	**1.7**	**0.48[b] ± 0.31**
Barkley Sound (n=47)	1992	36	16	44	21	0.58
	1993	35	20	57	26	0.74
	1994	30	8	27	12	0.40
	1995	30	11	37	21	0.7
	1996	26	16	61	19	0.73
	1997	21	7	33	8	0.38
	Mean*	**29.7**	**13.0**	**44**	**17.8**	**0.58[b] ± 0.12**

a,b = data not sharing the same letter are significantly different ($p<0.05$)
* = all years pooled

Table 1.3. Average brood size, prey delivery rates, adult and eaglet behavior, and eaglet lipid plasma levels (analyzed using two different methods of analysis) including 95% confidence intervals at nests near Crofton and in Barkley Sound.

Location	Average brood size (1992-1997)	Mean prey deiveries $hour^{-1} eaglet^{-1}$	Mean prey biomass $day^{-1} eaglet^{-1}$	**Mean prey energy $day^{-1} eaglet^{-1}$	*Mean adult nest attendance (%)	*Mean eaglet activity (%)	Eaglet plasma lipid (%)	
							Gravimetric	Colorimetric
North of mill	$1.63^{a} \pm 0.50$	$0.30^{a} \pm 0.04$	$498^{a} \pm 112$	$1967^{b} \pm 438$	$33^{a} \pm 8$	$27^{b} \pm 3$	$0.163^{a} \pm 0.09$	$0.82^{a} \pm 0.17$
South of mill	$1.29^{ab} \pm 0.31$	$0.29^{a} \pm 1.50$	$395^{ab} \pm 105$	$1494^{c} \pm 410$	$18^{b} \pm 9$	$42^{a} \pm 5$	$0.228^{a} \pm 0.22$	$3.20^{a} \pm 2.52$
Barkley Sound	$1.25^{b} \pm 0.12$	$0.23^{a} \pm 0.07$	$337^{b} \pm 36$	$2262^{a} \pm 408$	$12^{b} \pm 4$	$42^{a} + 5$	$0.073^{a} \pm 0.04$	$0.612^{a} \pm 0.10$

*In relation to total observation time.
a, b, c = data not sharing the same letter are significantly different ($p<0.05$)
** $p<0.09$

location. Broods of two were more common north of the mill while broods of one were most common in Barkley Sound. Broods of one tended to be more common south of the mill compared to north of the mill but the difference was not significant, possibly due to the small sample size of successful nesting attempts observed between 1992-1997 in those areas (South of the mill, n = 8, north of mill, n = 11).

Prey species

A total of 12 prey species were identified during nest observations in this study (Table 1.4). Prey deliveries were identified to class (fish, bird or mammal) for 58 deliveries (61%) south of the mill, 167 deliveries (49%) north of the mill, and 87 deliveries (55%) in Barkley Sound. Prey were identified to species for 29 deliveries (31%) south of the mill, 77 deliveries (29%) north of the mill, and 58 deliveries (37%) in Barkley Sound. Fish prey were classified to species for 28 deliveries (50%) south of the mill, 73 deliveries north of the mill (45%), and 57 deliveries in Barkley Sound (67%). Bird and mammal prey were classified to species for 1 (mammal) delivery (50%) south of the mill, 4 (2 birds and 2 mammals) deliveries north of the mill (100%), and 1 (bird) delivery in Barkley Sound (50%).

Fish comprised more than 95% of the prey deliveries to nests near Crofton and in Barkley Sound and accounted for 8 of the 12 prey species identified in this study. However, the principle fish species utilized by nesting eagles in each study area differed. South of the mill, Pacific herring (*Clupea harengus*) comprised the majority of prey deliveries (48%) with an average weight of 61 ± 13 grams and an average energy content of 238 ± 50 kJ. North of the mill, the plainfin midshipman (*Porychthys notatus*) was the most common prey delivery comprising 74% of all known deliveries (average weight = 96 ± 8 grams, average

Table 1.4. Prey types delivered to nests near Crofton and in Barkley Sound during the 1996 breeding season.

Location	Species	Scientific name	% prey type	Mean prey size (cm)	Mean biomass (grams)	Mean energy content (kJ)
North of mill	Plainfin midshipman	*Porychthys notatus*	74	16	96	403
	Pacific herring	*Clupea harengus*	17	15	56	212
	English sole	*Inopsetta ischyra*	3	16	177	526
	Silver Surf perch	*Hyperprospon ellipticum*	1	20	91	352
	European rabbit (juvenille)	*Oryctolagus cuniculus*	1	20	1350	5967
	Townsend's vole	*Microtus townsendii*	1	13	20	90
	Mallard duckling	*Anas platyrhynchos*	1	9	150	1046
	Pigeon guillemot	*Cepphus columba*	1	38	487	3394
South of mill	Pacific herring	*Clupea harengus*	48	17	61	238
	Plainfin midshipman	*Porychthys notatus*	26	16	96	405
	Ling cod	*Ophiodon elongatus*	10	29	263	349
	European rabbit (juvenille)	*Oryctolagus cuniculus*	6	21	685	3028
	Coho salmon	*Oncorhynchus kisutch*	6	30	884	4137
	Pollock	*Theragra chalcogramma*	3	32	1005	3075
Barkley Sound	Mackerel	*Scomber japonicus*	69	26	226	1713
	Pacific herring	*Clupea harengus*	18	18	79	307
	Mallard duckling	*Anas platyrhynchos*	4	21	327	2277
	Silver Surf perch	*Hyperprospon ellipticum*	4	9	7	26
	English sole	*Inopsetta ischyra*	4	17	101	334
	Coho salmon	*Oncorhynchus kisutch*	2	23	287	1343

energy content = 403 ± 70 kJ). In Barkley Sound, Pacific mackerel (*Scomber japonicus*) comprised 68% of observed deliveries with an average weight of 219 ± 41 grams and an average energy content of 1713 ± 289 kJ. The second most common prey delivery to nests north of the mill and those in Barkley Sound was Pacific herring (18%).

Very few birds and mammals were delivered to nests in the three study areas. No birds were delivered to nests under observation south of the Crofton mill. Bird deliveries (mallard ducklings (*Anas platyrhynchos*) and pigeon guillemots (*Cepphus columba*)) comprised approximately 3-4% of the prey deliveries to nests north of the mill and those in Barkley Sound. Similarly, European rabbits (*Oryctolagus cuniculus*) and Townsend's voles (*Microtus townsendii*) comprised 2-6% of the total prey deliveries to nests near Crofton. No mammals were delivered to nests under observation in Barkley Sound.

Energetics

Average length of prey delivered to nests in Barkley Sound (19.0 ± 1.5 cm) was greater than that for nests north of mill (15.0 ± 0.6 cm). No difference in prey length was evident between nests south of mill (16.0 ± 1.3 cm) and those in Barkley Sound.

Mean number of prey deliveries per hour per eaglet was not significantly different among all study locations. However, sample sizes were small and nests north of the mill were highly variable in terms of prey delivery rates. Personal observations suggest that nestlings in Barkley Sound received fewer prey deliveries (Table 1.3).

When data from all study areas were pooled, prey delivery rates were positively correlated with the average number of chicks produced per occupied territory (Figure 1.3). For nests south of the Crofton mill and in Barkley Sound, the lower prey delivery rates

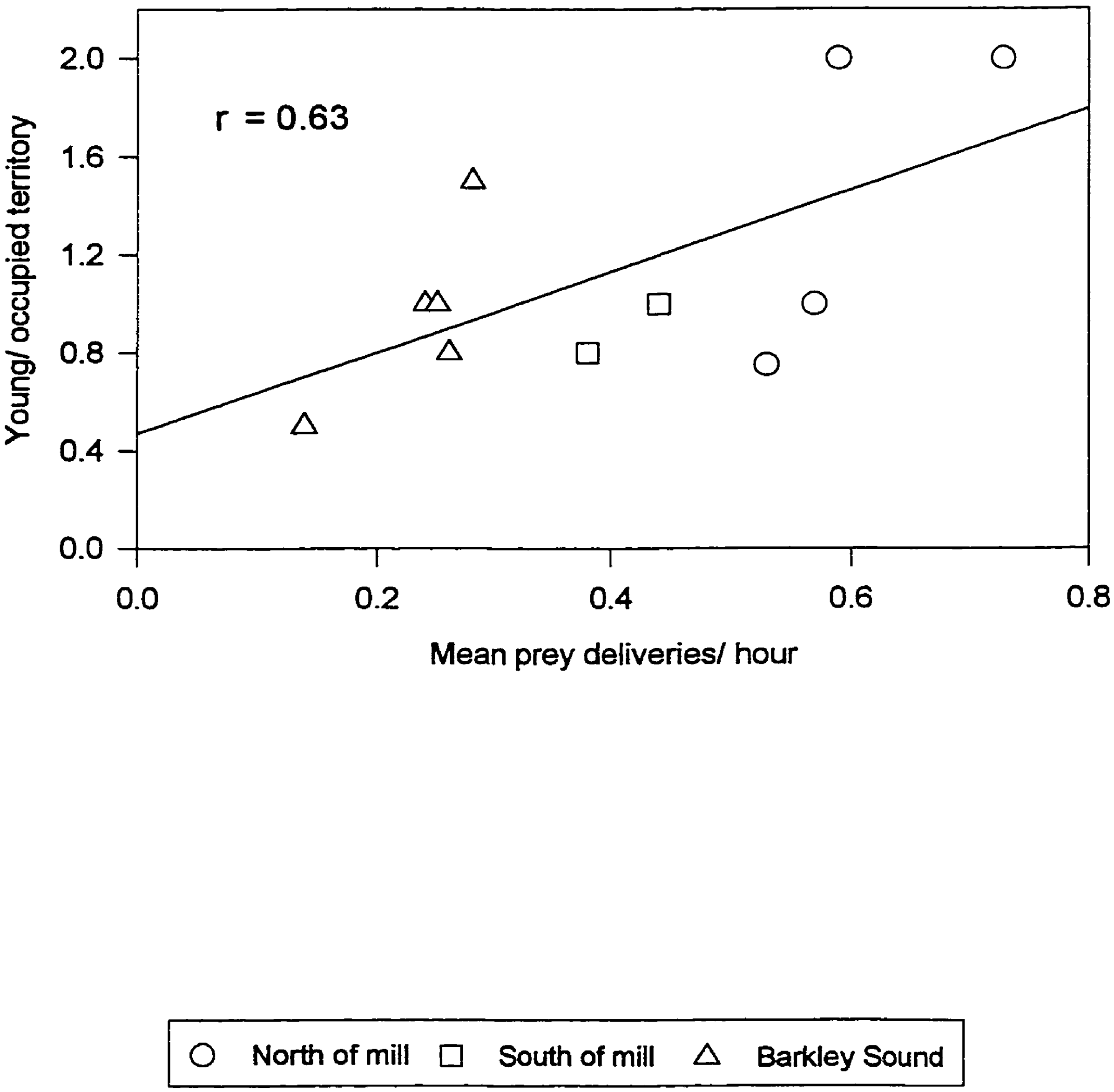

Figure 1.3. Number of young per occupied territory (1992-1997) for nests near Crofton and Barkley Sound in relation to mean number of prey deliveries per hour.

corresponded to fewer chicks per occupied territory. However, this correlation may be due to 2 nests north of the Crofton mill which had high prey delivery rates and high productivity compared to all other nests in this study.

Prey biomass per eaglet north of the mill averaged 498 ± 112 g eaglet^{-1}day^{-1} and was greater than that delivered to nests in Barkley Sound (337 ± 105 g eaglet^{-1} day^{-1}). South of the mill, prey biomass averaged 395 ± 36 g eaglet^{-1} day^{-1} and did not differ from that estimated for nests north of the mill or Barkley Sound (Table 1.3).

There was a tendency for prey energy per eaglet to be lowest at nests south of the Crofton mill averaging 1494 ± 410 kJ eaglet^{-1} day^{-1}, intermediate at nests north of the mill (1967 ± 438 kJ eaglet^{-1} day^{-1}), and highest at nests in Barkley Sound (2262 ± 408 kJ eaglet^{-1} day^{-1}, $p \leq 0.09$, Table 1.3). Prey energy was highly variable north of the mill and in Barkley Sound.

Productivity was positively correlated with prey biomass per eaglet delivered to nests near Crofton and Barkley Sound (Figure 1.4). Prey biomass and productivity was usually lower for nests in Barkley Sound and south of the mill. However, this trend may be due to 2 nests which had significantly higher prey biomass and productivity than all other nests in this study. Biomass estimated per eaglet north of the Crofton mill was highly variable ranging from 205 - 975 grams.

The number of prey deliveries per hour increased with increasing brood size (Figure 1.5). For broods of 1, prey delivery rates averaged 0.2 ± 0.04 deliveries per hour. Broods of 2 received approximately 0.5 ± 0.08 prey deliveries per hour while the only brood of 3 in this study received 0.95 prey deliveries per hour. Most broods of one, however, occurred in Barkley Sound while the majority of 2 eaglet nests were found north of the Crofton mill.

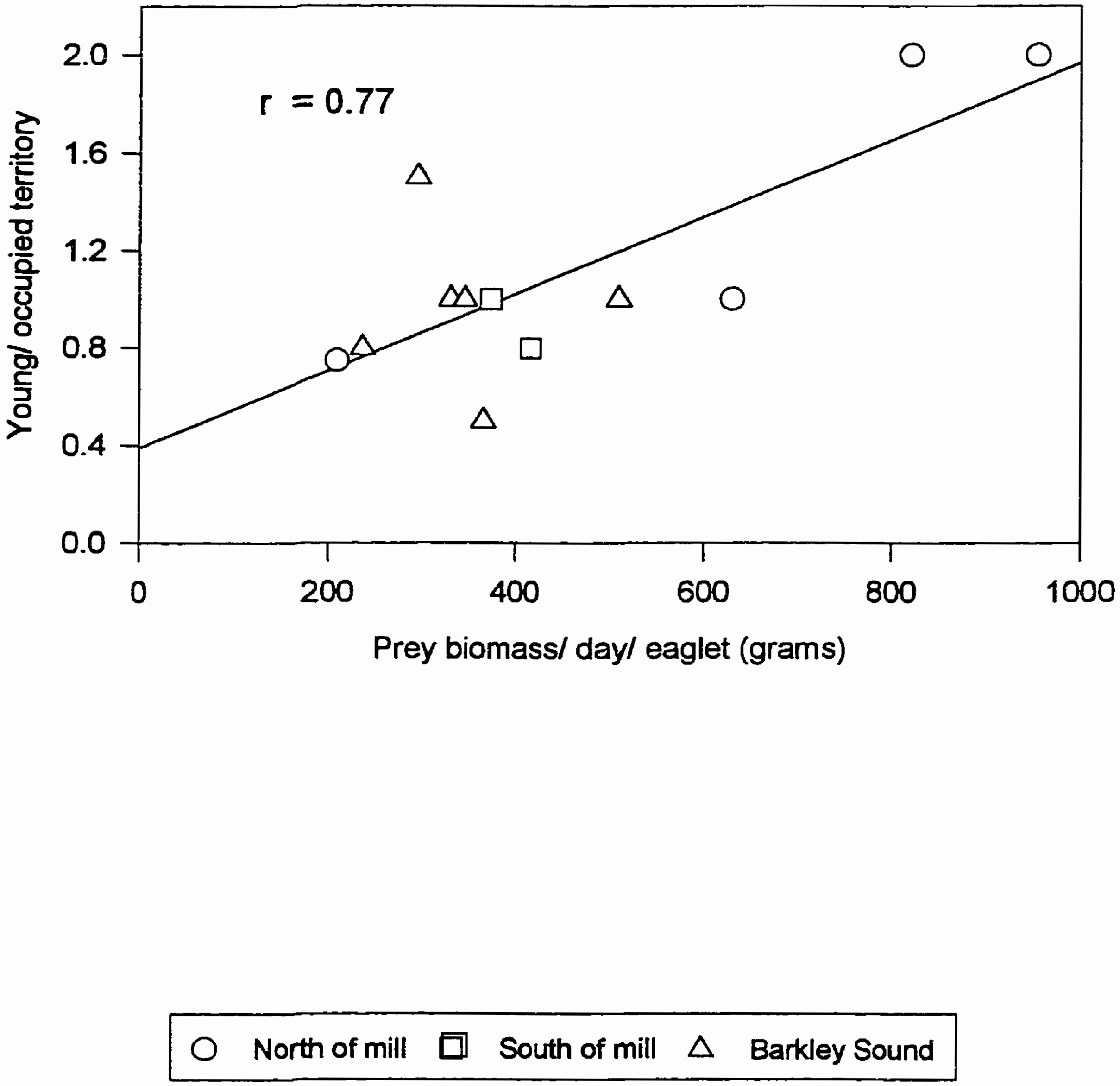

Figure 1.4. Number of young per occupied territory (1992-1997) for nests near Crofton and Barkley Sound in relation to mean prey biomass delivered to nests per day per eaglet.

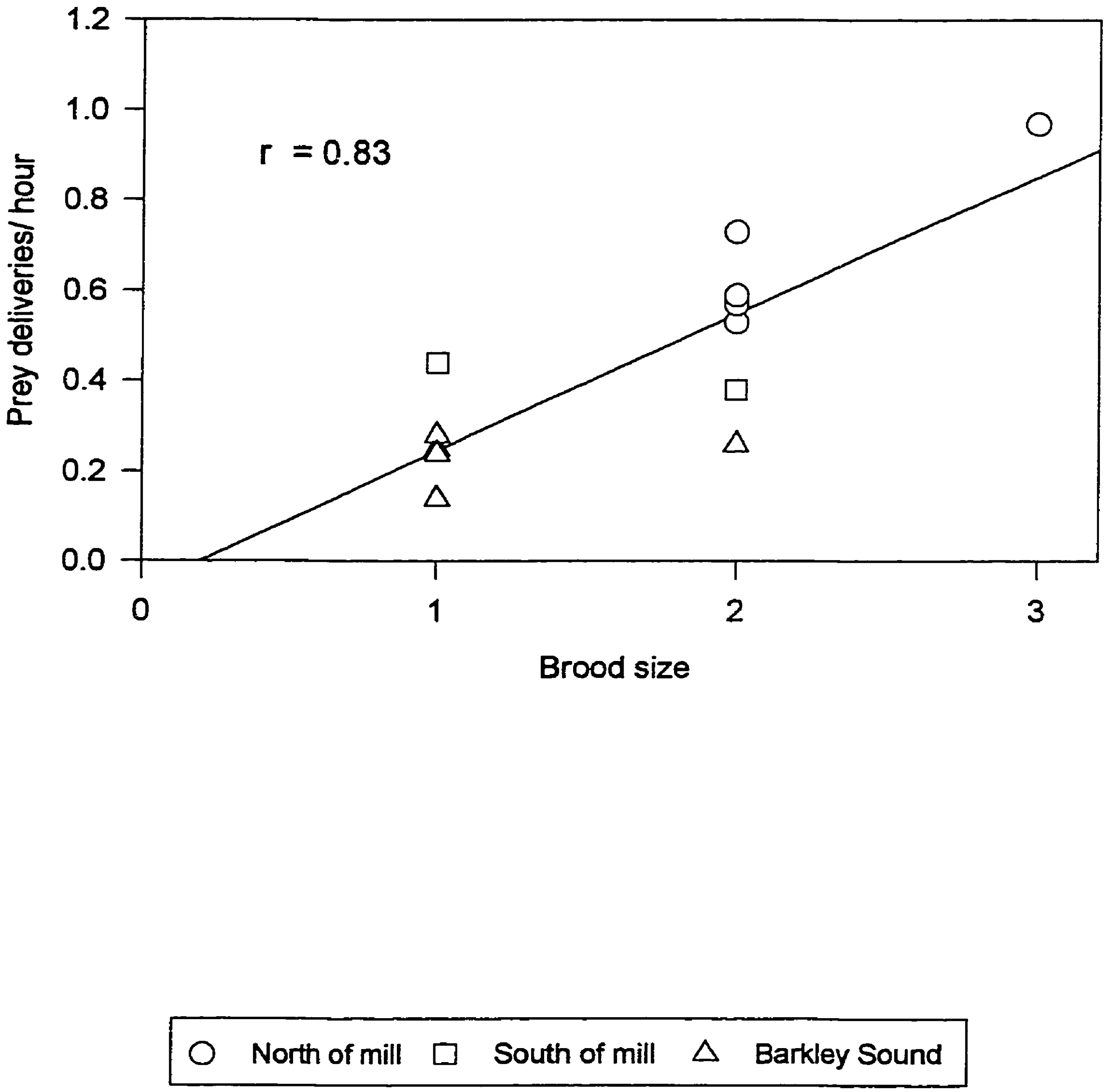

Figure 1.5. Number of prey deliveries per hour to nests near Crofton and Barkley Sound in relation to brood size.

Prey delivery rates were weakly correlated with eaglet age for nests near Crofton and those in Barkley Sound ($r = -0.36$, $P < 0.049$, Figure 1.6). Prey delivery rates were maximal at 3 weeks of age for nests north of the mill and in Barkley Sound. Data was unavailable at this age for nests south of the mill. In Barkley Sound, delivery rates gradually declined as the eaglets matured with the fewest deliveries occurring at 9 weeks of age. South of the mill, prey delivery rates were lowest at 2 and 4 weeks of age and maximal at 6 weeks.

Lipid plasma levels

Eaglet lipid plasma levels determined by the gravimetric and colorimetric methods were not significantly different among all study locations possibly due to high variability among samples south of the Crofton mill (gravimetric: 0.228 ± 0.22 %, colorimetric: 3.20 ± 2.52 %, Table 1.3). Both methods of lipid determination were highly correlated (Figure 1.7). Colorimetric values were significantly higher than gravimetric values possibly because both triglycerides and phospholipids are measured by the colorimetric method while only triglycerides are measured by the gravimetric method (Frings *et al.* 1972). Two samples with lipid levels that were significantly higher than all other values were omitted from the plot but included in the correlation analysis. Lipid levels in eaglet blood plasma determined by the colorimetric method were not significantly correlated with mean 6-year productivity, prey delivery rates, prey biomass, prey energy or eaglet activity for nests near Crofton and in Barkley Sound (Figures 1.8, 1.9, 1.10, 1.11, and 1.12).

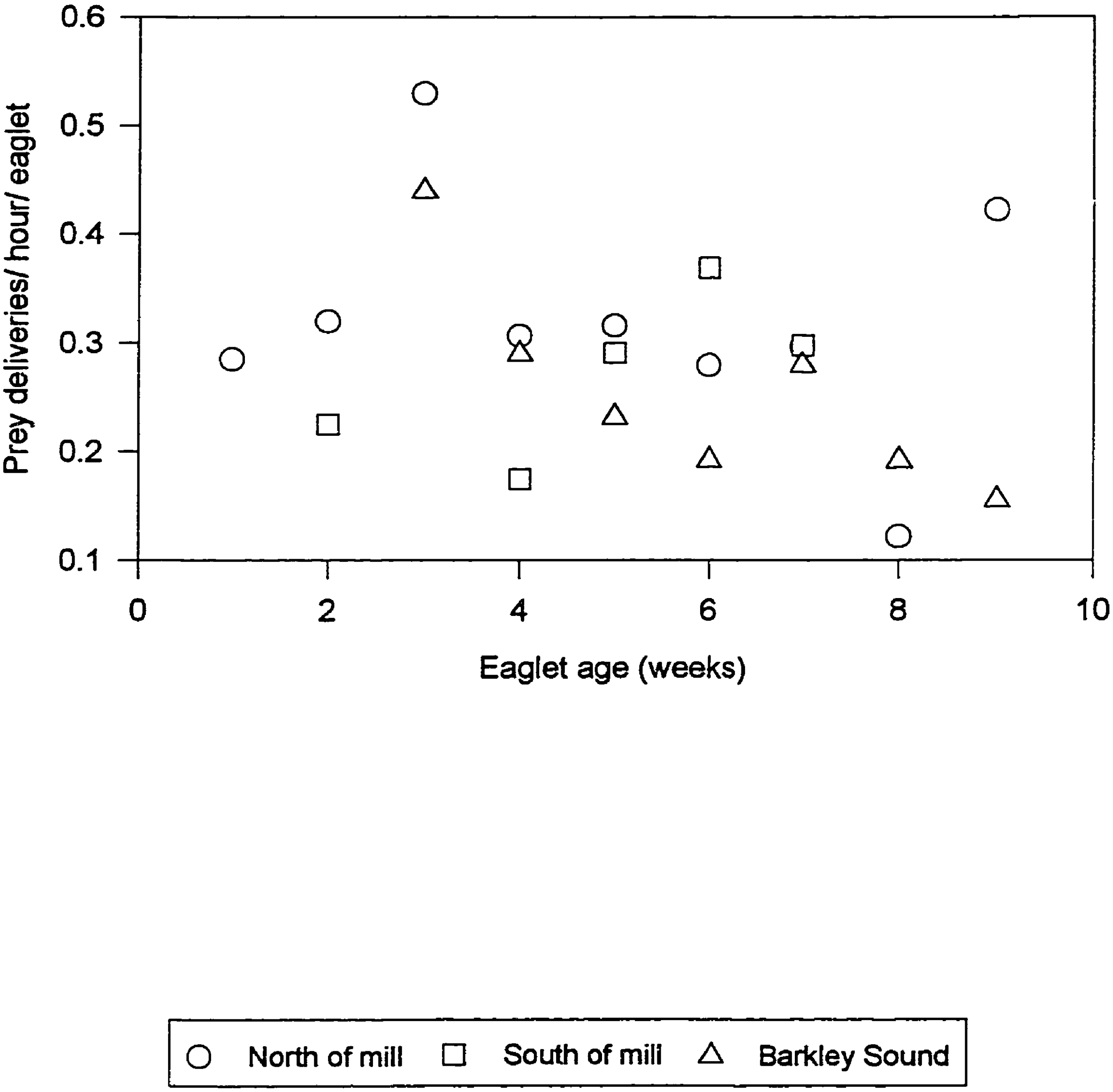

Figure 1.6. Mean prey deliveries per hour per eaglet for nests near Crofton and Barkley Sound in relation to eaglet age.

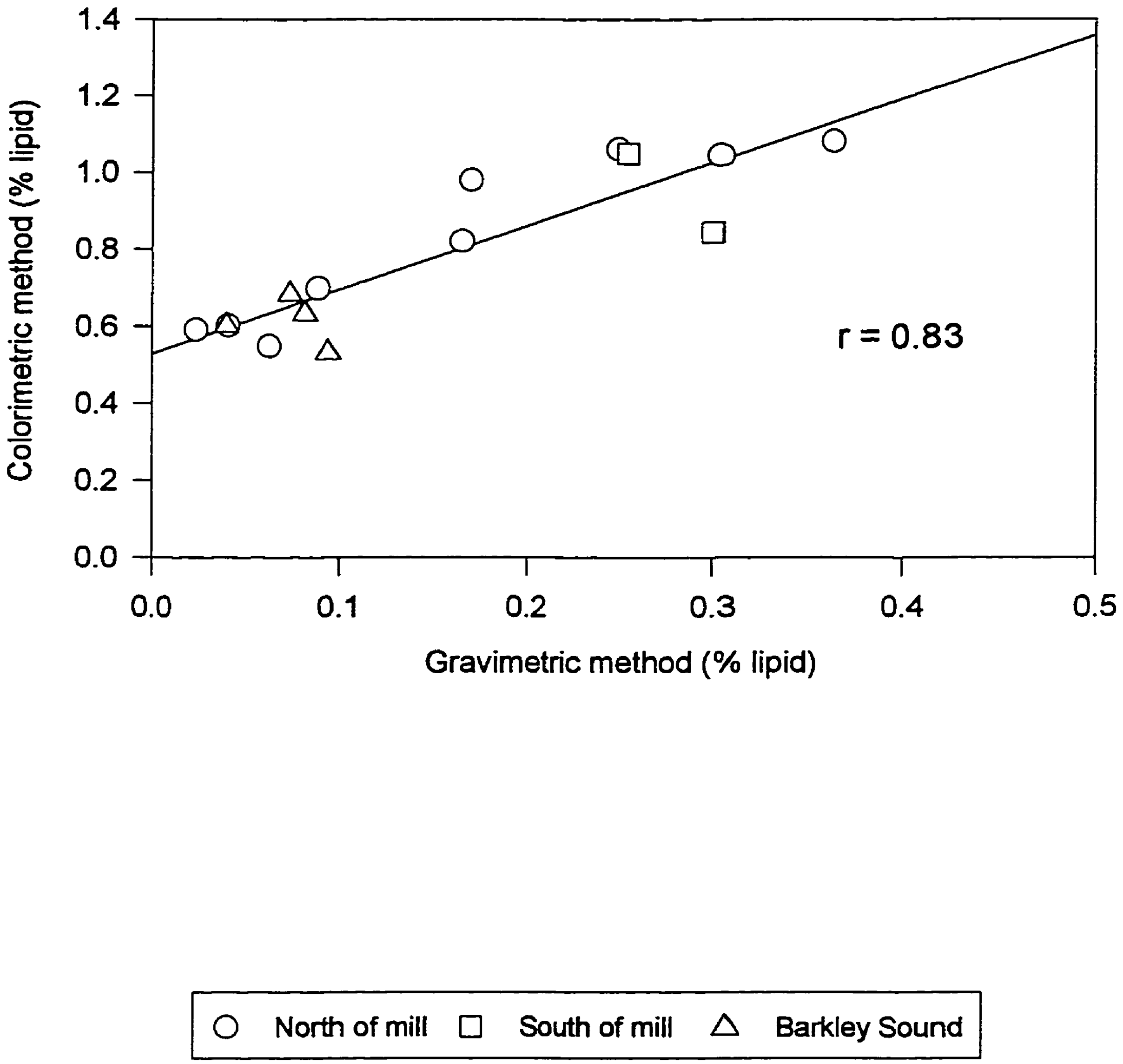

Figure 1.7. Comparison of two methods of lipid determination for eaglet plasma samples collected from Crofton and Barkley Sound.

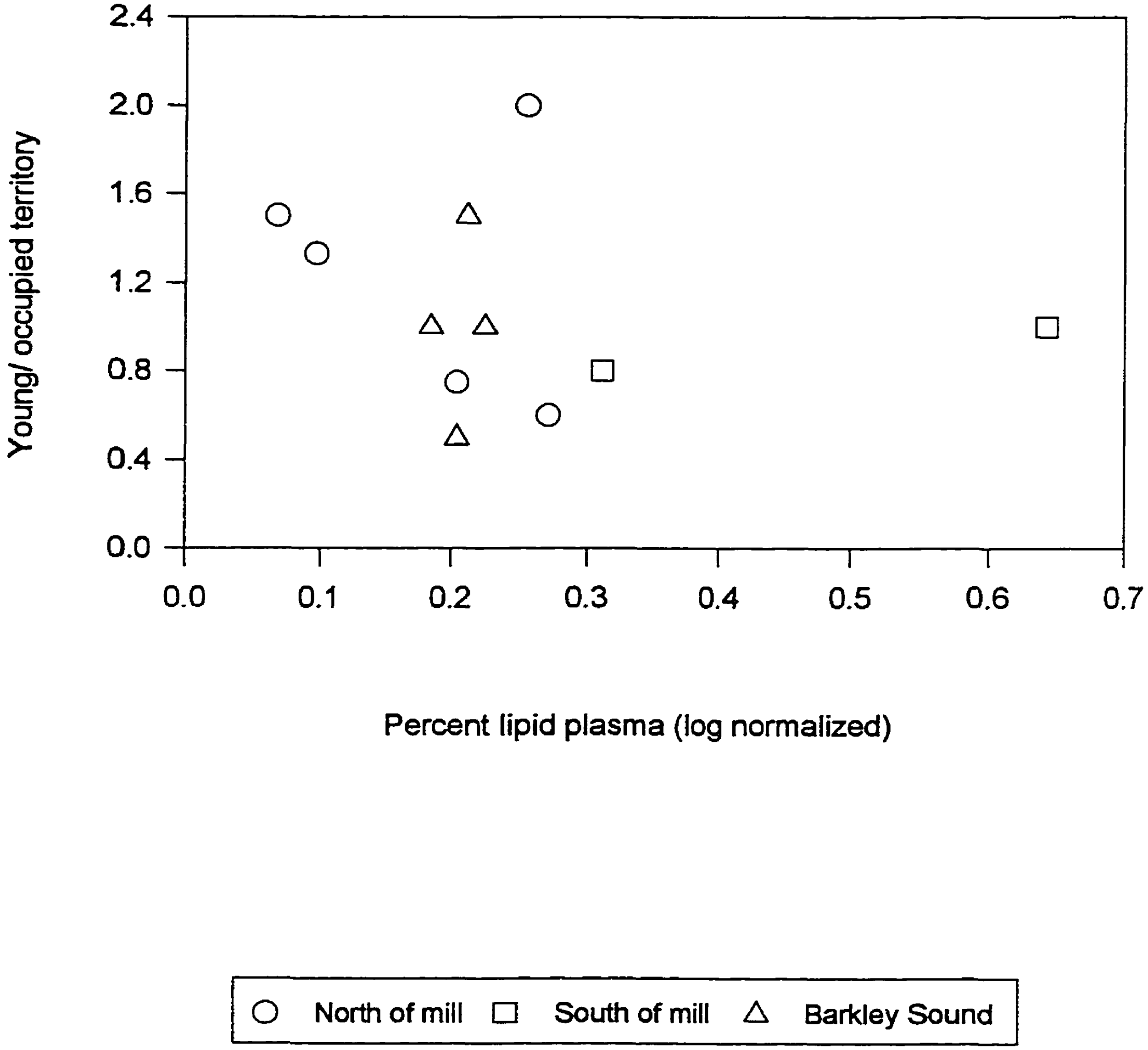

Figure 1.8. Average 6-year productivity near Crofton and in Barkley Sound in relation to eaglet lipid plasma levels (determined by the colorimetric method).

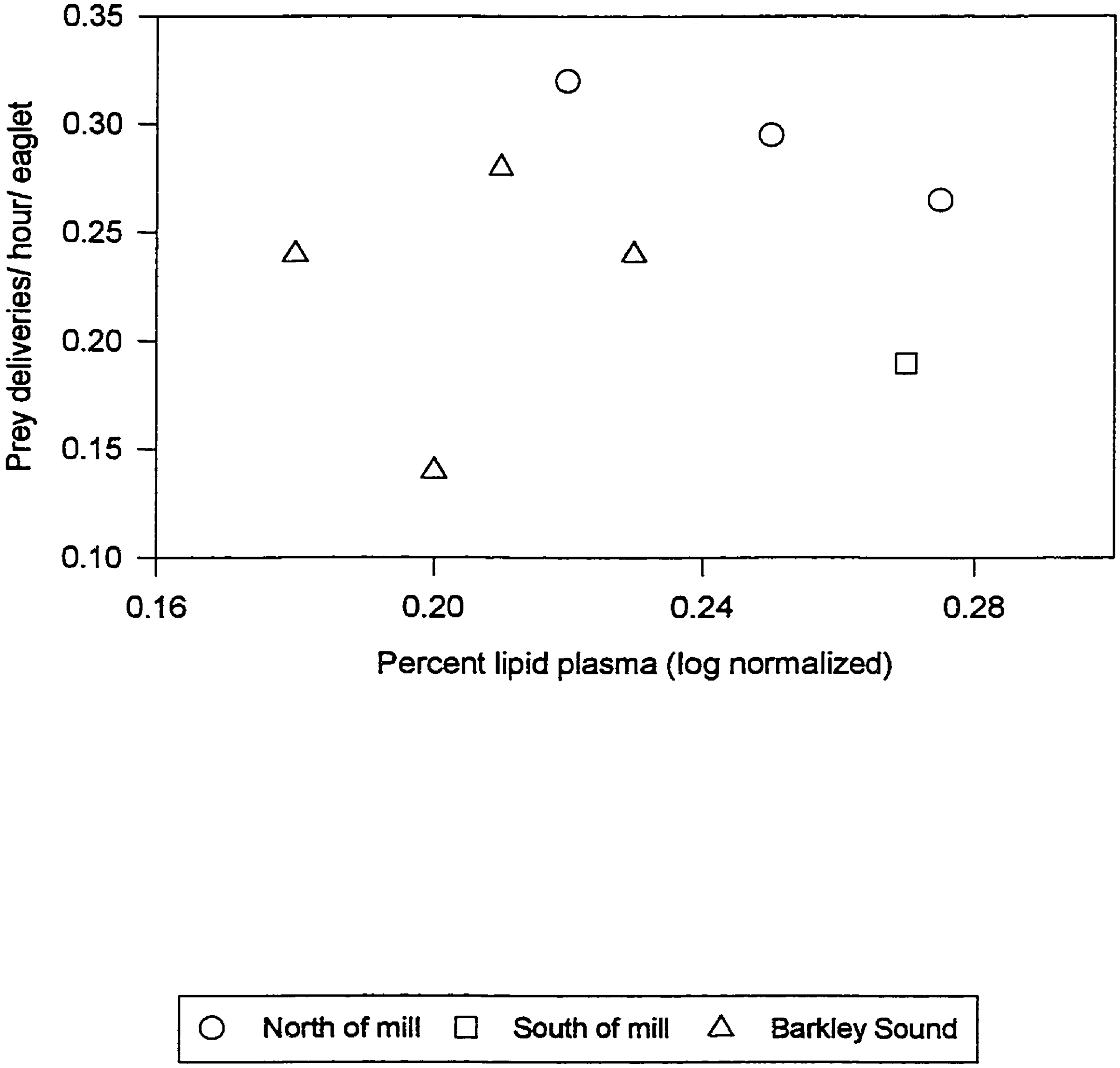

Figure 1.9. Mean number of prey deliveries per hour per eaglet delivered to nests near Crofton and Barkley Sound in relation to eaglet lipid plasma levels (determined by the colormetric method).

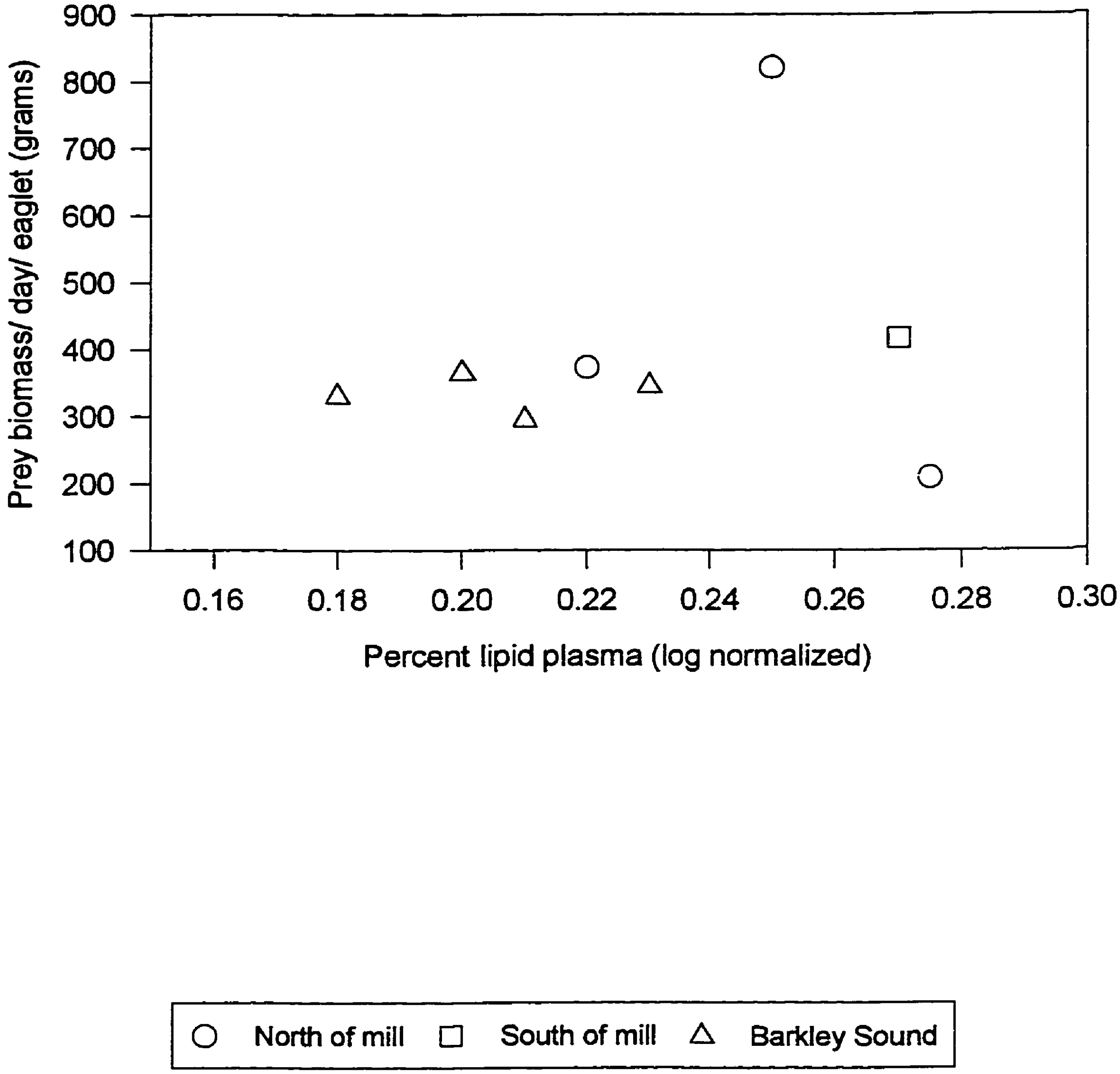

Figure 1.10. Average prey biomass per eaglet delivered to nests near Crofton and Barkley Sound in relation to eaglet lipid plasma levels (determined by the colorimetric method).

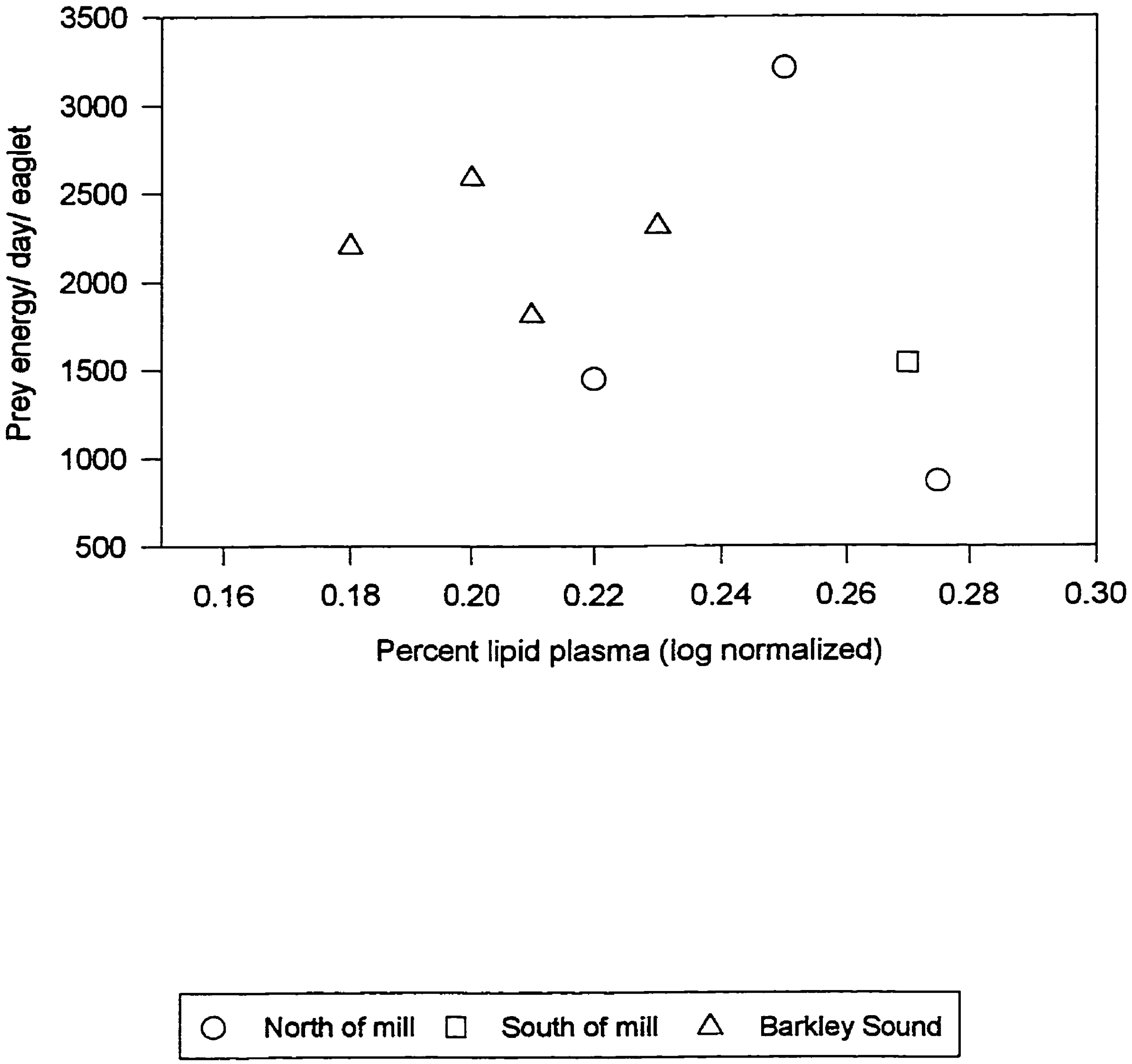

Figure 1.11. Average prey energy per eaglet delivered to nests near Crofton and Barkley Sound in relation to eaglet lipid plasma levels (determined by the colorimetric method).

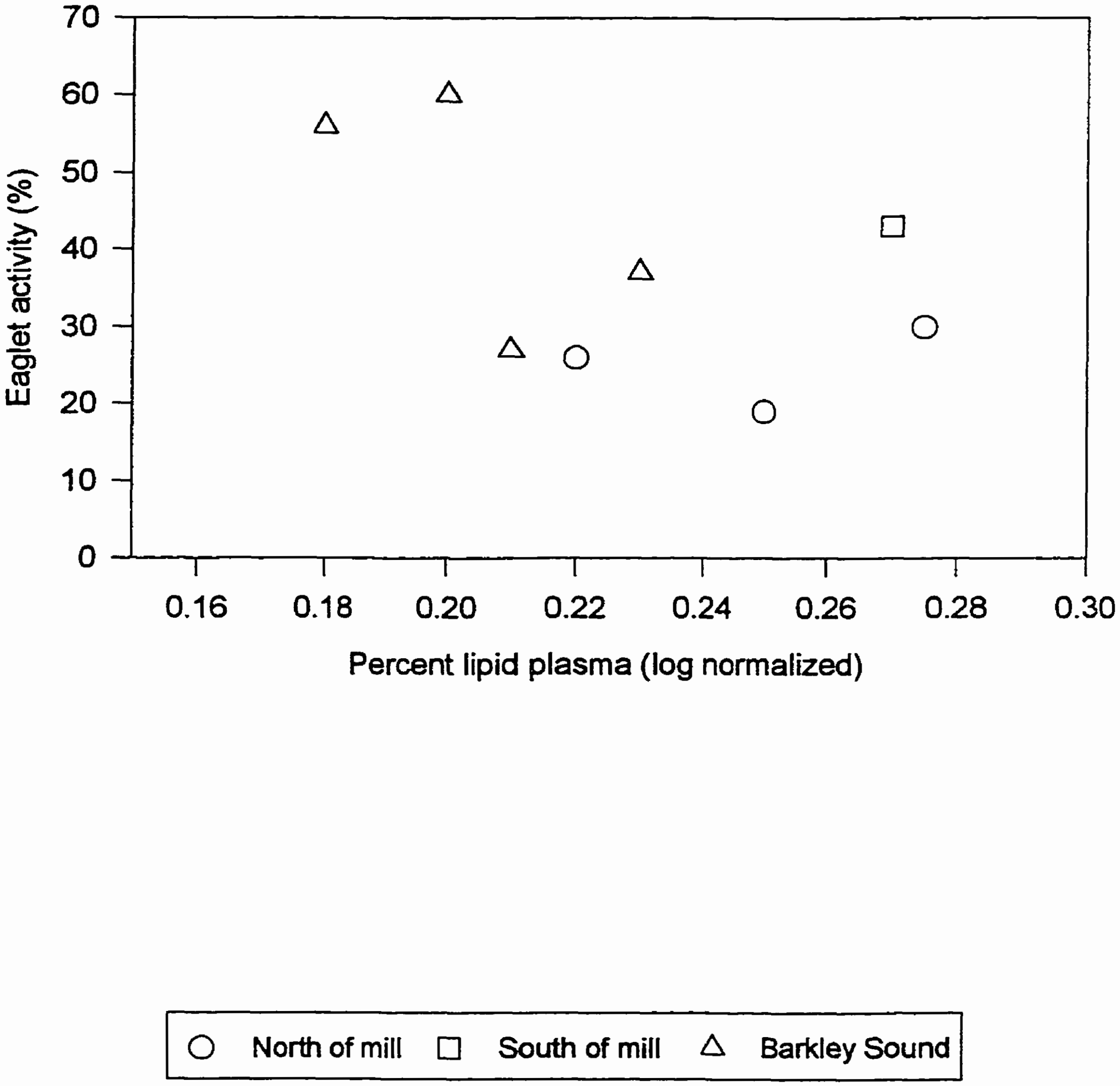

Figure 1.12. Average eaglet activity at nests near Crofton and Barkley Sound in relation to eaglet lipid plasma levels (determined by the colorimetric method).

Timing of prey deliveries

The number of prey deliveries per hour varied depending on tide height, tidal conditions, and time of day (Figures 1.13, 1.14, 1.15). Prey delivery rates peaked during tides of intermediate height, and between ebb and slack low tide. Near Crofton, maximal prey delivery rates occurred in the early morning, between 5:00 and 6:00 a.m.. Peak prey delivery periods also occurred around 10:00 a.m., 12:00 p.m. and 5:00 p.m.. In Barkley Sound, prey delivery rates were maximal around 8:00 a.m.. Lowest prey delivery periods occurred at 1:00 p.m. and at 8:00 p.m.. Overall, prey delivery rates tended to decline gradually throughout the day at all study locations.

Adult nest attendance

Nest attendance north of the Crofton mill was highly variable ranging from 16 - 75 % of the total observation time. Less variation was found for nests south of the mill (16 - 18 %) and in Barkley Sound (2 - 24 %). Adult nest attendance was greater at nests north of the Crofton mill (mean = 33 ± 8 % of total observation time) compared to nests south of the mill (mean = 18 ± 9 %), and those in Barkley Sound (mean = 12 ± 4 %). Mean adult nest attendance south of the mill did not differ significantly from that recorded for nests in Barkley Sound (Table 1.3). Productivity was positively correlated to mean adult nest attendance when data from all study areas were combined (Figure 1.16). However, this correlation may be due to 2 nests north of the Crofton mill that had significantly higher nest attendance times and productivity than all other nests in this study.

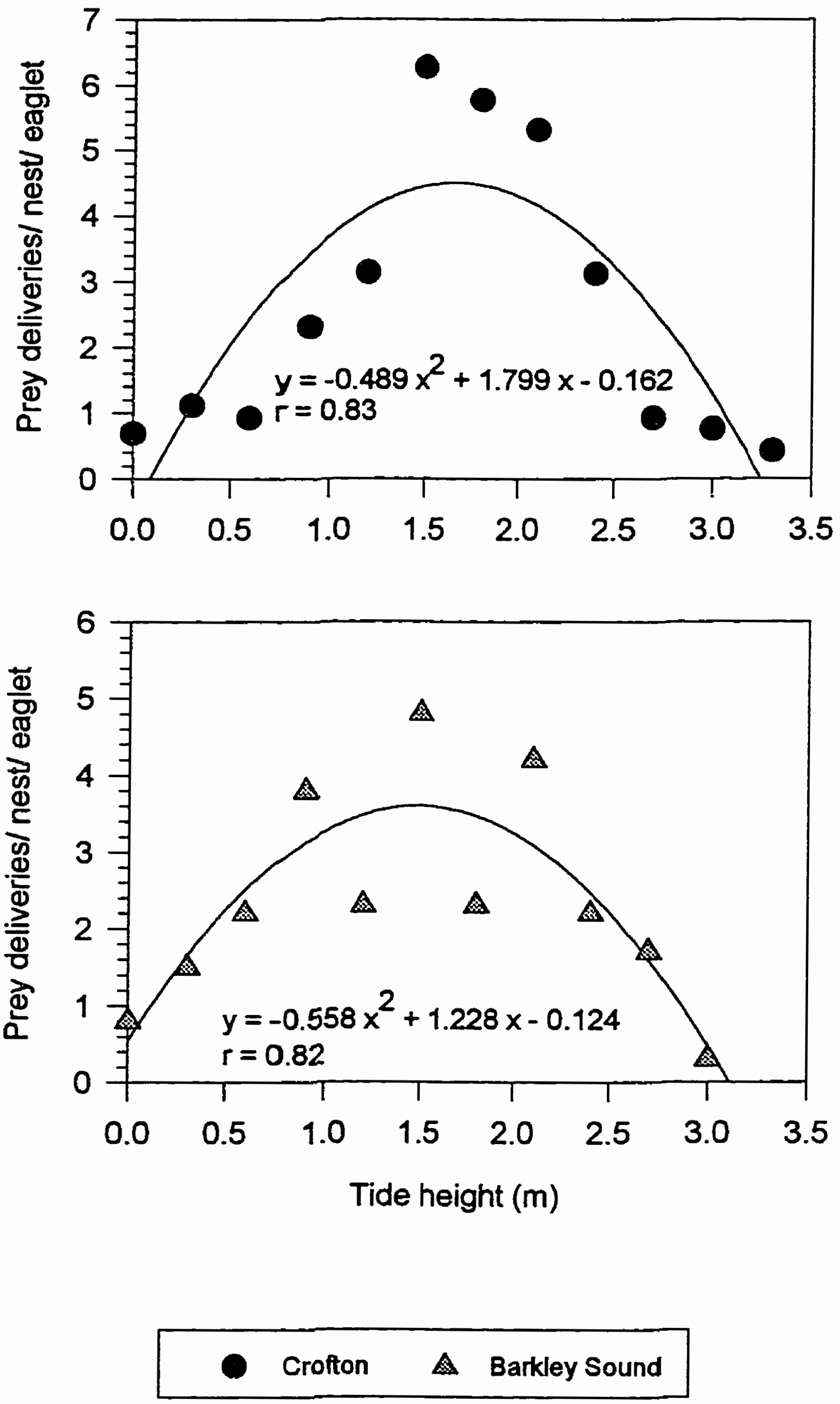

Figure 1.13. Number of prey deliveries per nest per eaglet near Crofton and Barkley Sound in relation to tide height.

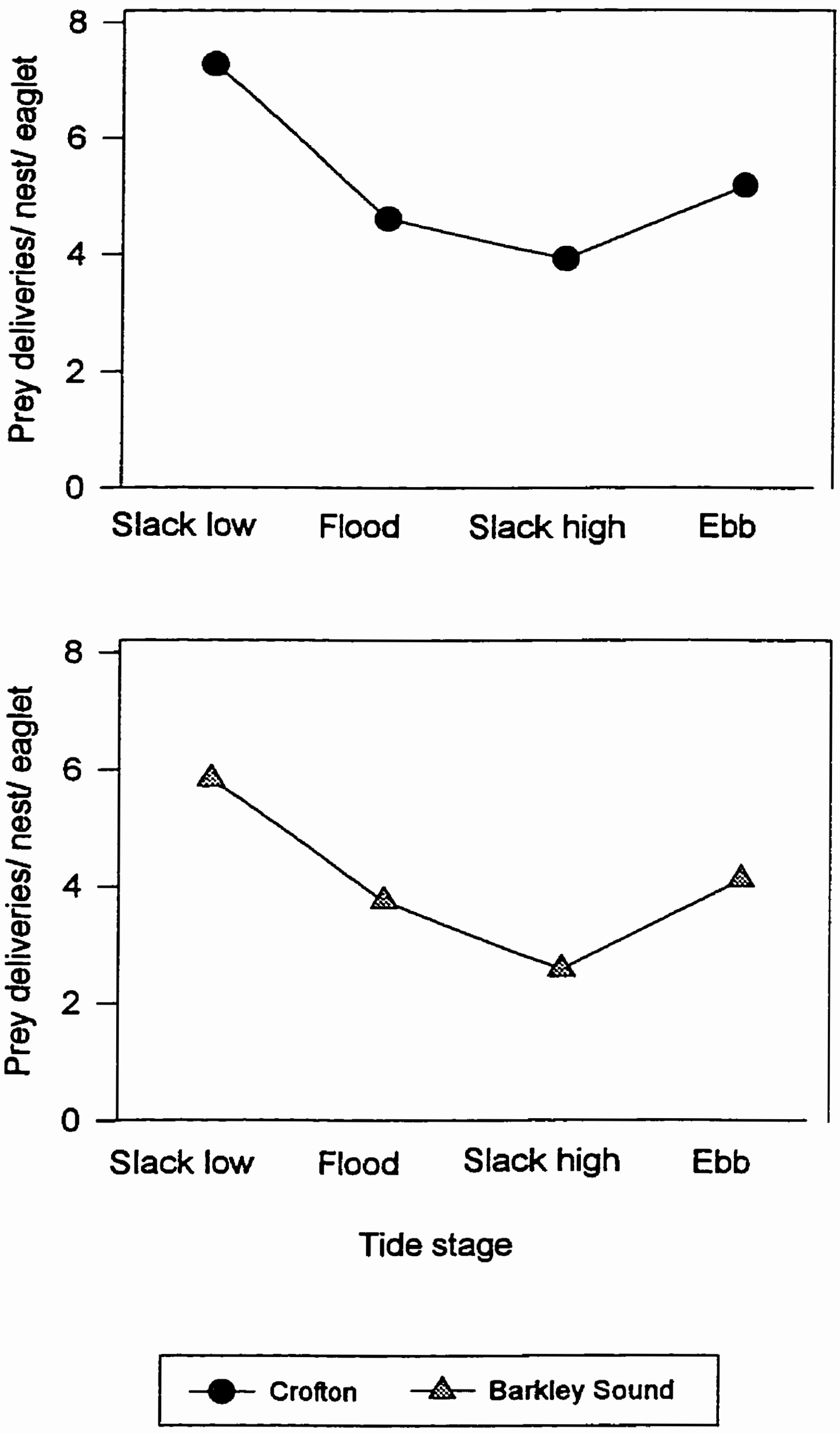

Figure 1.14. Number of prey deliveries per nest per eaglet near Crofton and Barkley Sound in relation to tidal conditions.

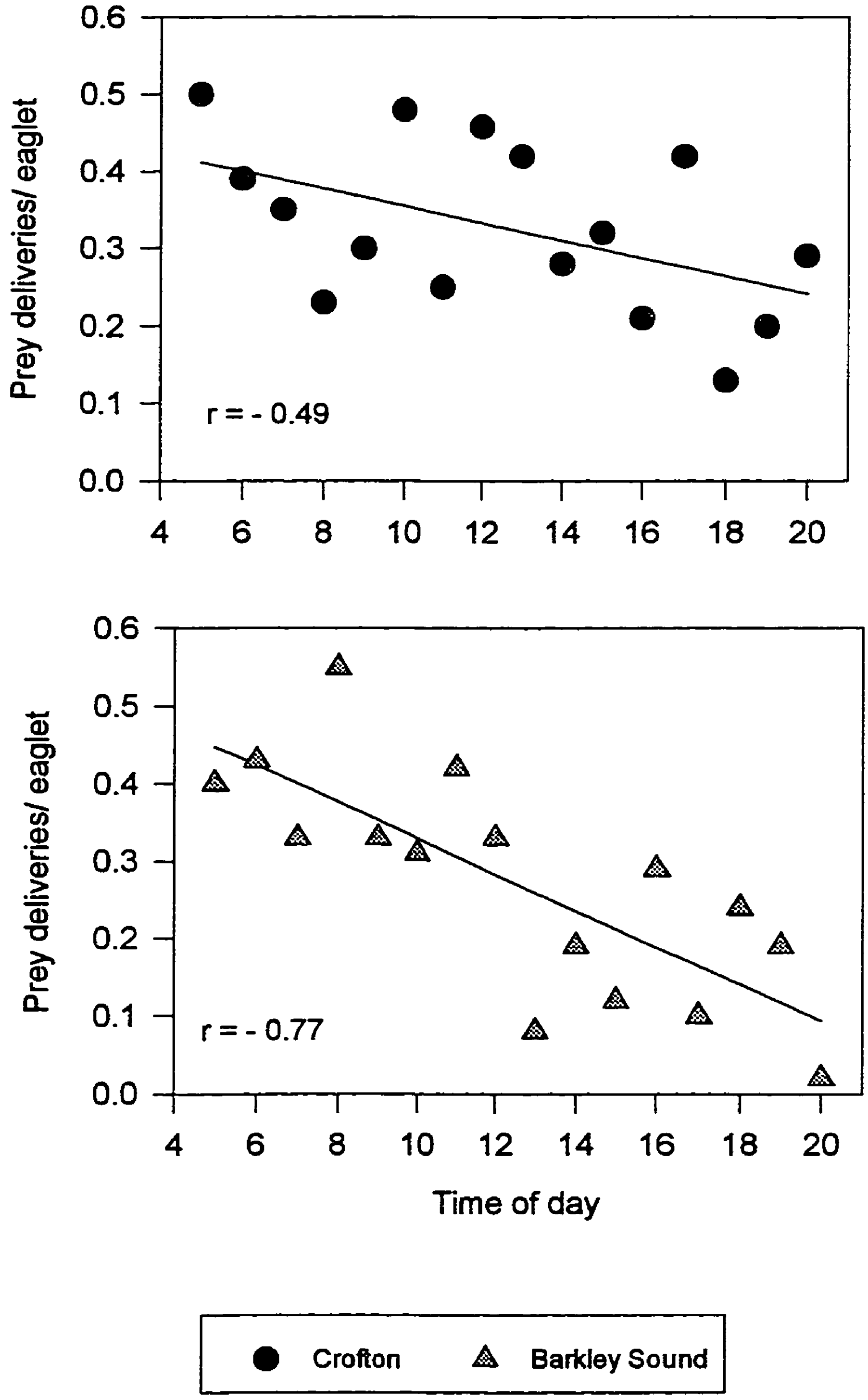

Figure 1.15. Number of prey deliveries per nest per eaglet near Crofton and Barkley Sound in relation to time of day.

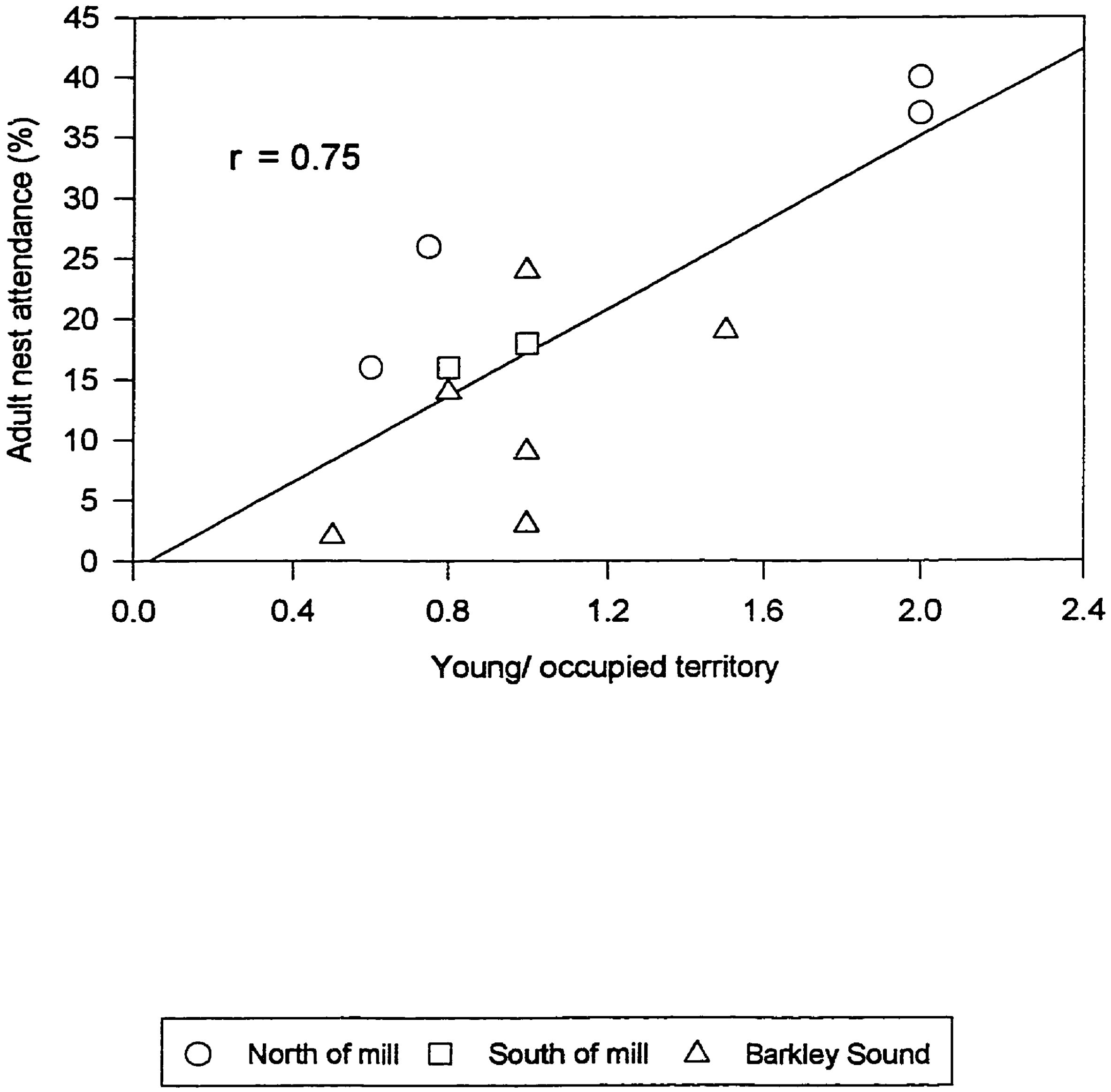

Figure 1.16. Average productivity near Crofton and Barkley Sound (1992-1997) in relation to mean adult nest attendance.

Adult nest attendance was weakly correlated with both brood size (Figure 1.17, $r = 0.33$, $p \leq 0.010$) and mean number of prey deliveries per hour per eaglet (Figure 1.18, $r = 0.34$, $p \leq 0.002$). As adult nest attendance increased, a corresponding increase in brood size and prey delivery rates was observed.

Nest attendance time was negatively correlated with eaglet age at all study areas (Figure 1.19). Nest attendance was highest when eaglets were 1-3 weeks of age. At this age, adult nest attendance was almost 100 % north of the mill. Attendance times declined rapidly between 3-7 weeks of age. By the time eaglets were 7 weeks old, attendance time had decreased to 42 ± 8 % of the total observation time for nests north of the mill, and approximately 5 ± 4 % for nests south of the mill and in Barkley Sound.

Eaglet activity

Eaglet activity levels were comparable between nests south of the Crofton mill and those in Barkley Sound (both 42 ± 5 % of total observation time, Table 1.3). Activity levels of nestlings north of the Crofton mill, however, were significantly less (27 ± 3 %). Eaglets from nests south of the mill and in Barkley Sound spent more time standing, feeding, preening, fighting with siblings, exercising wings, playing with nest material, and walking around the nest, than did their counterparts from nests north of the Crofton mill. Sibling activity levels were similar throughout the nestling stage regardless of the hatching order.

Eaglet activity was negatively correlated with adult nest attendance (Figure 1.20). North of the Crofton mill, nest attendance was the highest of all study areas. Eaglet activity, however, was below that found for nests south of the mill and in Barkley Sound. The difference in eaglet activity between broods of 1 and 2 may a result of differing geographical

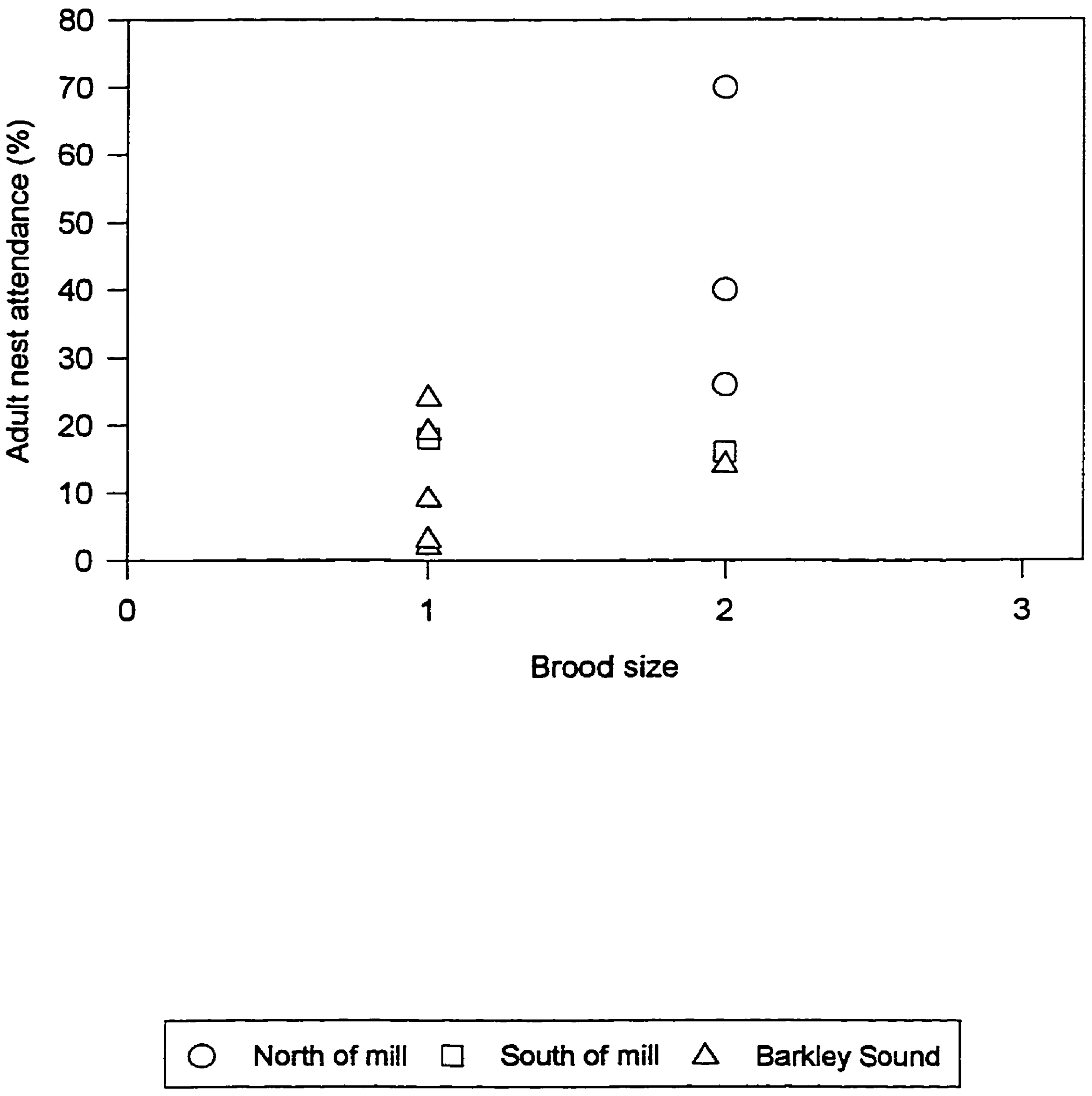

Figure 1.17. Mean adult nest attendance near Crofton and Barkley Sound in relation to brood size.

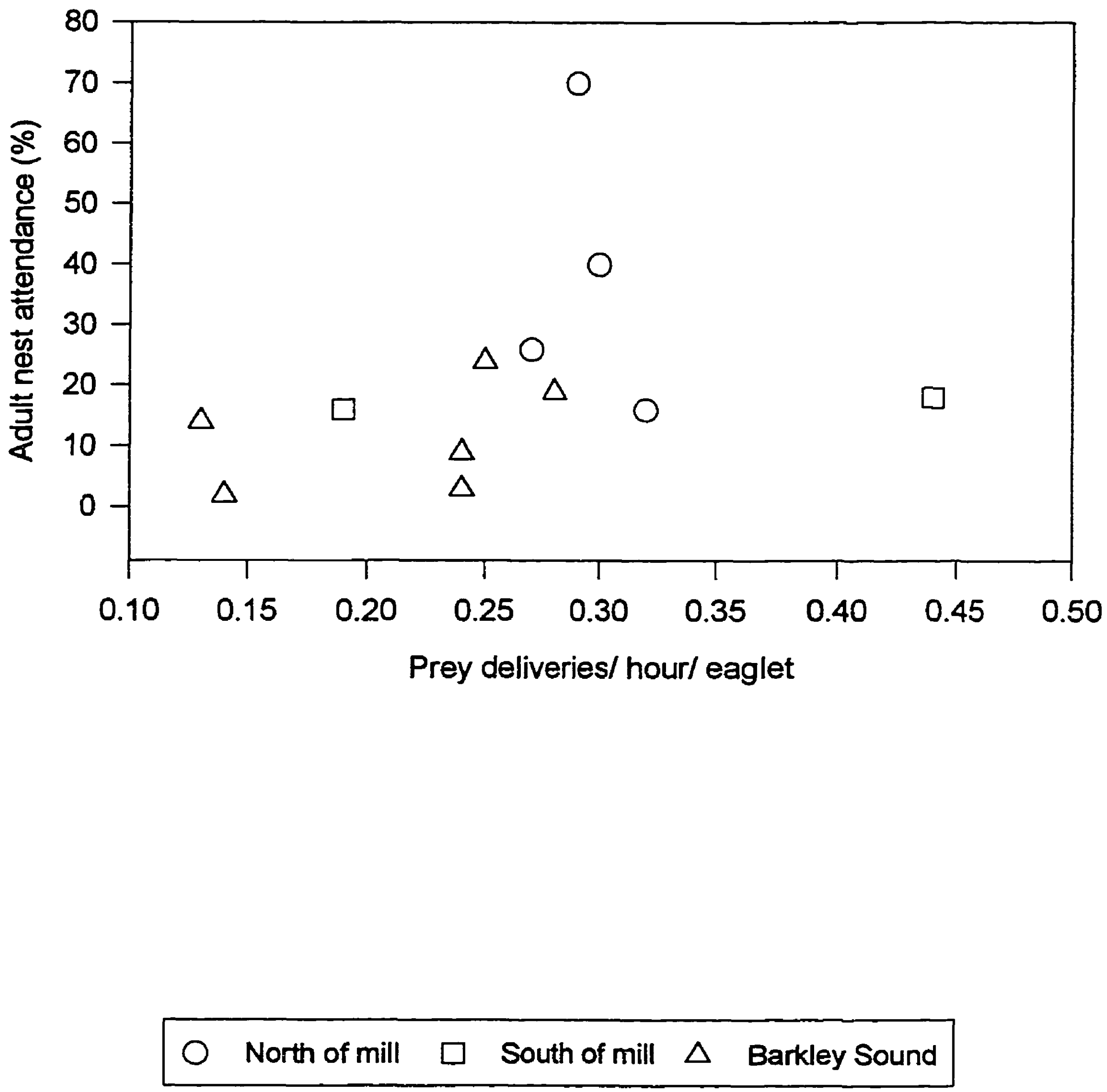

Figure 1.18. Mean adult nest attendance near Crofton and Barkley Sound in relation to mean number of prey deliveries per hour per eaglet.

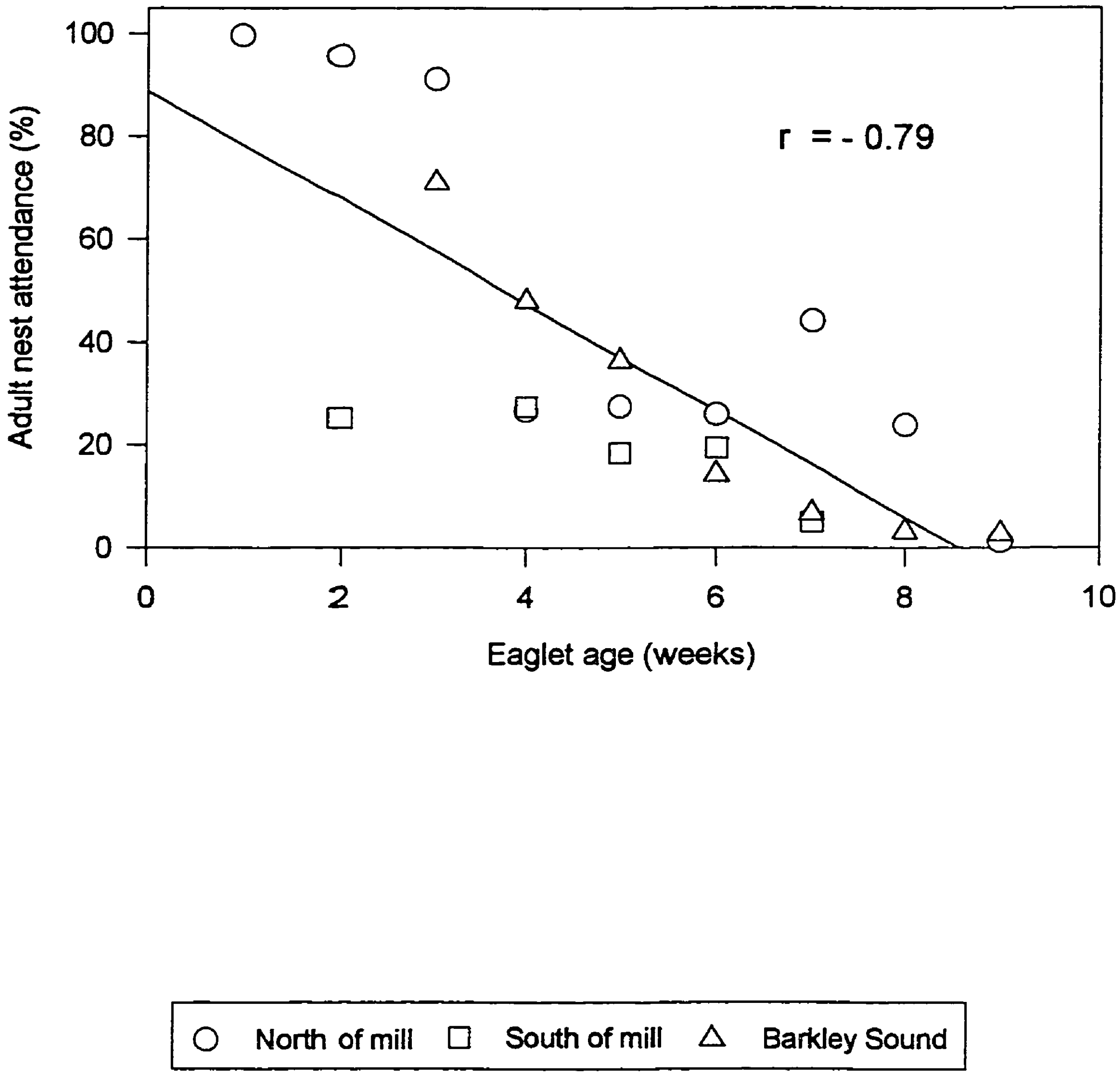

Figure 1.19. Adult nest attendance at nests near Crofton and Barkley Sound in relation to eaglet age.

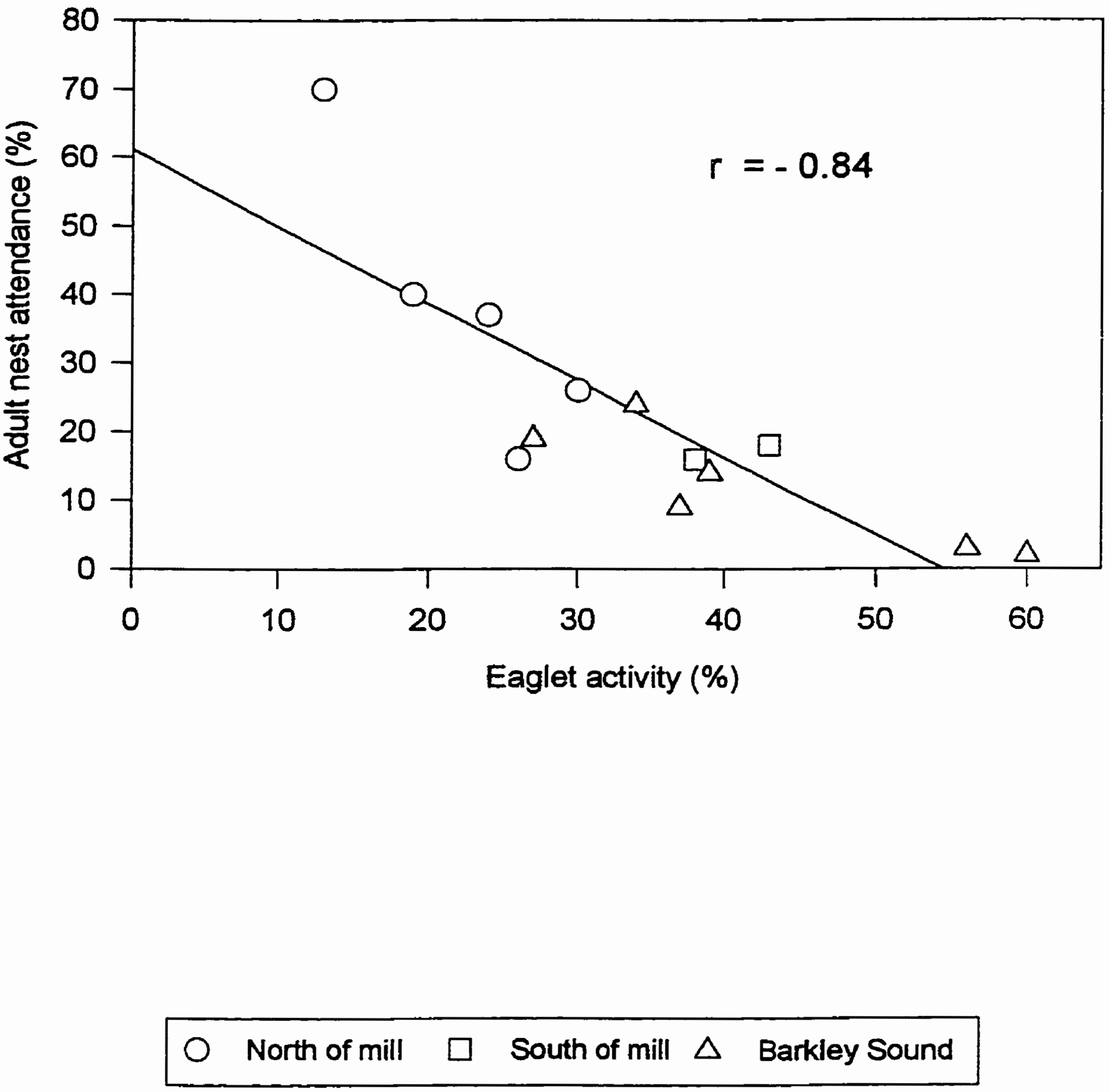

Figure 1.20. Average adult nest attendance at nests near Crofton and Barkley Sound in relation to level of eaglet activity.

locations. Most broods of one occurred in Barkley Sound while broods of two were most common north of the Crofton mill. For example, the single brood of 2 found in Barkley Sound had similar activity levels compared to broods of 1 from this area. North of the mill, one brood of 3 also had similar activity levels compared to broods of two here.

Eaglet activity was positively correlated with eaglet age (Figure 1.21). Activity levels throughout the nestling stage tended to be greater at nests south of the Crofton mill and in Barkley Sound compared to those nests north of the mill. Activity levels increased steadily as the eaglets matured averaging approximately 15 ± 8 % of the total observation time at 3 weeks of age. By 8 weeks of age, activity levels had increased to 45 ± 6 %.

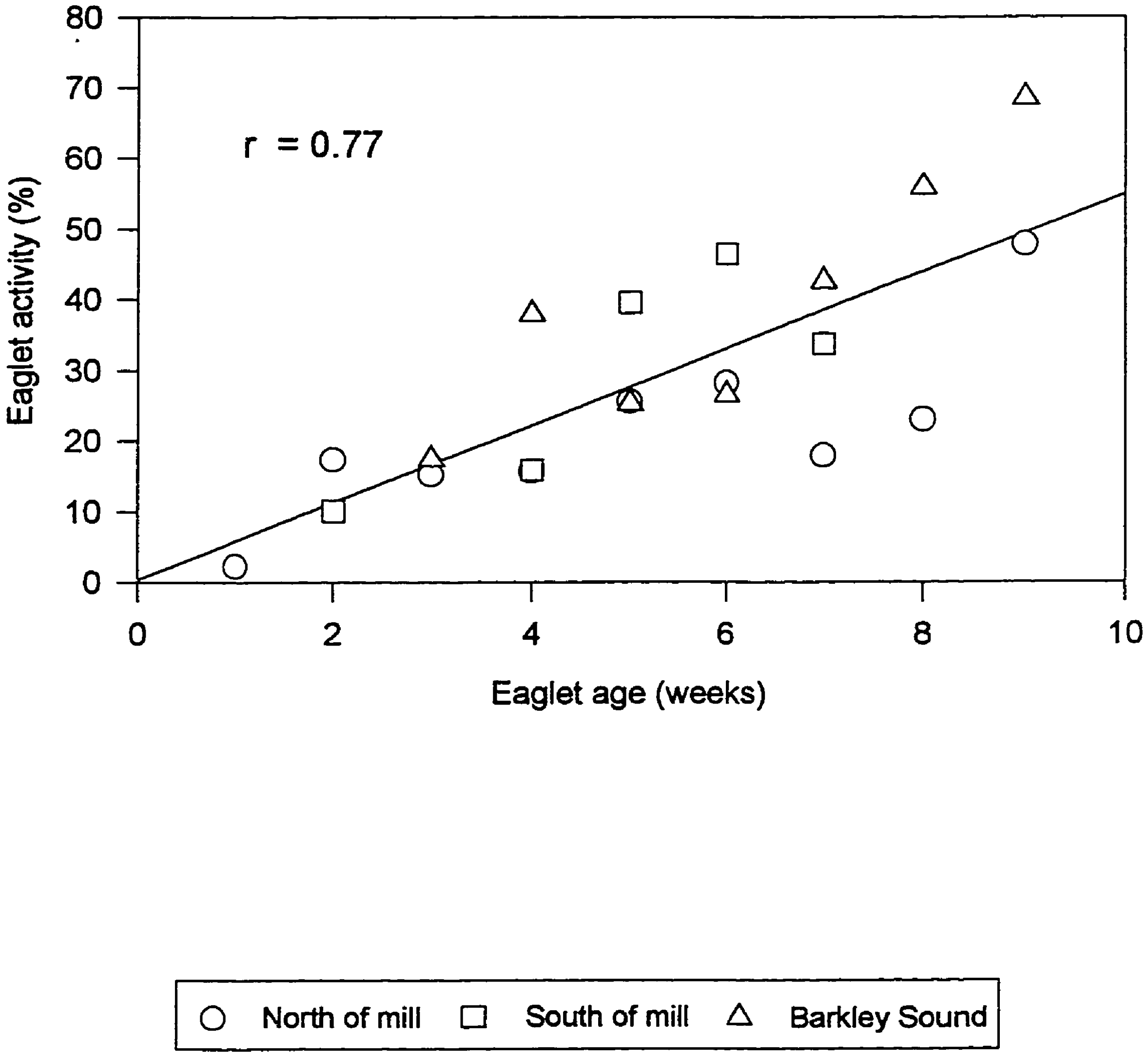

Figure 1.21. Eaglet activity for nests near Crofton and Barkley Sound in relation to eaglet age

DISCUSSION

The objective of this study was to determine the cause of the low bald eagle productivity within the dioxin fishery closure area that surrounds the Fletcher Challenge/ TimberWest Ltd. bleached kraft pulp and paper mill at Crofton. Breeding success was determined for the Crofton area and Barkley Sound (control site) and several measures of food abundance were compared between the two areas.

GENERAL BIOLOGY

Productivity

Breeding success was lower at nests within the dioxin fishery closure area that surrounds the Crofton pulp and paper mill compared to nests adjacent to the closure area. Similar trends were reported by Elliott and Norstrom (1998b) in those areas. Within the closure area, productivity was lower at nests adjacent to, or south of the Crofton mill and similar to that found for nests in Barkley Sound. Nests in those areas were often active during incubation but abandoned by the post-hatch stage. The apparent pattern of nest failure near Crofton and in Barkley Sound may reflect that of population experiencing food stress during, or just prior to, the post-hatch stage, with nest initiation occurring in late March or April followed by abandonment in May or June (Elliott *et al.* 1998a). Migrating waterbirds and spawning Pacific herring are abundant in early March and are utilized by eagles near Crofton and in Barkley Sound (Butler and Campbell 1987, Hart *et al.* 1939, Vermeer and Morgan 1989). For example, Vermeer and Morgan (1989) reported large congregations of bald eagles gathering on beaches in Barkley Sound in early March to feed on Pacific herring spawn washed ashore. As the breeding season progresses, these prey species disperse forcing eagles to switch to alternate and possibly less abundant prey. Food stress imposed by this change in prey abundance may be resulting in lower eagle productivity near Crofton and in Barkley Sound. A study on the reproductive performance of ring turtle doves concluded that the timing of food restriction was as important as the degree of restriction (Keith and Mitchell 1993). When food restrictions were imposed during incubation, egg hatchability and survival of young was reduced. Food restrictions at egg laying caused nesting behavior (e.g. care of young) to steadily decrease during the nestling stage. Food restrictions, however, did not influence clutch size.

Bald eagle diet during the breeding season

Fish comprised the majority of prey deliveries to nests near Crofton and in Barkley Sound. The main prey species utilized at the three study locations differed dramatically although Pacific herring was either the primary prey item or second most abundant prey. The average prey biomass and energetic content of the most common fish prey was usually lowest south of the Crofton mill, intermediate north of the mill, and highest in Barkley Sound. This is due to the fish species most commonly utilized at each study location. For example, the Pacific mackerel was the most common prey delivery to nests in Barkley Sound. Oil content of this fish is high, thus the energetic content of this prey item is much greater than most other prey identified in this study (Food composition and nutrition tables, 1989). Pacific herring, the main prey for eagles nesting south of the

Crofton mill is high in energetic content during the fall but levels decline rapidly reaching a very low value during spawning time in March (Hart *et al.* 1939).

North of the mill, the most common prey delivery was the plainfin midshipman. This fish is a bottom-dwelling, mid-water sculpin, therefore, it was initially unknown as to how the eagles were obtaining this prey item. After speaking with two local commercial fishermen conducting bottom trawls for shrimp near Crofton, I discovered that this fish is accidentally caught by the shrimpers. This method of shrimp fishing results in significant by-catch of several fish species including plainfin midshipman, yellow-eyed rockfish (*Sebastes ruberrimus*), English sole (*Inopsetta ischyra*), hake (*Merluccius productus*), pollock (*Theragra chalcogramma*), and shortfin eel pout (*Lycodes brevipes*). The most common fish caught by the shrimpers is the plainfin midshipman which corresponds to the most numerous prey species delivered to nests north of the Crofton mill. Many fish die or are injured from overextended swim bladders as a result of the pressure change. Once the by-catch is separated from the shrimp, the fish are thrown back becoming easy prey for eagles and other scavengers. Interviews with the skippers of both shrimp trawlers and personal observations confirmed that eagles in this area regularly utilize this abundant food source. The low incidence of nest failure and high prey energy per eaglet north of the mill reflect this local abundance of prey available for eagles nesting in this area.

Eagle diets can vary among location and even among nests depending on the most abundant food source in the local environment (Retfalvi 1970, Newton 1979). In Barkley Sound and south of the mill, large aggregations of waterbirds are uncommon, therefore, eagles breeding in this area feed primarily on fish. The estuaries and shallow bays north of the mill attract large flocks of several bird species (Butler and Campbell 1987). Prey deliveries to nests in this area, however, do not reflect this local abundance of waterbirds. As mentioned previously, the large fish by-catch provided by the shrimp fishery north of the mill is regularly utilized by eagles breeding in this area. Breeding adults would expend less energy obtaining dead or dying fish compared to that necessary to capture a fast moving waterbird. Observations of prey type delivered to nests in southeast Alaska reported that fish comprised approximately 80% of all deliveries (Ofelt 1975). Birds and mammals comprised less than 3%. Similar results were reported for bald eagles breeding near Lake Superior and eagles foraging on the Columbia River Estuary (Dykstra 1994, Watson *et al.* 1991). Other studies on food habits of bald eagles nesting in the Pacific Northwest concluded that birds constituted the majority of all prey items (Vermeer *et al.* 1989, Knight *et al.* 1990, Norman *et al.* 1989). However, only prey remains were collected from the base of nest trees in most of these studies. Mersmann *et al.* (1992) suggested that the collection of food remains may result in significant biases favoring birds and mammals. Prey items such as small to medium sized fish, reptiles, and amphibians are not well represented since many are entirely consumed. Additionally, this bias favoring mammals and birds may increase over time since large, bony prey items such as birds and mammals persist while softer bodied prey such as fish tend to decompose relatively quickly. Thus, nests that have remained active for several years may gradually accumulate prey remains. This was confirmed by Retfalvi (1970) who reported that very few prey items were found at the base of nest trees in the year following collection of prey remains.

Timing of prey deliveries

Prey delivery rates to nests near Crofton and in Barkley Sound were found to be influenced by both the time of day and tidal conditions. Peak prey delivery periods occurred in the early morning and during tides of intermediate height. Early morning foraging by bald eagles has also been reported by several other studies (S. Cain pers. comm., Watson *et al.* 1991, Harmata 1984). McGarigal *et al.* (1991) speculated that early morning foraging is driven by morning hunger and low levels of human activity. The influence of tidal conditions on foraging opportunities has been reported for bald eagles in the Gulf Islands of British Columbia, the Columbia River Estuary, and Alaska (Hancock 1964, Watson *et al.* 1991, Ofelt 1975). Intensified foraging at intermediate tide heights near Crofton and in Barkley Sound contradicts results from other studies. Watson *et al.* (1991) reported that predation attempts by bald eagles on the lower Columbia River Estuary were greatest at low tide levels. At low tide, shallow water and mudflats are present increasing the availability of fish carrion and live fish.

Near Crofton and in Barkley Sound, prey delivery rates were greatest at ebb through low slack tide. Similar results were reported by Watson *et al.* (1991). They concluded that intensive foraging during an ebb tide reduces competition for prey and may trigger foraging behavior that gradually declines throughout the tidal cycle as eagles become satiated. Advancing flood tides covered any remaining prey exposed during low tide reducing foraging opportunities.

Prey delivery rates and eaglet age

Prey delivery rates were negatively correlated with eaglet age. The number of prey deliveries per hour gradually declined throughout the nestling stage. Another raptor study failed to find any relationship between eaglet age and number of prey deliveries (Stinson 1978). However, S. Cain (pers. comm.) suggested that the number of eaglet feedings per day gradually declined through the nesting period. Similar feeding patterns have also been observed in golden eagles (Ellis and Ellis 1979). The peak prey delivery period occurred when eaglets were approximately 3-4 weeks of age, after which, delivery rates gradually declined. This maximum prey delivery period corresponds closely to the nestling age at which maximal growth occurs (approximately 30 days, Bortolotti 1984). In golden eagle nestlings, the growth rate of males and females was also maximal around 30 days of age. Growth efficiency peaked at two weeks of age with 27% of the biomass consumed being converted to body weight. As the nestlings approached asymptotic weights, growth efficiencies steadily decreased to levels below 5% as more energy was allocated to maintenance rather than growth (Collopy 1986).

Lipid plasma levels

Two methods of lipid determination were employed in this study. The gravimetric method of lipid determination measures only triglyceride levels in blood plasma, which comprise approximately 59.7 % of the total lipid volume (Christie and Moore 1972). A second method of lipid determination (colorimetric approach) was used to measure both triglycerides and phospholipids (31.8 % of total lipid volume) in eaglet plasma (Frings *et al.* 1972). Preference is not given to either method since each provides useful data.

Triglycerides comprise the majority of depot fat (> 80%, Blem 1990), therefore changes in lipid level following a meal may be more evident by measuring changes in triglyceride concentration using the gravimetric method. Since both triglycerides and phospholipids are measured by the colorimetric approach, small increases in triglyceride levels may not be detected by this method. However, if total lipid volume is desired, the colorimetric method of lipid determination is preferable.

Eaglet plasma lipid levels determined by the colorimetric approach were not correlated with productivity in this study. Values determined by the gravimetric method were not significantly different among study areas, possibly due to a high degree of variation among samples near Crofton. However, trends were similar to that found by Elliott *et al.* (1998a). They found that low lipid levels determined by the gravimetric method were weakly associated with areas of low productivity ($r^2 = 0.42$), such as the west coast of Vancouver Island, Johnstone Strait, and the Queen Charlotte Islands. Sample size in their study, however, was large (n=52) and overcame much of the variation among nests within a study area. Elliott *et al.* (1998a) suggested that the significant association between productivity and lipid plasma levels indicated body condition of eaglets in each study area. In productive areas, energy intake of eaglets is higher resulting in better body condition and higher survival rates during fledging. A study on Lake Superior by Kozie and Anderson (1991) found that breast muscle of bald eagle chicks found dead or dying in areas of high food abundance had greater mean fat content (inland sites) than those found in areas thought to be food stressed (shoreline of Lake Superior).

MEASURES OF FOOD ABUNDANCE FOR BALD EAGLES

Estimating food availability in the local environment for bald eagles and any other species is a highly complex and difficult procedure. Dykstra (1995) used several important behavioral measures to estimate the amount of food available for bald eagles breeding near Lake Superior. Productivity, brood size, prey delivery rates, prey energy, adult nest attendance times, and level of eaglet activity were compared individually and in combinations among her different study locations. These measures were also used in my study to determine food availability near Crofton and in Barkley Sound.

Productivity and prey delivery rates

Dykstra (1995) found that prey delivery rates were significantly correlated with bald eagle productivity. Low food availability during the post-hatch phase was reflected by low food delivery rates or prolonged adult foraging time away from the nest resulting in increased chick mortality. Dykstra (1995) suggested that the low prey delivery rates and breeding success for Lake Superior nests was due to food stress. At inland nests, higher prey delivery rates and nesting success reflected a greater food abundance in the local environment. In my study, prey delivery rates were also positively correlated with mean 6-year productivity. Prey delivery rates and breeding success tended to be lower at nests in Barkley Sound compared to the Crofton area. Although prey delivery rates near Crofton were similar, breeding success was significantly lower south of the mill.

Hansen (1984, 1987) also reported a positive correlation between nesting success and food availability for bald eagles in Alaska. Nests at which food supplementation experiments were performed experienced an increased reproductive success compared to control nests. Laying dates were advanced at nests located within 3 km of the food stations compared to those nests located farther away. Increased productivity was reported even when food supplementation only occurred during the post-hatch stage. This suggests that food limitation can influence nesting success both during the early courtship stage and also during the nestling stage. However, other studies attempting to replicate this experiment failed to find any significant increase in productivity (Gende and Willson 1997).

Other raptor studies have also found a link between raptor breeding performance and food supply. At Snake River, Idaho, golden eagle nesting success was recorded through two complete 10-year jackrabbit cycles, their main prey (Watson 1997). Breeding success was high during periods of peak jackrabbit numbers. During this time, more than 1 chick per active nest was produced and almost all pairs attempted to breed. As jackrabbit numbers declined, so did golden eagle fledging success. In Russia, steppe eagles are provided with large quantities of food in the form of dead or dying saiga antelope which had been shot by hunters (Agafanov *et al.* 1957). This abundance of food resulted in higher breeding densities and unusually large clutches for the steppe eagles. By the nestling stage, however, saiga antelopes were no longer being hunted, thereby forcing adults to rely on less abundant food sources. Widespread breeding failure occurred at this time possibly due to this change in food supply as adults were unable to rear the larger broods triggered by the high food abundance during courtship.

Brood size and prey delivery rates

Brood size of many avian species is dependent on the amount of food available during the breeding season (Newton 1979). When food is scarce, brood size is reduced. In areas of higher food abundance, brood size tends to be larger. Newton (1979) suggested that prey delivery rates should increase with increasing brood size when food was plentiful but remain similar in populations experiencing food stress. In other bald eagle studies, prey delivery rates did not increase with increasing brood size (S. Cain pers. comm., Collopy 1984). Similarly, Dykstra (1995) did not find an increase in the number of bald eagle prey deliveries with increasing brood size for nests along the shore of Lake Superior, an area thought to be food stressed. However, as brood size increased at inland nests, where food was plentiful, a corresponding increase in prey delivery rates was observed. Dykstra (1995) suggested that eagles attempting to breed in areas of low food availability are unable to increase prey delivery rates to compensate for a larger brood size. Consequently, brood reduction may occur as a result of insufficient food to raise more than one chick in these areas. In my study, prey delivery rates varied depending on both the study area and brood size. South of the mill and in Barkley Sound, broods of 1 received a similar number of prey deliveries as did broods of 2 in these areas. North of the Crofton mill, a brood of 3 received more prey deliveries compared to broods of 2 in this area.

Adult nest attendance

In areas where food is scarce, adults must spend an increased amount of time foraging in order to provide adequate food for their young (Dykstra 1995). Increased foraging time reduces adult nest attendance time which, in turn, increases the probability of eaglet mortality through predation and exposure to adverse weather (Dykstra 1995). In her study, nest attendance times were lower at Lake Superior nests where food abundance was low. Nest attendance was greater at inland sites where food was thought to be abundant (Dykstra 1995).

In my study, adult nest attendance was greatest north of the Crofton mill compared to both south of the mill and Barkley Sound. The difference in nest attendance may be due to the topographical conditions in each area. The landscape south of the mill and in Barkley Sound is steep and fjord-like which may limit access to fish, the main prey utilized by breeding eagles in this study. Waterways in these areas are very deep (up to 280 m) and effective foraging environments, such as shoals and estuaries used by fish for breeding and feeding habitat, are rare (Elliott *et al.* 1998a, Vermeer 1983). The scarcity of this particular habitat type south of the mill and in Barkley Sound may allow fish prey to escape into deeper water when the risk of surface predation is high. Prey availability may thus be reduced in such areas thus forcing adults to increase foraging time in order to provide adequate food for their young. Increased foraging time reduces nest attendance time which, in turn, increases the probability of eaglet mortality through predation and exposure to adverse weather (Dykstra 1995).

North of the mill, where adult nest attendance was greatest, estuaries and shallow bays are abundant providing numerous food sources for eagles breeding in this area (Vermeer 1983). At low tide, small pools on tidal flats trap fish becoming easy prey for eagles breeding in this area. The mudflats and shallows also attract many migratory and non-migratory bird species such as white-winged scoters (*Melanitta fusca*), great blue herons (*Ardea herodias*), double-crested cormorant (*Phalacrocorax auritus*), mallard (*Anas platyrhynchos*), American widgeon (*Anas americana*), northern pintail (*Anas acuta*), and several other species (Butler and Campbell 1987). Although few birds were delivered to nests north of the mill during the breeding season, personal observations conducted during the winter showed that eagles in this area regularly prey on several species of waterfowl. For example, numerous great blue heron skulls were found beneath nests located near the Crofton heron rookery. Norman *et al.* (1989) also reported predation of great blue heron chicks by bald eagles in the Strait of Georgia.

Eaglet activity

Dykstra (1995) found that in areas she considered to be food stressed, such as Lake Superior, eaglet activity was lowest. Additionally, Lake Superior broods of two had lower activity levels compared to broods of one from this area. Eaglets from food stressed areas of Lake Superior spent more time lying down and sitting than those from areas of high food availability (inland sites). Dykstra (1995) concluded that the low eaglet activity was a behavioral modification resulting from the low energy intake. The lower activity levels allowed broods of 2 to conserve approximately 265 kilojoules per day on average.

South of the Crofton mill and in Barkley Sound, activity levels of eaglets were greatest. Eaglets in these areas spent more time standing, feeding, preening, fighting with siblings, exercising wings, playing with nest material, and walking around the nest, than did their counterparts from nests north of the Crofton mill, regardless of brood size.

Prey energy and biomass

Dykstra (1995) found that prey energy per eaglet was lower in areas she considered to be food stressed. At Lake Superior nests, an area of low food availability, prey energy per eaglet (1400 kJ eaglet^{-1} day^{-1}) was similar to that found south of the Crofton mill in my study. These estimates, however, were significantly lower than the typical amount of energy expended for field metabolic rate (FMR) and growth (2556 kJ day^{-1}) and marginally higher than calculated minimum energy requirements for maintenance metabolism and growth (1326 kJ eaglet^{-1} day^{-1}) reported by Dykstra (1995). She concluded that the low productivity of Lake Superior nests was due in part to low food abundance.

Prey energy north of the mill was comparable to nests in inland areas of Dykstra's (1995) study which were characterized by high food availability (2500 kJ eaglet^{-1}day^{-1}) and low nest failure. Energy intake of eaglets north of the mill and at inland nests were similar to the average energy expended for FMR. Dykstra (1995) suggested that eaglets from inland nests in her study were receiving an adequate daily energy intake which may account for the higher productivity observed at Lake Superior inland nests. Prey energy delivered to Barkley Sound nests was also similar to that found by Dykstra (1995) at inland nests. However, productivity in Barkley Sound did not reflect this high prey energy intake.

Prey biomass per eaglet was positively correlated with mean 6-year productivity in my study. Prey biomass and productivity tended to be lower in south of the mill and Barkley Sound compared to north of the mill. Dykstra (1995) did not report any correlation between these two variables.

EXPLANATION OF FOOD ABUNDANCE RESULTS

Several behavioral measures obtained from Dykstra (1995) were employed in order to estimate food abundance in the local environment for eagles breeding near Crofton and in Barkley Sound. Productivity, brood size, prey delivery rates, prey biomass and energy, adult nest attendance, and eaglet activity levels were measured at several nests in each study area. These behavioral measures were then compared among study locations and also to the results of Dykstra's (1995) study.

Crofton

Near Crofton, productivity and most food abundance measures except eaglet activity levels tended to be highest north of the mill. This may indicate that food availability is not limiting bald eagle productivity here. In contrast, productivity and most measures of food abundance were low south of the mill suggesting that food stress may be affecting breeding success in this area.

Barkley Sound

Barkley Sound is a relatively pristine area with large numbers of suitable nest and roost trees, minimal human disturbance, and low contaminant levels (Gill pers. obs., Elliott 1995). Most results from my study suggest that eagles attempting to breed here may be food stressed. Productivity remains below that necessary to sustain a viable population (Sprunt *et al.* 1973), brood size was significantly smaller than that found north of the Crofton mill, prey delivery rates tended to be lower, as did prey biomass per eaglet and adult nest attendance. However, other measures of food abundance such as prey energy delivered to nests and eaglet activity levels suggest that Barkley Sound eagles are not food stressed.

Prey energy per eaglet determined for Barkley Sound nests was the highest of all study areas and similar to that found by Dykstra (1995) for inland nests, an area of high food availability. Despite this, average 6-year productivity was lower here compared to north of the Crofton mill and similar to that determined for nests south of the mill. The high prey energy per eaglet suggests that food is not a factor limiting productivity in this area. However, prey energy estimated for Barkley Sound in 1996 may be abnormally high due to the occurrence of El Nino. El Nino is a disturbance in the climatic state of the equatorial Pacific Ocean that has an impact on the state of the climate over much larger regions (Diaz and Markgraf 1992, Wooster and Fluharty 1985). Off North America, El Nino events cause warming of the coastal ocean. These warm currents allow unusual species such as the Pacific mackerel to migrate north far beyond their normal range. As mentioned previously, this fish species was the main prey type utilized by eagles in Barkley Sound in 1996. The high oil content of the Pacific mackerel results in an extremely high energy content, approximately twice that of all other fish prey identified in this study. Pacific mackerel occurred in large numbers in Barkley Sound, and I observed that they frequently exposed themselves to eagle predation by chasing juvenile Pacific herring into shallow bays. Although prey may be scarce in Barkley Sound, adults need only to catch one average sized Pacific mackerel in order to satisfy the daily energetic needs of a nestling. However, the availability of this prey may vary among years since it is only brought to the Pacific northwest when the warm currents of El Nino are present, as occurred in 1996. Thus food availability determined for Barkley Sound in this year may not necessarily reflect the average amount of prey available during a normal non-El Nino year. During these times, adults would have to rely on other prey types, such as Pacific herring. The lower energy content of prey such as this would require a larger number of prey deliveries per day in order to meet the energetic requirements of nestlings. Prey abundance and foraging opportunities may be typically much lower during a normal non-El Nino year and may account for the low productivity in Barkley Sound.

Other evidence of localized food stress

The possibility that food stress is present south of the mill and in Barkley Sound may also be indicated by the willingness of adults breeding in these areas to accept food supplementation. During the 1997 field season, adult bald eagles were caught at all three study locations using a floating-fish snare (Cain and Hodges 1989) for contaminant analyses (see Chapter 2). In order to accomplish this, breeding adults were provided with frozen herring for several days before trapping attempts were made in order to allow the birds to become comfortable with our close approach by boat. South of the Crofton mill, an area thought to be experiencing food stress, adults immediately picked up these herring and fly back to the nest. Adults breeding in Barkley Sound reacted in a similar manner. At both of these study areas, several birds would circle our boat before the floating-fish snare was even placed in the water and were usually caught on the first trapping attempt. North of the mill where food seems to be abundant, I observed that breeding adults showed less interest in the herring, often allowing juvenile birds to take the fish while they looked on. These observations suggest that food stress may be occurring south of the Crofton mill and in Barkley Sound and that nest failure rates in these areas could be reduced by supplemental feeding. Similar conclusions were reached by Dykstra (1995) who suggested that the low productivity at Lake Superior nests may be enhanced by food supplementation.

Eaglet activity

Dykstra's (1995) results suggested that eaglet activity should be lowest south of the mill and in Barkley Sound where most food abundance measures were low, and highest north of the mill where prey seems to be abundant. However, results contradicted this. Eaglet activity levels were found to be much higher south of the mill and in Barkley Sound.

There seemed to be an inverse relationship between eaglet activity and adult nest attendance. In areas of low adult nest attendance such as south of the mill and Barkley Sound, eaglet activity was high. Conversely, activity levels were low north of the mill where nest attendance was high. As mentioned previously, broods of two were most common north of the mill while broods of 1 occurred most frequently in Barkley Sound. The difference in activity levels north of the mill compared to Barkley Sound and south of the mill may be simply due to the amount of room available in the nest. Nest attendance for broods of 2 was high, therefore, overcrowding of the nest may have forced eaglets to remain inactive to a greater extent. Personal observations of nest activity for broods of 2 showed that eaglet activity was lower when adults were at the nest. Nest attendance was low for broods of 1 thereby allowing the eaglet more room to exercise wings, preen, play with nest material, and walk around the nest.

Conclusion

Results of my study suggest that the area south of the Crofton mill is less than optimal habitat for eagles attempting to raise young. Food availability seems to be limited there, reflected by the high incidence of nest failure, low adult nest attendance, and low energy intake of eaglets. Adults breeding here must spend a significant amount of time foraging in order to provide adequate food for their young. Increased foraging time reduces adult nest attendance, which, in turn, increases the probability of eaglet mortality through predation and exposure to adverse weather conditions. North of the mill, the low incidence of nest failure, high adult nest attendance, and high prey energy per eaglet may reflect the abundance of prey in this area. Productivity and most food abundance measures obtained for Barkley Sound nests suggest that food stress is limiting bald eagle productivity here. However, measurements of prey energy per eaglet and level of eaglet activity contradict these results.

CHAPTER 2

ENVIRONMENTAL CONTAMINANTS AND PRODUCTIVITY OF BALD EAGLES ON VANCOUVER ISLAND, BRITISH COLUMBIA.

The purpose of this study was to investigate the possibility that the low bald eagle productivity near Crofton is due to high levels of chlorinated hydrocarbons released as byproducts of the pulp bleaching process from the Timber West/ Fletcher Challenge pulp and paper mill. Mean 6-year productivity of bald eagles near Crofton and in Barkley Sound is reported here. Concentrations of selected PCDDs/PCDFs, non-ortho PCBs, and organochlorines in eaglet and adult blood plasma are presented on a wet weight basis. Additionally, adult nest attendance is reported in relation to levels of selected chlorinated hydrocarbons in adult plasma.

METHODS

Productivity

Nesting success was determined for the Crofton and Barkley Sound areas by a standard two flight method (Fraser *et al.* 1983) using helicopters and a minimum of two observers. The preliminary flight took place during incubation, (first week of April for Crofton and the end of April for Barkley Sound) in order to determined the number of occupied breeding territories. An occupied territory was considered one in which an adult was present either on or within 200 metres of the nest. The second flight occurred when eaglets were approximately 5-8 weeks of age (the first week of June for Crofton and mid-June for Barkley Sound) to count the number of nestlings produced. Mean productivity was considered the total number of young produced divided by the number of occupied breeding territories (Postupalsky 1974). Productivity was compared among nests located inside the dioxin fishery closure surrounding the Crofton mill, to those adjacent to this closure area, and to nests in Barkley Sound.

Data is presented as the number of chicks per occupied territory and as percent nesting success. Nests within the dioxin closure surrounding the Crofton mill were divided into nests north of the Crofton pulp mill outflow pipe and those adjacent to or south of this point due to differences in nest success rates between the two areas. Percent nest success was then compared among nests north of the mill, south of the mill, and Barkley Sound. Data presented here includes productivity surveys conducted from 1992-1995 at the same nests as reported by Elliott *et al.* (1998a).

Contaminants

Between 1995 and 1996, blood samples were collected from 14 eaglets at 6 nests near Crofton and 4 eaglets from 4 nests in Barkley Sound.

When the eaglets were approximately 5-8 weeks of age, a professional tree climber was hired to climb nest trees near Crofton and in Barkley Sound. Not all nests in this study could be accessed for sample collection due to unsuitable climbing conditions or private land access problems.

Eaglets were lowered to the ground in a soft canvas bag, weighed, aged by the length of the eighth primary feather (Bortolotti 1984) and a CWS band attached to the left tarsus. Up to 24 ml of blood was taken from the brachial vein using a 12 ml sterile syringe and a 21 gauge needle. Blood was transferred to heparinized vacutainers and stored upright on ice. Samples were centrifuged within 6 hours of collection and plasma drawn off, transferred to chemically cleaned (acetone/hexane) glass vials and then frozen. Frozen plasma samples were shipped to the Canadian Wildlife Service National Wildlife Research Center (NWRC) for organochlorine, PCDD, PCDF, and non-*ortho* PCB analysis. For organochlorines, 1 ml plasma samples were first deproteinized with methanol containing aldrin as an internal standard (Smrek *et al.* 1981). Following deproteinization, 1 ml of water was added to the mixture, extracted three times with hexane, and centrifuged. The hexane extracts were passed through sodium sulfate, evaporated to 1 ml or less and separated into three fractions using hexane and methylene chloride on a florisil column. The three fractions were made up to 1 ml/ml of plasma with iso-octane for GC injection. Analyses were performed by GC-electron capture detector with capillary-column separation on a Hewlett Packard 7673A. Total PCBs were quantitated as the sum of 42 major congener peaks. The extraction efficiency was approximately 62-90%. All residue results from plasma samples were corrected for extraction recovery using aldrin as an internal standard.

For PCDDs, PCDFs, and non-ortho PCBs analysis, 5 ml plasma samples were spiked with 10 ul of $^{13}C_{12}$ labeled PCDDs, PCDFs, and non-ortho PCBs standards. Samples were allowed to equilibrate for 30 minutes. Formic acid (1:1 plasma/formic acid) was added to the spiked plasma in order to denature proteins. Samples were then extracted three times with hexane, combined, and filtered through anhydrous sodium sulphate. The sample volume was then reduced for clean-up by gel permeation chromatography (GPC) (Norstrom and Simon 1991). GPC and alumina column clean up were used to separate lipids and biogenic materials from OCs. PCDDs, PCDFs, and non-ortho PCBs were separated from other contaminants using a carbon/fibre column (Norstrom and Simon 1991). Further separation of PCDDs and PCDFs from the non-ortho PCBs was accomplished using florisil column cleanup. Quantitative analysis for OCs was performed with a VG Autospec double-focusing high resolution mass spectrometer linked to a HP 5890 Series II high resolution gas chromatograph computerized data system. Results were accepted when recoveries of $^{13}C_{12}$-PCDDs/PCDFs/ non-ortho PCBs were between 70% and 120%. Contaminant values falling below the detection limits were assigned a value of half the detection limit for statistical analyses.

Quality assurance protocol

One diluted Herring Gull egg pool reference material sample was simultaneously analyzed with the plasma samples for quality assurance purposes (Turle *et al.* 1991). All major analytes in this reference material have been assigned reference values with associated uncertainties by the National Wildlife Research Centre (see Laboratory Services Manual CWS-87-00).

A set of data generated by the NWRC analytical lab is accepted based on several criteria that are reported by Turle and Norstrom (1987). The key criterion is that no more than 1 in 20 results should be more than ± 2 standard deviations from the reference mean. In a set of analyses, approximately 1 in 10 samples is reference material to be used for quality assurance purposes. Additionally, solvent blanks and spiked samples are analyzed throughout the procedure. Standards are analyzed every fifth sample to track response factors and retention times in the chromatogram (NWRC Laboratory Services Manual CWS-87-00).

Adult bald eagle trapping

In 1997, a total of 10 adult and sub-adult bald eagles were trapped near Crofton and in Barkley Sound using a floating-fish snare (Cain and Hodges 1989, Jackman *et al.* 1993). Six adults and one sub-adult were trapped within 4 nautical miles of the Crofton mill. Five of these adults were trapped within active territories from which eaglet blood samples were obtained in 1996. Three breeding adults were captured in Barkley Sound to obtain control blood. Each individual was aged based on plumage (Bortolotti 1984), weighed using a 10 kg Pesola spring scale, and measurements of the wing chord, length of 8th primary, and culmen length were obtained. The sex of each bird was determined using bill depth and hallux claw length measurements (Bortolotti 1984). Blood samples were obtained, prepared, and analyzed for OCs, PCDDs, PCDFs, non-ortho PCBs, and lipid plasma concentration using the same method reported for eaglets.

Adult nest attendance and selected chlorinated hydrocarbon levels

Studies on Forster's terns and ring turtle doves have reported decreases in nest attendance and defense times for birds experimentally dosed with certain chlorinated hydrocarbons such as DDE and PCBs (McArthur *et al.* 1983, Kubiak *et al.* 1989). To compare adult nest attendance times with levels of selected chlorinated hydrocarbons in adult blood plasma of eagles breeding near Crofton and in Barkley Sound, nest attendance was first determined for 7 nests near Crofton and 6 nests in Barkley Sound (see methods, Chapter 1). The percentage of time an adult was present on the nest was then compared to DDE, total PCBs, and TEQ-WHO levels in adult plasma samples.

Exposure rates and bioaccumulation

In order to estimate eaglet exposure rates (ng day^{-1} eaglet^{-1}) for selected PCDDs and PCDFs, the amount of prey biomass delivered to nests north and south of the Crofton mill was first determined (see methods, Chapter 1). The majority of prey deliveries to nests near

Crofton were fish, therefore, unlike Elliott's (1995) estimates of bioaccumulation, no birds or mammals were included in these calculations. Information on PCDD and PCDF levels in three fish species collected near Crofton was taken from table 3.1 in Elliott (1995) since no prey items were analyzed for contaminants in my study.

Levels of selected PCDDs and PCDFs in the three fish species analyzed near Crofton were first divided by the change in contaminant concentrations in great blue heron eggs collected in this area between 1990 and 1991. Adjusted residue levels were then multiplied by the average prey biomass each eaglet received at nests near Crofton, and divided by the average brood size in this area. Results were multiplied by the average age of eaglets when blood samples were obtained. These values were then compared to actual contaminant levels determined in eaglet blood plasma from nests near Crofton.

Exposure rates are only a rough estimate of the amount of contaminant each eaglet actually received on a daily basis. Levels of chlorinated hydrocarbons in the three fish species tested near Crofton were analyzed in 1990 (Harding and Pomeroy). Changes in the chlorine pulp bleaching process occurred in the late 1980s, therefore, the chemical residues in fish analyzed in 1990 may be far greater than the levels found in these same fish species during this study in 1996. Levels of PCDDs and PCDFs in great glue heron eggs collected near the Crofton mill declined dramatically following the change in the bleaching process (Whitehead *et al.* 1992a). For example, 2,3,7,8-TCDD declined in heron eggs from 102 ppt in 1990 to 16 ppt in 1991. Contaminant levels in fish were therefore adjusted according to this dramatic decrease in chlorinated hydrocarbon levels in heron eggs collected from the same area.

Fish species analyzed for contaminant levels by Harding and Pomeroy (1990) were also not the most common prey items delivered to nests near Crofton (see Chapter 1).

Concentrations of chlorinated hydrocarbons in the common prey items utilized by breeding adults near Crofton may thus be very different from the species used by Elliott (1995) for his bioaccumulation model.

Statistical Analyses

All statistical analyses was performed using the SAS v.6.11 software package. Residue levels were transformed to common logarithms and geometric means and grouped according to sampling location (north of the Crofton mill, south of the mill, and Barkley Sound). Confidence intervals (95%) were calculated for contaminant concentrations in each of the study areas. Unlike Elliott and Norstrom's study (1998b), chlorinated hydrocarbon levels in all but one eaglet were not correlated with lipid plasma concentrations. Adult contaminant levels, however, were significantly correlated with plasma lipid levels. Adult contaminant data were therefore lipid adjusted prior to statistical analyses because the level of lipid in blood plasma can affect the concentration of lipid soluble contaminants (Phillips *et al.* 1989). This was accomplished by dividing the actual residue levels determined for a sample by the percent lipid in that sample (Hebert and Keenlyside 1995).

Dietary lipids are absorbed via the hepatic portal system in birds (Bensadoun and Rothfield 1972). Shortly after a meal, the combination of dietary and liver re-processed lipids cause blood lipids levels to rise. However, contaminants in these lipids do not have time to reach an equilibrium with levels in adipose tissue stores. Because organochlorine concentrations in the diet are usually much less than in the bird, the net effect is to dilute the concentrations in blood on a lipid weight basis. Braune and Norstrom's (1989) research on herring gulls showed that organochlorines in egg lipids are significantly lower than that measured in adipose tissue. They interpreted this result as a direct cycling of dietary lipids into egg yolk with most of the contaminant coming from existing stores in the liver.

However, if several hours have elapsed since feeding, and plasma lipids are still elevated, a concentration gradient will form between the high contaminant levels in body fat stores and the lower concentrations in blood lipids. Lipid soluble contaminants in adipose tissue will diffuse into the blood lipids causing contaminant levels in blood plasma to rise. Thus, contaminant levels measured in blood samples can reflect body burden rather than concentrations in the dietary item (R. Norstrom pers. comm.). However, the absolute amount or wet weight concentration is still influenced by the post-digestive lipid bolus. Therefore, blood samples should be drawn ideally from a fasting individual (Phillips *et al.* 1989).

Lipid plasma levels in one eaglet and two adults were 9 - 30 times greater than the mean of other samples from that study area. In most cases, samples were cloudy, indicating a high lipid content and suggesting that the individual was sampled soon after feeding. However, of the three individuals, only the eaglet was found to have a full crop.

Relative toxicities of dioxin-like compounds found in adult and eaglet blood plasma in relation to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin were estimated using the most recent toxic equivalency factors (TEFs) for birds (World Health Organization, 1997).

Due to the unbalanced nature of the sample design, a general linear model (GLM) was used for comparisons of productivity; PCDDs/PCDFs; TEQs-WHO; non-*ortho* PCBs; and eaglet lipid plasma levels. In cases where differences were detected, Tukey's multiple comparison tests were carried out on the main factors in the analysis. For Tukey's, the experiment wise probability level was 0.05. Correlation analyses were performed using Pearson Product Moment Correlation Coefficients (PPCC) with the experiment wise probability level of 0.05. Unless stated otherwise, results were considered significant if $p < 0.05$ and possibly significant when $p < 0.10$.

RESULTS

Productivity

Productivity surveys conducted for nests near Crofton and in Barkley Sound from 1996-1997 were combined with surveys conducted at the same nests from 1992-1995 as reported by Elliott *et al.* (1998a).

The number of chicks per occupied territory was highest outside the dioxin fishery closure that surrounds the Crofton mill (see Table 1.1, Chapter 1). Productivity was similar between those nests within the closure area and nests in Barkley Sound (0.74 ± 0.28 and 0.58 ± 0.12 chicks/occupied territory, respectively). Productivity was more variable among nests within the dioxin fishery closure area surrounding the Crofton mill compared to those adjacent to this closure area. When nests inside the dioxin fishery closure area were divided into those adjacent to, or south of the Crofton mill outflow pipe and nests north of this point, significant differences in productivity were noted. South of the Crofton mill, productivity was similar to that found for nests in Barkley Sound but significantly lower than that found north of the mill (see Table 1.2, Chapter 1).

PCDD and PCDF levels in blood plasma

Residue levels of selected PCDDs and PCDFs in 18 eaglet and 10 adult blood samples for the three study areas are shown in Table 2.1. Most PCDDs and PCDFs measured in eaglet blood plasma were highest south of the Crofton mill, intermediate north of the mill, and lowest in Barkley Sound. Samples from Barkley Sound were below detection limits for most PCDDs and PCDFs, except OCDD. Residue levels were generally 2 - 9 fold higher in eaglet plasma samples from south of the mill compared to those taken north of the mill.

In contrast, levels of most PCDDs and PCDFs in adult blood plasma tended to be similar among all study areas. Adult concentrations of most chlorinated hydrocarbons south of the Crofton mill were approximately 2-fold higher than levels in eaglets from this area. North of the mill, levels were generally 7-times greater in adults. In Barkley Sound, OCDD levels in adults was 8-fold higher than that found in eaglet blood samples.

The pattern of PCDDs and PCDFs levels in eaglet blood plasma from nests south of the Crofton mill was generally 1,2,3,6,7,8-HxCDD > 2,3,7,8-TCDF > 1,2,3,7,8-PnCDD > 2,3,7,8-TCDD > OCDD. North of the mill the pattern was slightly different; 1,2,3,6,7,8-HxCDD > 2,3,7,8-TCDF > 1,2,3,7,8-PnCDD ~ OCDD > 2,3,7,8-TCDD. For adults, the pattern of PCDDs and PCDFs levels in blood plasma near the Crofton mill and Barkley Sound was 1,2,3,6,7,8-HxCDD > 1,2,3,7,8- PnCDD > OCDD > 2,3,7,8-TCDD > 2,3,7,8-TCDF. Detectable amounts of 2,3,4,7,8-PnCDF were found in both eaglet and adult samples from the three study areas.

Due to significant interaction between lipid plasma concentration in adult blood plasma and DDE, TEQs, and selected PCDDs, PCDFs, and PCBs, residue levels are further presented as lipid-adjusted log normalized mean values.

Table 2.1. Geometric means and 95% confidence intervals for selected PCDDs and PCDFs (ng/ kg, wet weight) in eaglet blood plasma from nests near Crofton and in Barkley Sound (1995-1996) and in blood plasma of breeding adults caught within active territories in each area (1997). Adult levels are lipid adjusted.

Location	N	2378-TCDD	12378-PnCDD	123678-HxCDD	1234678-HpCDD	OCDD	2378-TCDF	12378-PnCDF	234678-HxCDF	OCDF
Eaglet Samples										
South of mill	5	1.53 0.15-2.91	2.96 0.49-5.43	9.58 3.23-15.93	0.54 ND-1.87	0.90 ND-2.43	7.79 4.25-11.33	0.62 0.07-0.19	0.50 0.06-0.94	0.95 ND-10.16
North of mill	9	0.18 0.09-0.21	0.51 0.32-0.7	1.76 0.95-2.57	0.22 ND-0.46	0.62 0.24-1.0	1.17 0.56-1.73	0.11 0.06-0.16	0.17 0.08-0.26	0.43 ND-3.44
Barkley Sound	4	ND	ND	ND	ND	0.32 ND-0.81	ND	ND	ND	ND
Adult Samples										
South of mill	4	2.60 0.72-4.5	5.30 3.0-7.6	14.60 6.6-22.6	0.90*	4.20 ND-11.1	1.70 0.4-3.0	1.70 0.3-3.1	0.74 ND-3.7	0.70*
North of mill	3	2.01 ND-4.1	5.30 0.73-9.9	11.96 ND-29.4	0.50 ND-1.0	2.30 ND-5.2	1.40 ND-3.7	1.10 0.49-1.7	0.49 ND-3.0	0.50 ND-1.5
Barkley Sound	3	1.65 ND-3.6	5.20 1.7-8.6	6.00 2.0-10.0	0.70*	2.60 1.1-4.1	1.10 0.86-1.4	0.74 ND-1.7	0.88 ND-2.3	ND

ND - not detected, minimum detection limit 0.01-0.05 ng/ kg, wet weight.
* - one sample only.

2,3,7,8-TCDD - Levels of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in eaglet plasma were highest south of the mill (mean = 1.53 ± 1.4 ng/kg, wet weight, Figure 2.1). North of the mill, levels were comparatively less (0.18 ± 0.06 ng/kg, wet weight) and below detection limits (d.l. = 0.20 ng/kg) for all samples from Barkley Sound. In adult blood samples, levels of 2,3,7,8-TCDD were similar among all study locations averaging 2.09 ng/kg, wet weight (Figure 2.1). Concentrations were slightly greater south of the Crofton mill compared to samples from north of the mill and in Barkley Sound but the difference was not significant.

1,2,3,7,8-PnCDD - Highest levels of 1,2,3,7,8-PnCDD in eaglet blood plasma were found south of the mill (2.96 ± 4.52 ng/kg, wet weight). Concentrations were significantly lower north of the mill (0.51 ± 0.19 ng/kg, wet weight) and below detection limits for all samples from Barkley Sound (Figure 2.2). Levels of were greatest south of the mill, intermediate north of the mill, and below detection limits in Barkley Sound. Adult 1,2,3,7,8-PnCDD levels were similar among all study locations averaging 5.26 ng/kg, wet weight (Figure 2.2).

1,2,3,6,7,8-HxCDD - Concentrations of 1,2,3,6,7,8-HxCDD in eaglet blood plasma were more than 5 times greater south of the Crofton mill compared to levels found north of the mill (Figure 2.3). Adult levels were similar among all study locations. Levels tended to be higher near Crofton (mean = 13.28 ng/kg, wet weight) compared to Barkley Sound (6.00 ng/kg, wet weight) but the difference was not significant possibly due to a high degree of variability among samples in each area.

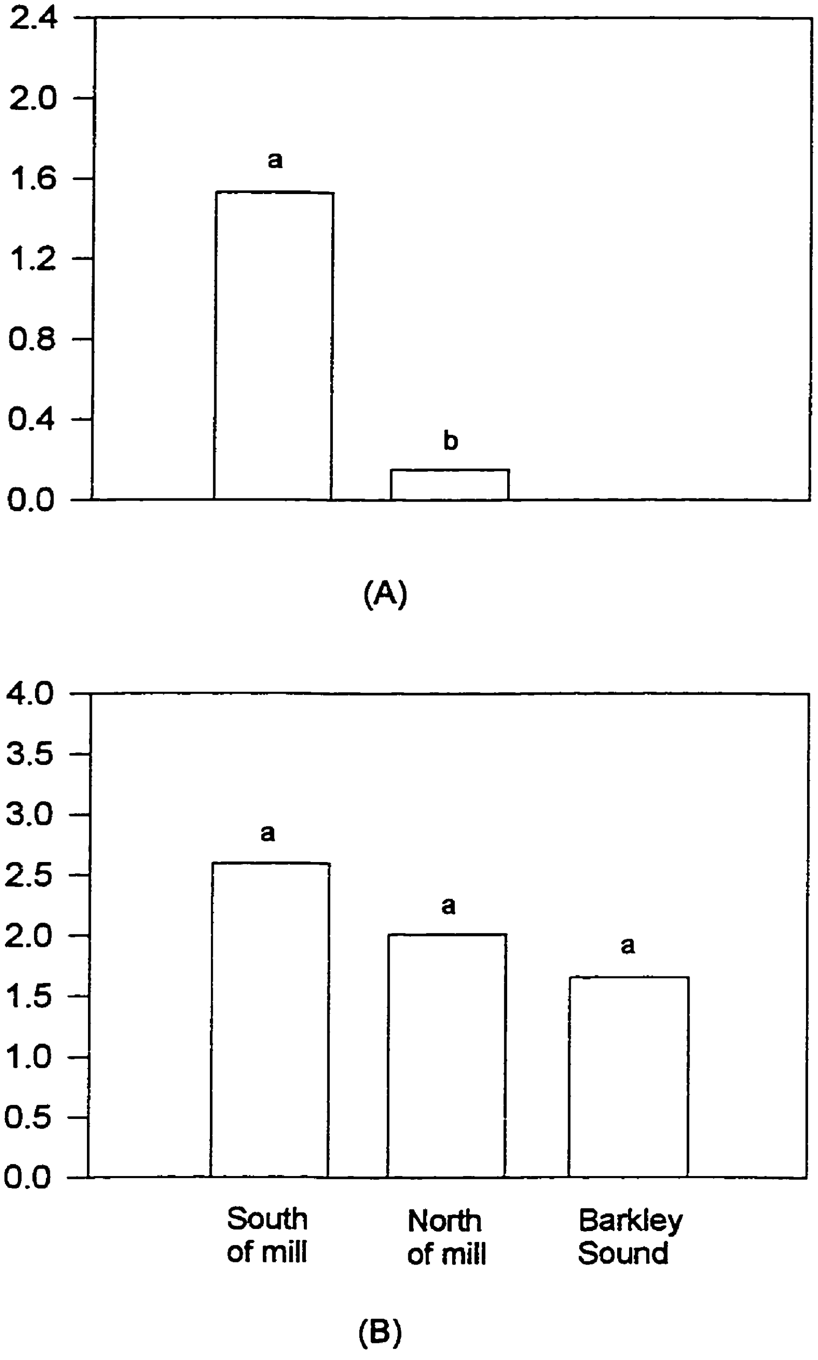

Figure 2.1. 2,3,7,8-TCDD levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

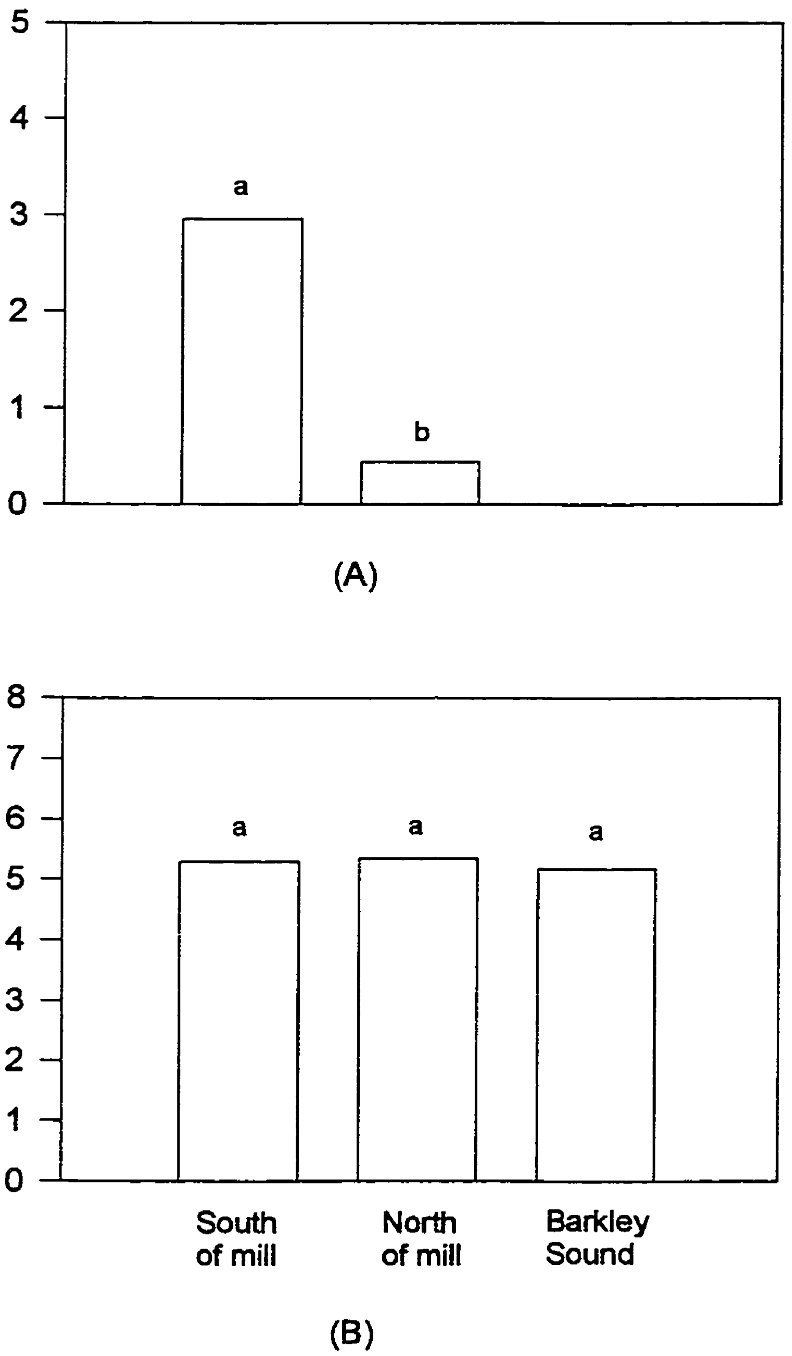

Figure 2.2. 1,2,3,7,8-PnCDD levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

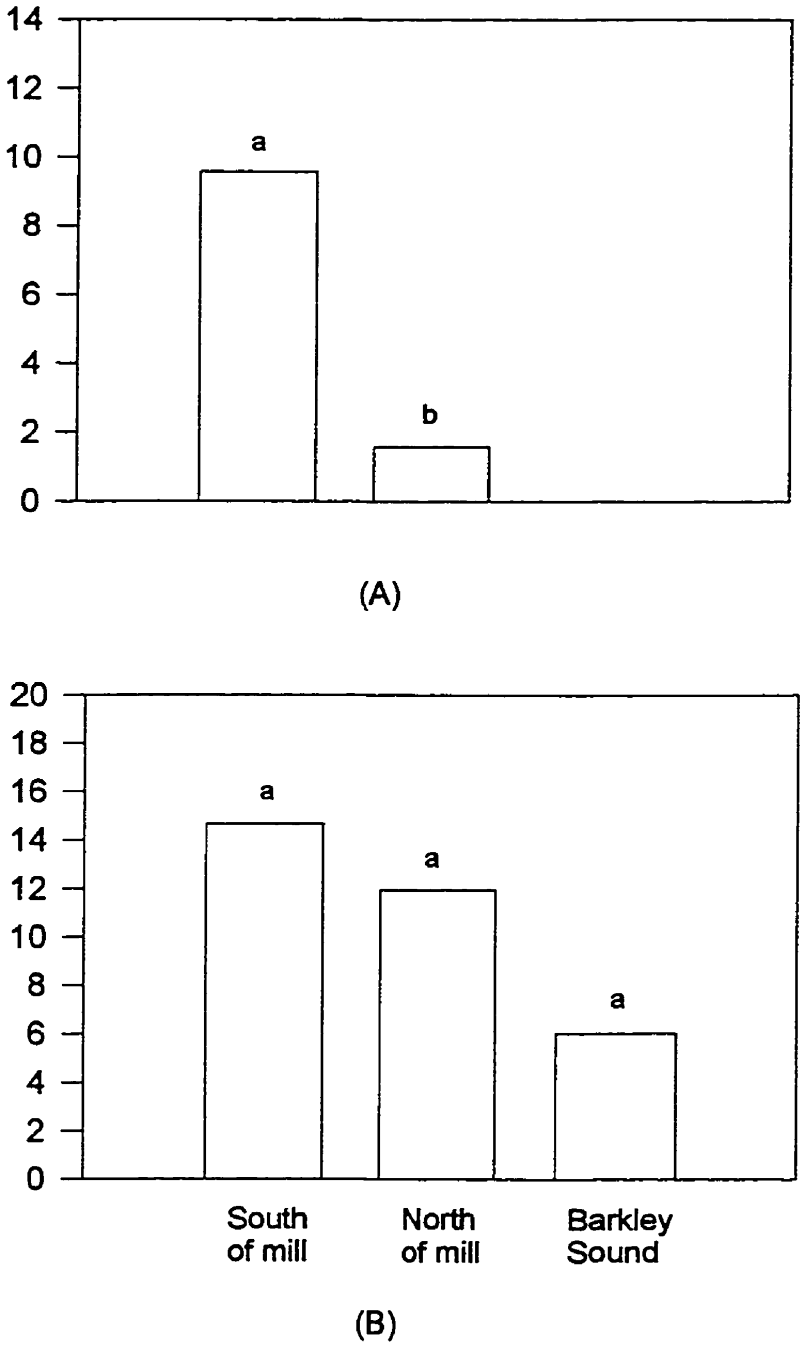

Figure 2.3. 1,2,3,6,7,8-HxCDD levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

1,2,3,4,6,7,8-HpCDD - Eaglet plasma levels of 1,2,3,4,6,7,8-HpCDD were similar near Crofton (Figure 2.4) but below detection limits for all samples collected in Barkley Sound. Adult concentrations were similar among all study areas possibly due to the small number of samples containing detectable amounts of this contaminant (Figure 2.4). Only one adult sample contained detectable levels of 1,2,3,4,6,7,8-HpCDD south of the Crofton mill (0.9 ng/kg, wet weight) and in Barkley Sound (0.70 ng/kg, wet weight). North of the mill, concentrations in two samples averaged 0.50 ng/kg, wet weight.

OCDD - Levels of OCDD were similar among all study locations for both eaglets and adults (Figure 2.5). Levels were generally higher south of the mill but the difference was not significant, possibly due to the small sample size and a high degree of variation among samples. Concentrations were 4 - 8 times greater in adults compared to eaglets.

2,3,7,8-TCDF - The highest concentrations of 2,3,7,8-TCDF in eaglet plasma occurred south of the Crofton mill (7.79 ± 3.54 ng/kg, wet weight, Figure 2.6). North of the mill, levels were significantly less (1.17 ± 0.61 ng/kg, wet weight). Adult 2,3,7,8-TCDF levels were similar among all study locations averaging 1.40 ng/kg, wet weight (Figure 2.6). TCDF in adult plasma were highly variable near Crofton and may account for the similarity among samples here.

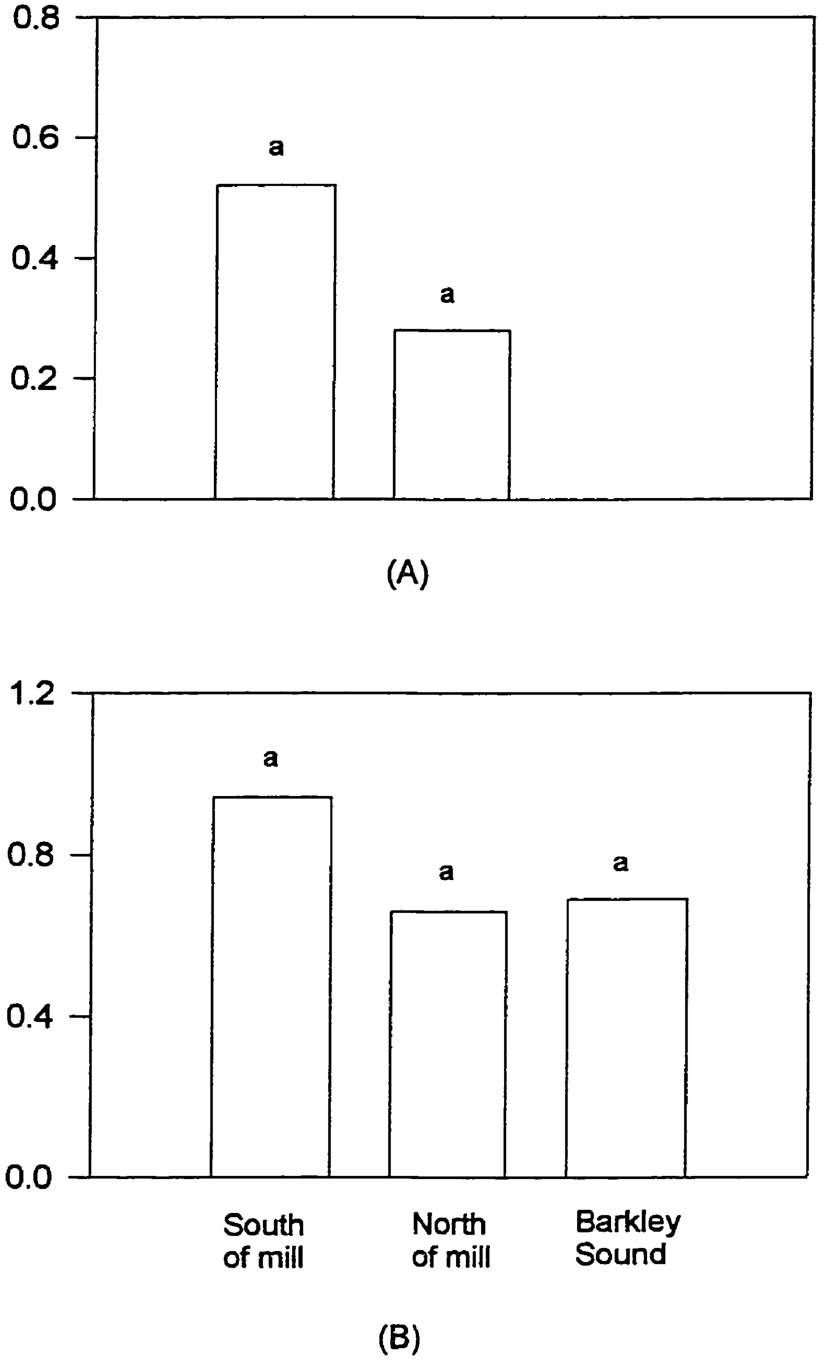

Figure 2.4. 1,2,3,4,6,7,8-HpCDD levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case number are significantly different ($p < 0.05$).

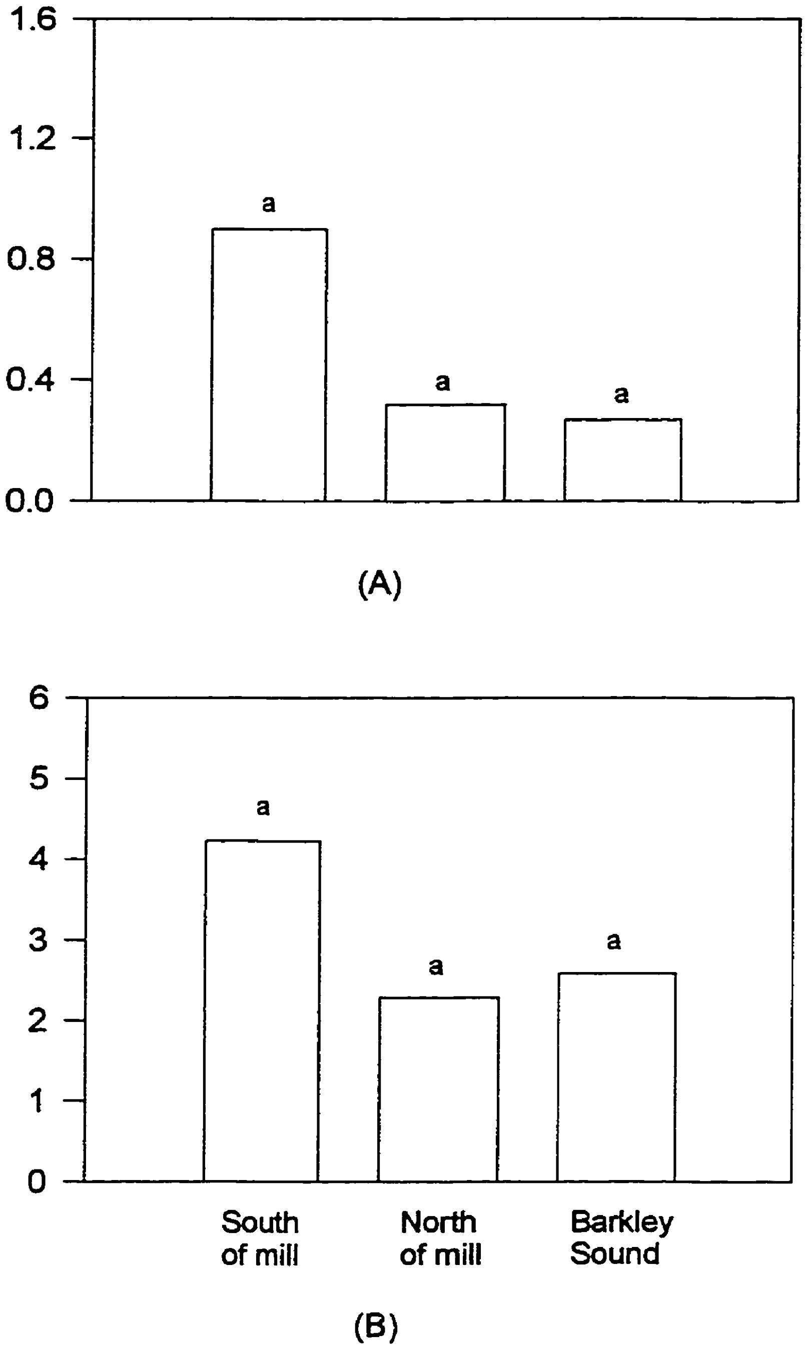

Figure 2.5. OCDD levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

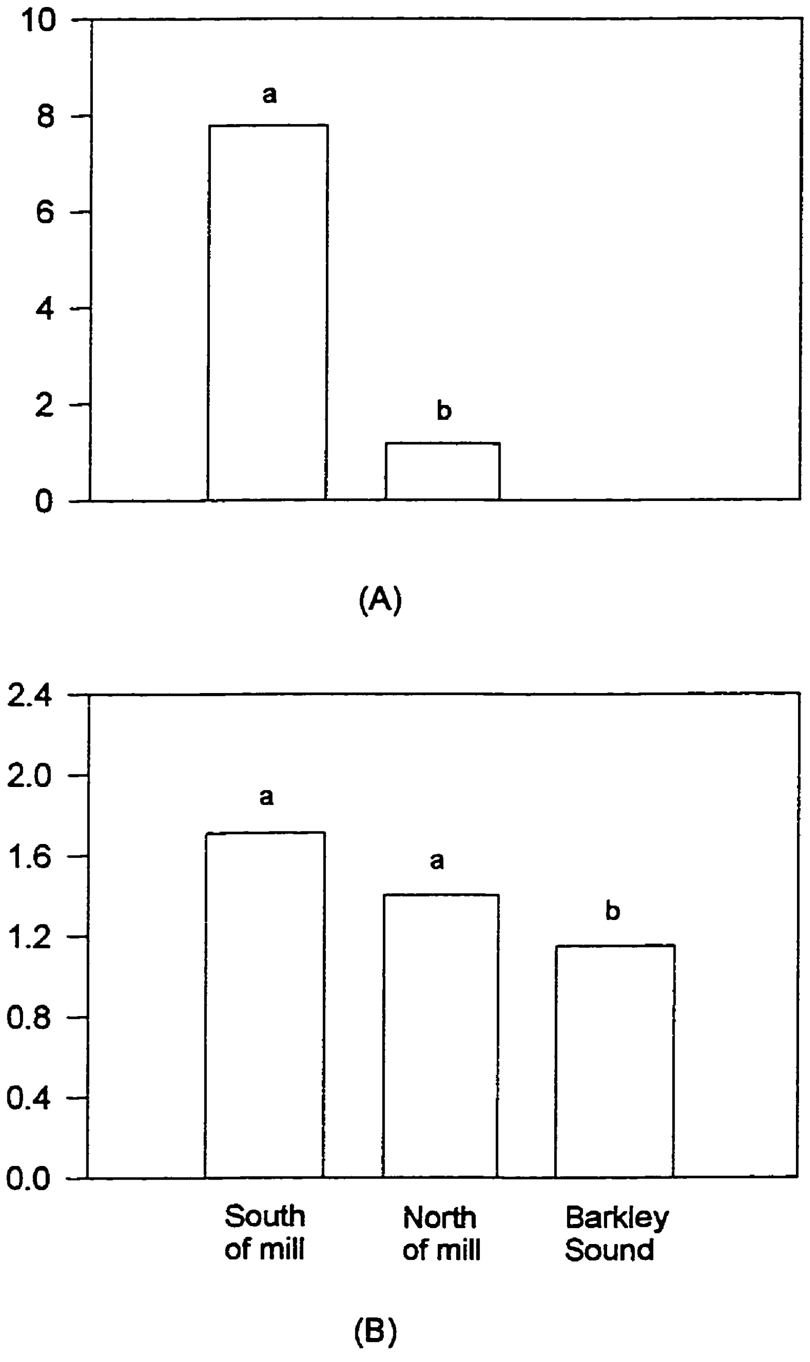

Figure 2.6. 2,3,7,8-TCDF levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

2,3,4,7,8-PnCDF - Levels of 2,3,4,7,8-PnCDF in eaglet blood plasma were 5 times greater south of the mill (0.62 ± 0.40 ng/kg, wet weight) compared to north of the mill (0.11 ± 0.06 ng/kg, wet weight). Concentrations were below detection limits in all samples from Barkley Sound (Figure 2.7). Adult levels tended to be higher south of the mill (1.70 ± 1.4 ng/kg, wet weight) compared to samples from north of the mill (1.10 ± 0.61 ng/kg, wet weight) and in Barkley Sound (0.74 ± 0.96 ng/kg, wet weight, Figure 2.7). The difference, however, was not significant possibly due to the large variation among samples south of the mill and small sample size.

1,2,3,6,7,8-HxCDF, OCDF - Both eaglet and adult levels of 2,3,4,6,7,8-HxCDF were similar among the three study areas (Figure 2.8). Similar trends were also found with OCDF levels (Figure 2.9). Adult concentrations of 2,3,4,6,7,8-HxCDF were slightly higher than that found in eaglet plasma samples. OCDF concentrations were similar in adult and eaglet blood samples taken near Crofton. Levels were below detection limits for all adult plasma samples from Barkley Sound.

DDE levels in blood plasma

Concentrations of DDE in eaglet blood plasma were greatest south of the mill (mean = 62.0 ± 61.47 ug/kg, wet weight) compared to levels north of the mill (6.50 ± 4.35 ug/kg, wet weight), and in Barkley Sound (2.80 ± 1.76 ug/kg, wet weight, Figure 2.10). The latter two sites did not differ in mean DDE levels. Levels in eaglet plasma were approximately half of that estimated to cause significant population effects (> 170 ug/kg, wet weight, Elliott and Norstrom 1998b, Wiemeyer *et al.* 1984).

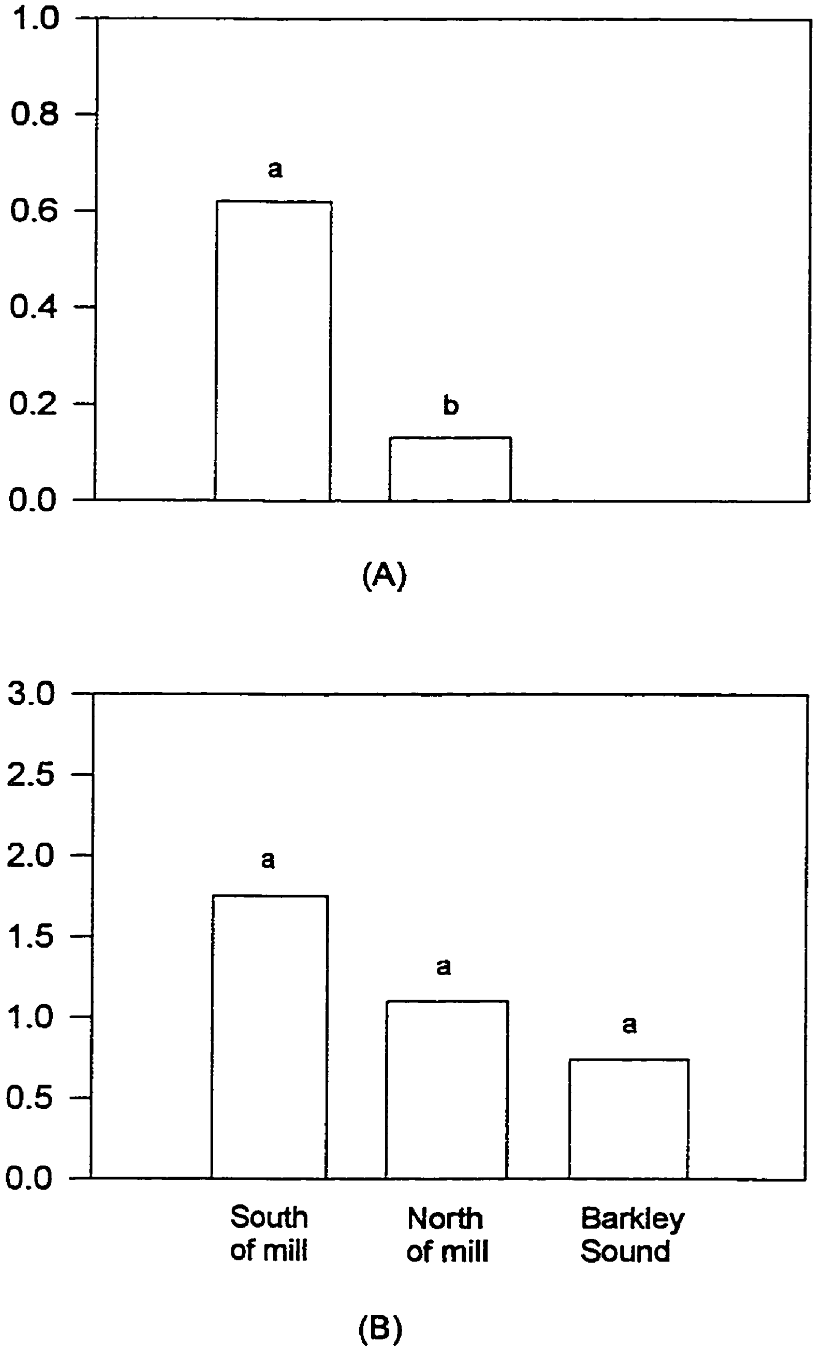

Figure 2.7. 2,3,4,7,8-PnCDF levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

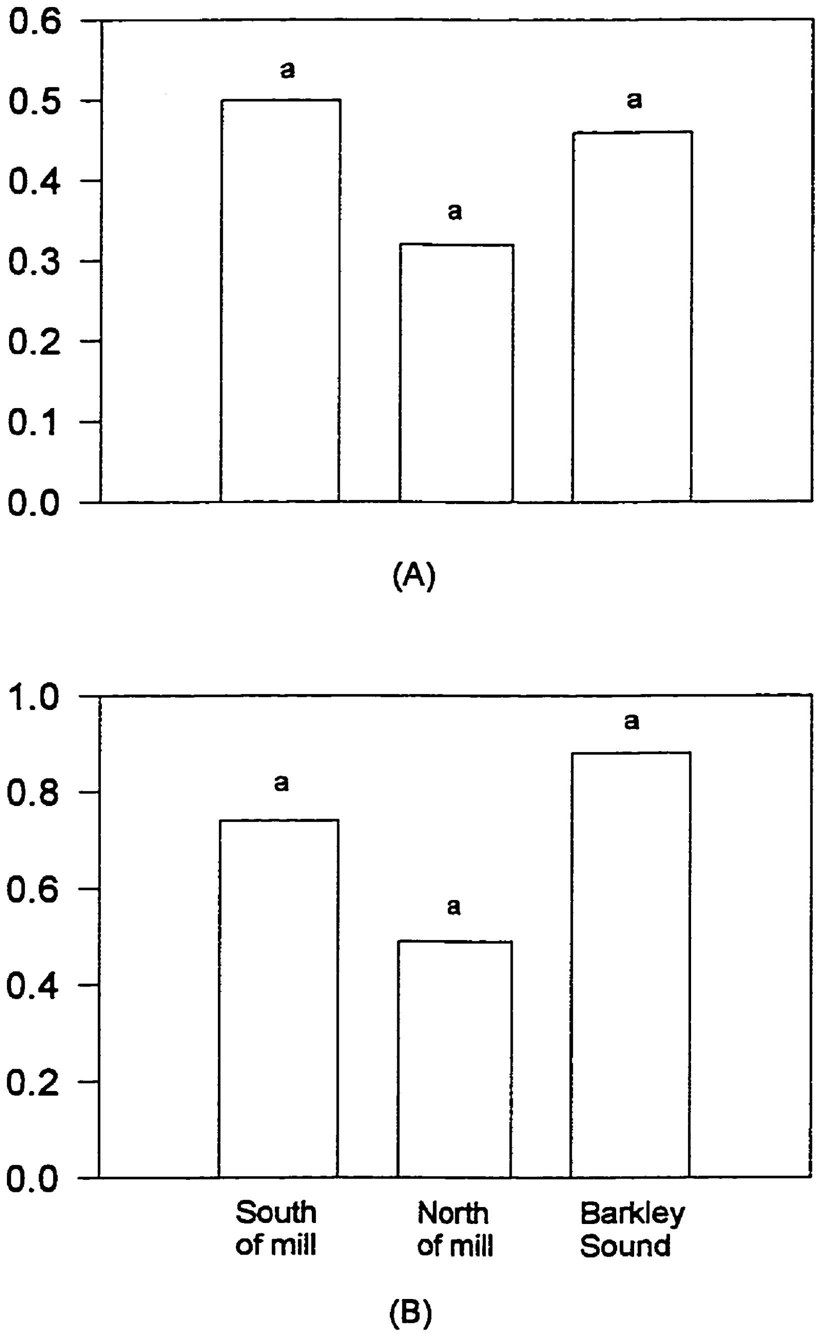

Figure 2.8. 2,3,4,6,7,8-HxCDF levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

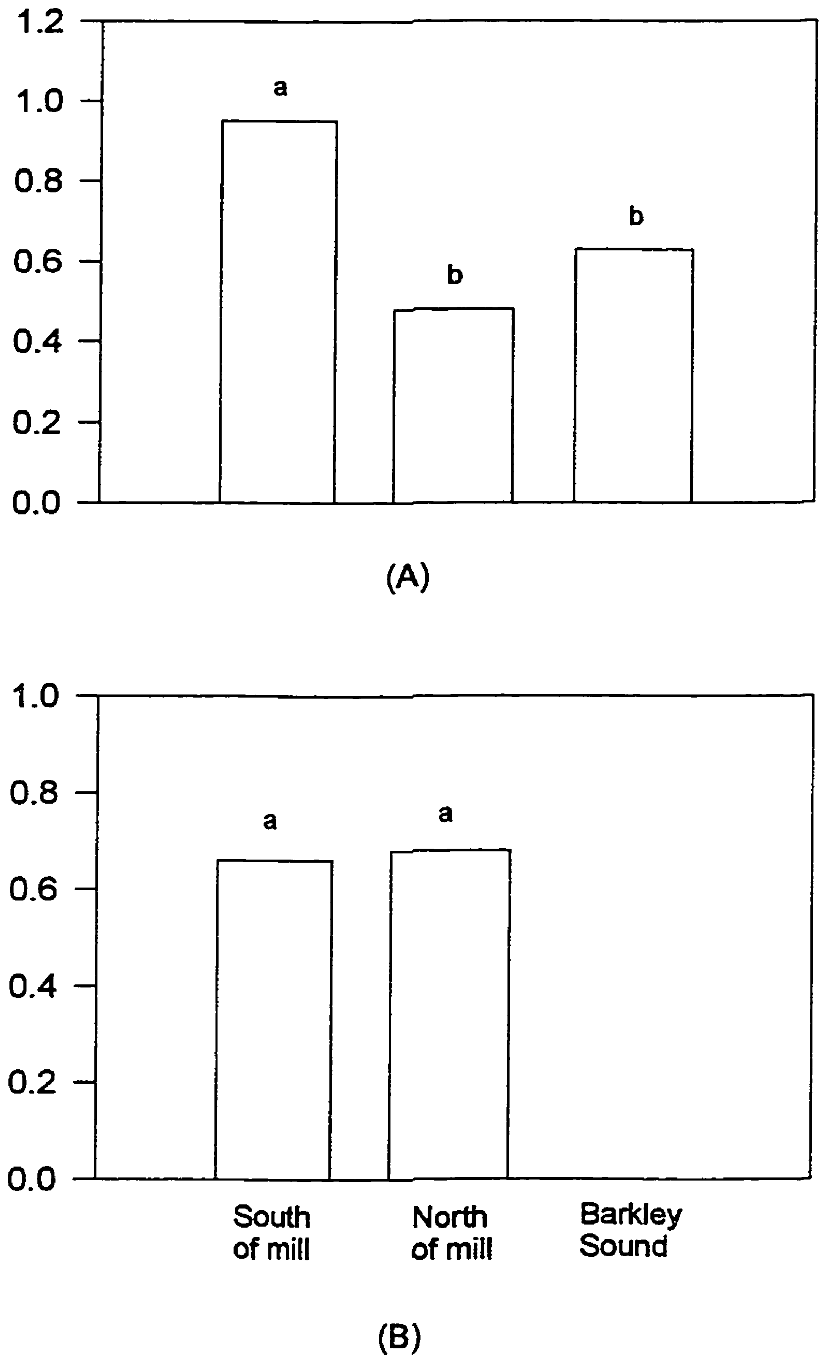

Figure 2.9. OCDF levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

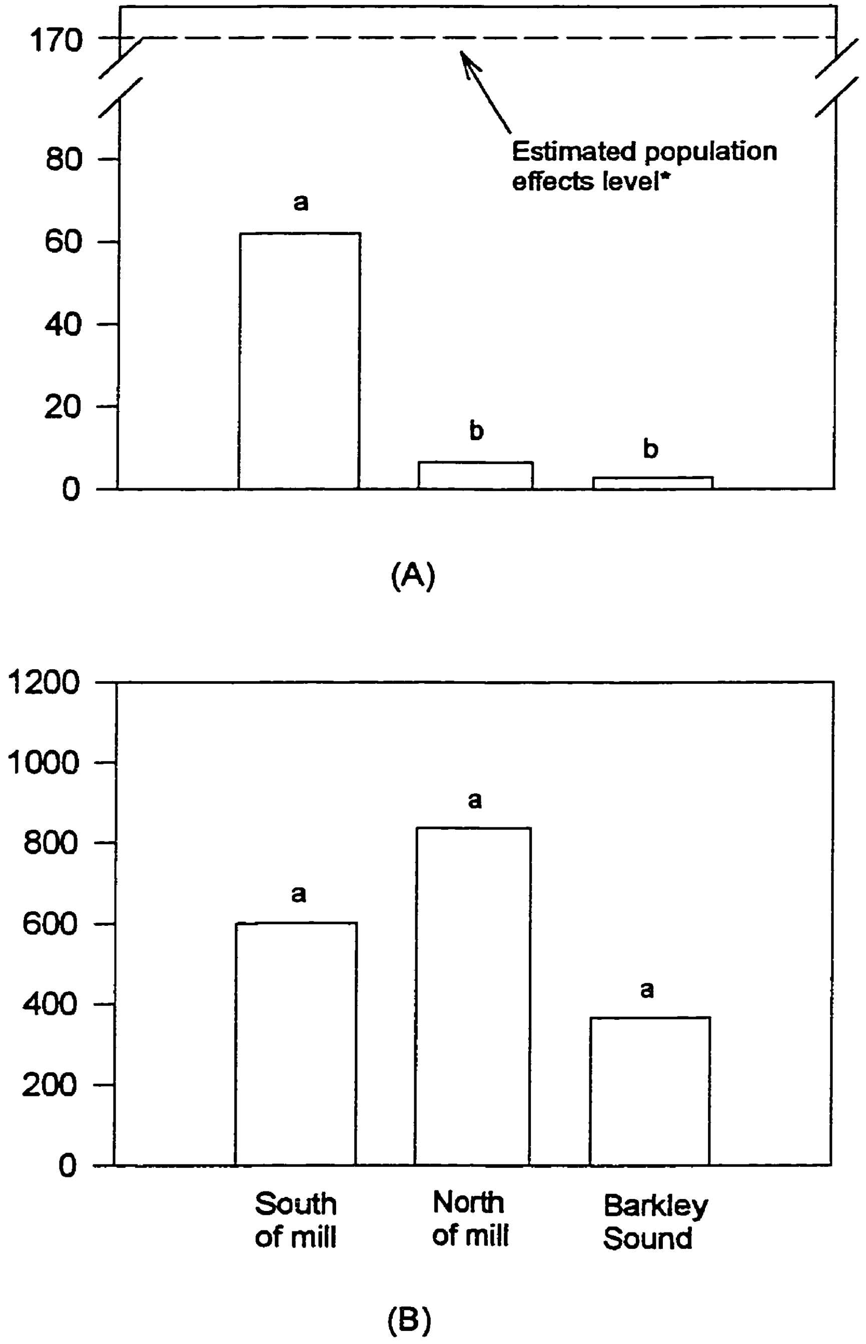

Figure 2.10. DDE levels (ug/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).
* Elliott and Norstrom 1998b, Wiemeyer *et al.* 1993.

DDE levels in adult blood plasma revealed a different trend from that found for eaglets. However, results were not significant possibly due to a high degree of variation among samples north of the Crofton mill (Figure 2.10). Levels tended to be greatest north of the Crofton mill (mean DDE = 836.20 ± 1517.00 ug/kg, wet weight), intermediate south of the mill (601.2 ± 338.84 ug/kg, wet weight), and lowest in Barkley Sound (366.72 ± 208.85 ug/kg, wet weight).

PCBs in blood plasma

Highest concentrations of total PCBs were found in eaglet blood plasma collected south of the mill (127.20 ± 56.68 ug/kg, wet weight, Figure 2.11). Levels north of the mill were intermediate (31.00 ± 10.38 ug/kg, wet weight) and lowest in Barkley Sound (11.10 ± 6.26 ug/kg, wet weight). Levels in eaglets were lower than that estimated to cause significant population effects (> 500 ug/kg, wet weight, Elliott and Norstrom 1998b, Wiemeyer *et al.* 1984). For adults, mean total PCBs levels in blood plasma were similar among the three study locations. Levels tended to be higher south of the Crofton mill (1334.00 ± 711.75 ug/kg, wet weight) compared to north of the mill (982.6 ± 1388.00 ug/kg, wet weight) and in Barkley Sound (775.7 ± 771.41 ug/kg, wet weight) but the difference was not significant (Figure 2.11).

The pattern of non-*ortho* PCB congeners in eaglet and adult blood samples varied depending on the maturity of the individual (Table 2.2). Near Crofton mill and in Barkley Sound, the pattern in eaglet blood plasma was generally 126 > 77 > 37 > 169 > 81. Adults showed a slightly different pattern (126 > 77 > 169> 37 > 81). Most non-*ortho* PCBs south of the Crofton mill were approximately 6 times greater in adults compared to eaglets from this

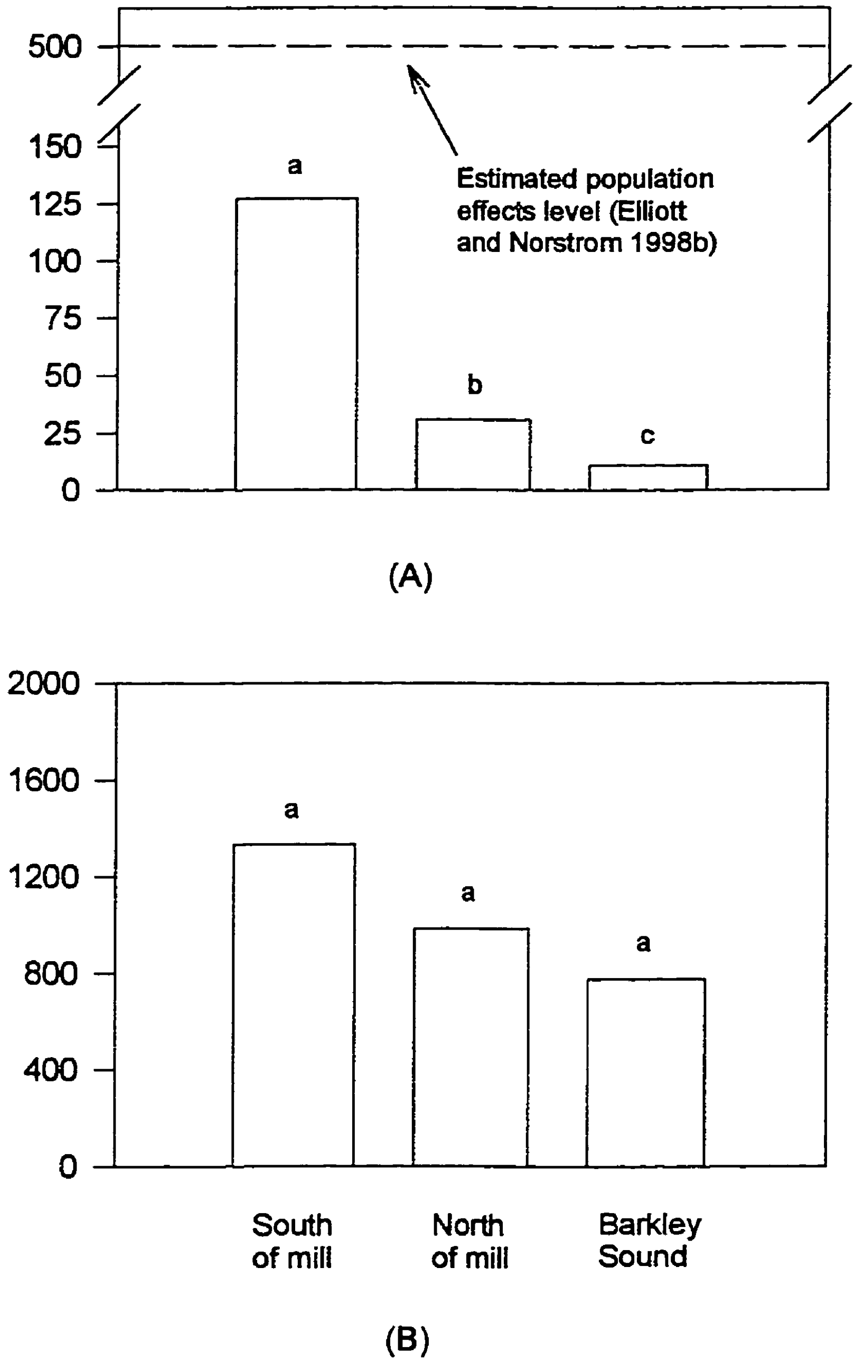

Figure 2.11. Total PCB levels (ug/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

Table 2.2. Geometric means and 95% confidence intevals for selected organochlorine and non-*ortho* PCB levels in eaglet blood blood plasma from nests near Crofton and Barkley Sound (1995-1996) and in blood plasma of breeding adults caught within active territories in each area (1997). Adult levels are lipid adjusted.

		Residue Levels							
		(ug/kg, wet weight)		(ng/kg, wet weight)					
Location	N	DDE	Total PCBs	PCB-37	PCB-81	PCB-77	PCB-126	PCB-169	PCB-189
Eaglet Samples									
South of mill	5	62.0 0.5-123.4	127.2 69.3-184.8	2.7 0.8-4.4	1.5 0.3-2.8	22.7 4.6-40.7	24.9 0.9-48.8	3.9 ND-7.9	0.4 ND-1.0
North of mill	9	6.5 2.1-10.8	31.0 2.06-41.4	1.9 1.1-2.6	0.4 0.2-0.7	5.5 1.8-9.1	3.0 1.5-4.5	0.7 0.5-1.0	0.1*
Barkley Sound	4	2.8 1.0-3.8	11.1 4.8-17.3	0.3 0.1-0.6	ND	1.7 0.8-2.7	0.8 ND-1.9	0.2 0.1-0.3	ND
Adult Samples									
South of mill	4	601.2 262.2-939.8	1334.0 622.2-2045.7	3.1 ND-6.7	6.5 3.6-9.4	60.1 31.9-88.3	119.3 70.9-167.6	28.9 12.4-45.4	5.7 1.6-9.8
North of mill	3	836.2 ND-2353.2	982.6 ND-2370.6	2.8 1.4-4.2	6.7 2.2-11.2	60.4 1.9-118.9	67.1 ND-134.2	15.4 ND-31.9	2.4 0.3-4.5
Barkley Sound	3	366.7 157.9-575.5	775.7 4.3-1547.1	4.8 ND-10.4	8.4 1.0-15.8	80.8 8.8-152.8	120.0 12.3-227.8	30.9 ND-66.6	7.4 1.1-13.7

ND - not detected, minimum detection limit 0.01-0.05 ng/ kg, wet weight
* - one sample only.

area. North of the mill, levels were generally 15 times greater in adults. In Barkley Sound, non-*ortho* PCB levels in adults were 92 times greater than that found in eaglet blood samples.*PCB-126, -169* - Highest concentrations of PCB-126 and 169 were found in eaglets south of the Crofton mill (PCB-126 = 24.90 ± 23.96 ng/kg, wet weight, Figure 2.12, PCB-169 = 3.90 ± 4.10 ng/kg, wet weight, Figure 2.13). Levels tended to be intermediate north of the mill (PCB-126 = 3.00 ± 1.62 ng/kg, wet weight, PCB-169 = 0.70 ± 0.23 ng/kg, wet weight) and lowest in Barkley Sound (PCB-126 = 0.80 ± 1.04 ng/kg, wet weight, PCB-169 = 0.20 ± 0.09 ng/kg, wet weight). In adults, plasma concentrations of both PCB-126 and 169 were similar among all study locations (Figures 2.12, 2.13). Levels were 5 - 150 times greater in adults compared to eaglets.

PCB-37 - Levels of PCB-37 in eaglet plasma were greater among samples taken near Crofton (south of mill = 2.70 ± 1.55 ng/kg, wet weight, north of mill = 1.91 ± 0.43 ng/kg, wet weight) compared to that found for samples from Barkley Sound (0.30 ± 0.79 ng/kg, wet weight, Figure 2.14). No difference in concentrations was evident between samples taken north and south of the Crofton mill. In adults, PCB-37 levels were similar among all study locations. Levels tended to be higher in Barkley Sound for PCB-37 compared the Crofton area but the difference was not significant (Figure 2.14).

PCB-77 - Highest concentrations of PCB-77 were found in eaglet blood plasma collected south of the Crofton mill (22.70 ± 18.07 ng/kg, wet weight, Figure 2.15). Levels north of the mill (5.50 ± 3.23 ng/kg, wet weight) were similar to that found in Barkley Sound samples (1.70 ± 0.92 ng/kg, wet weight). Adult levels of PCB-77 were similar among all study

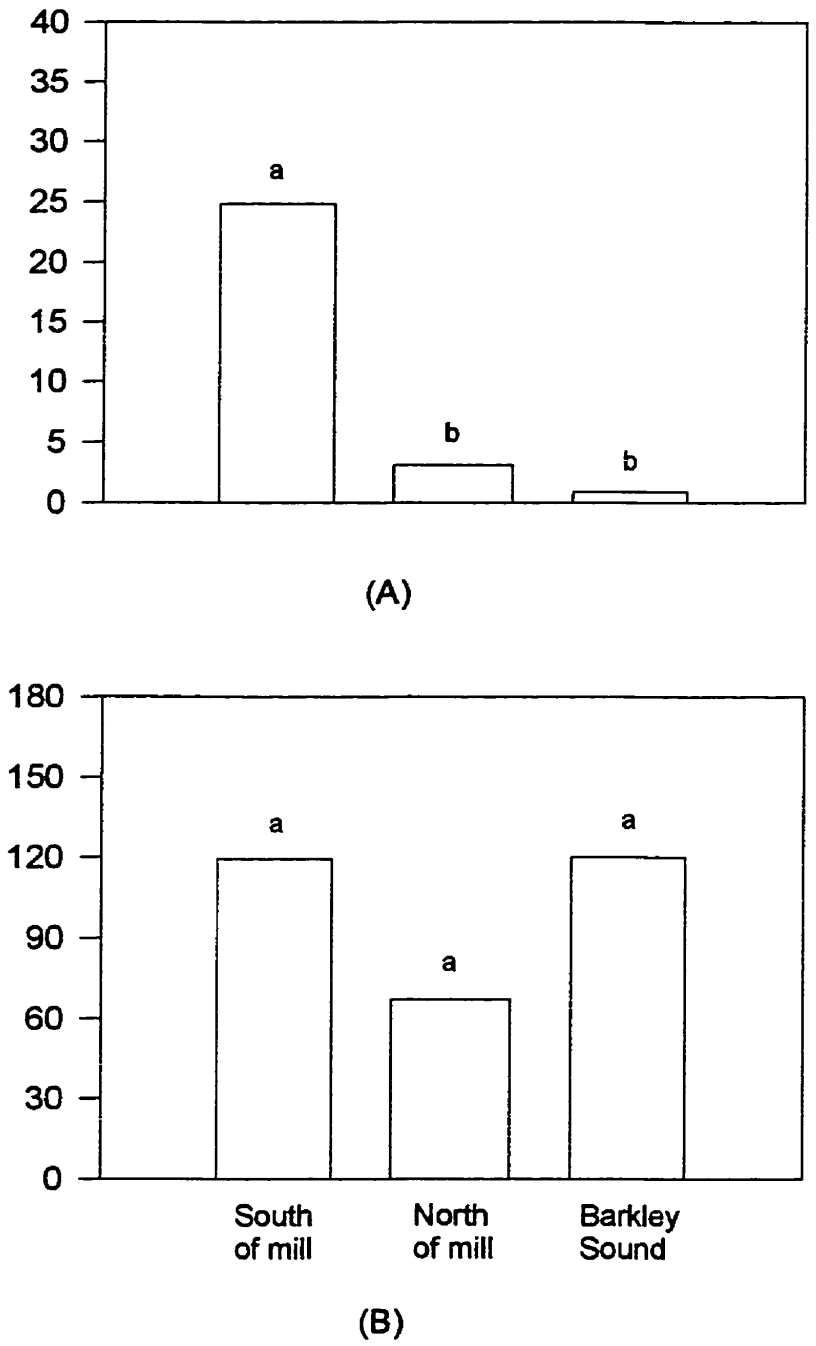

Figure 2.12. PCB-126 levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

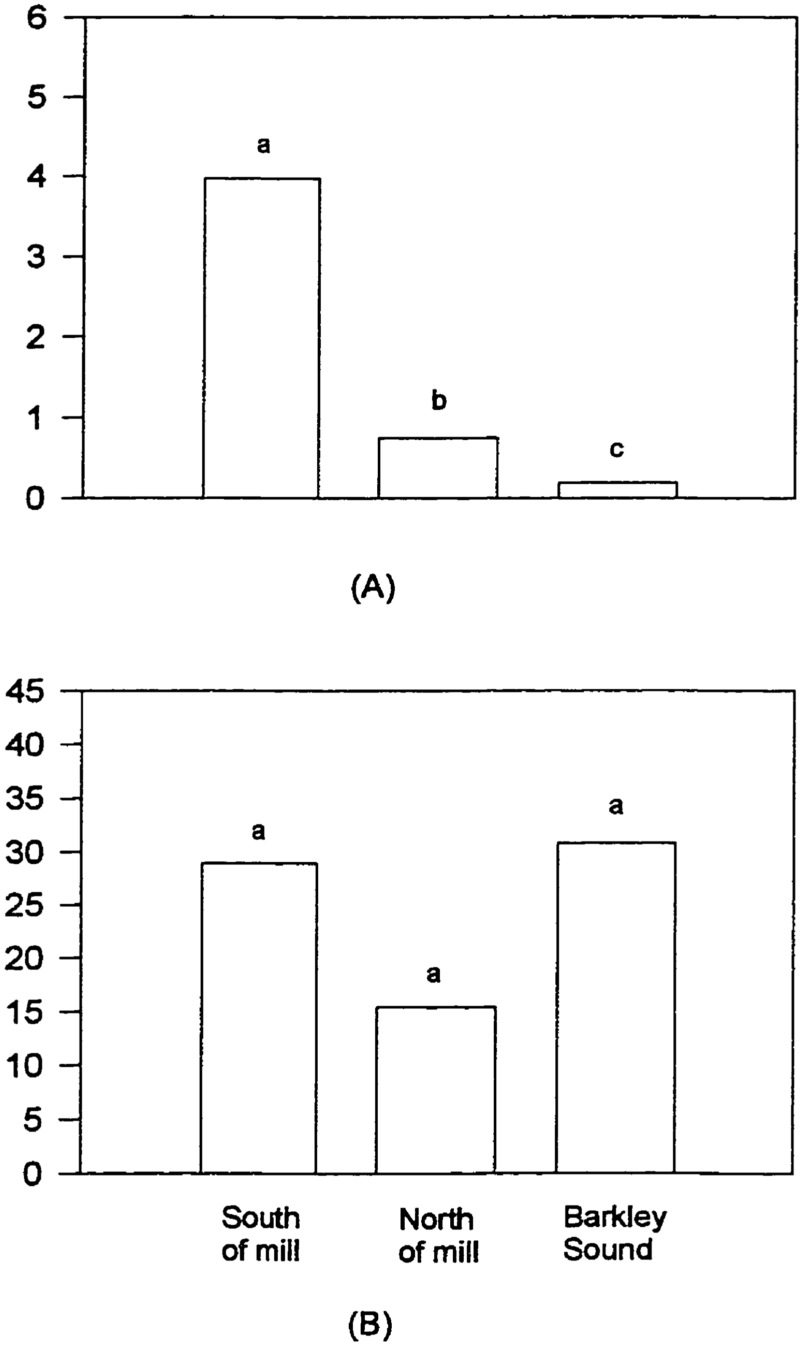

Figure 2.13. PCB-169 levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

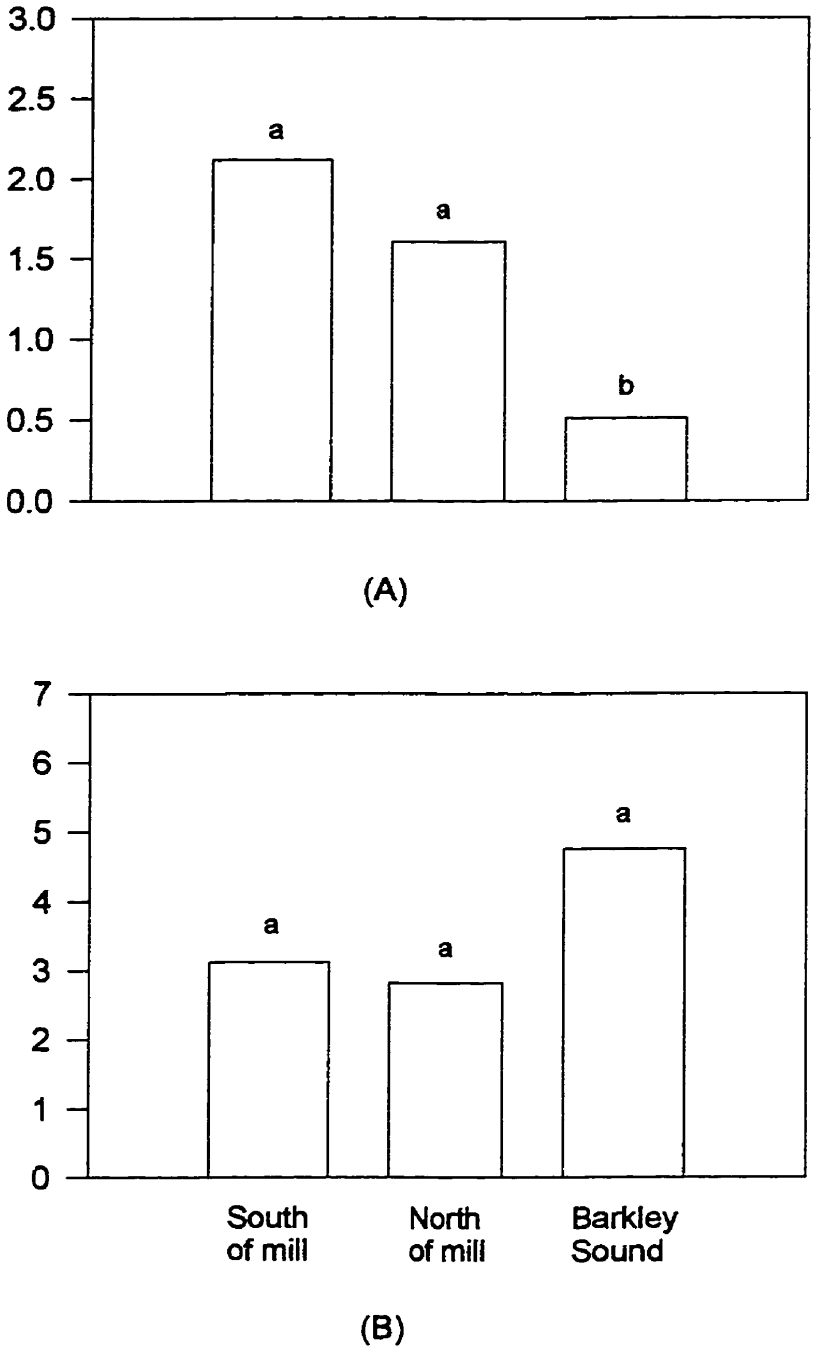

Figure 2.14. PCB-37 levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

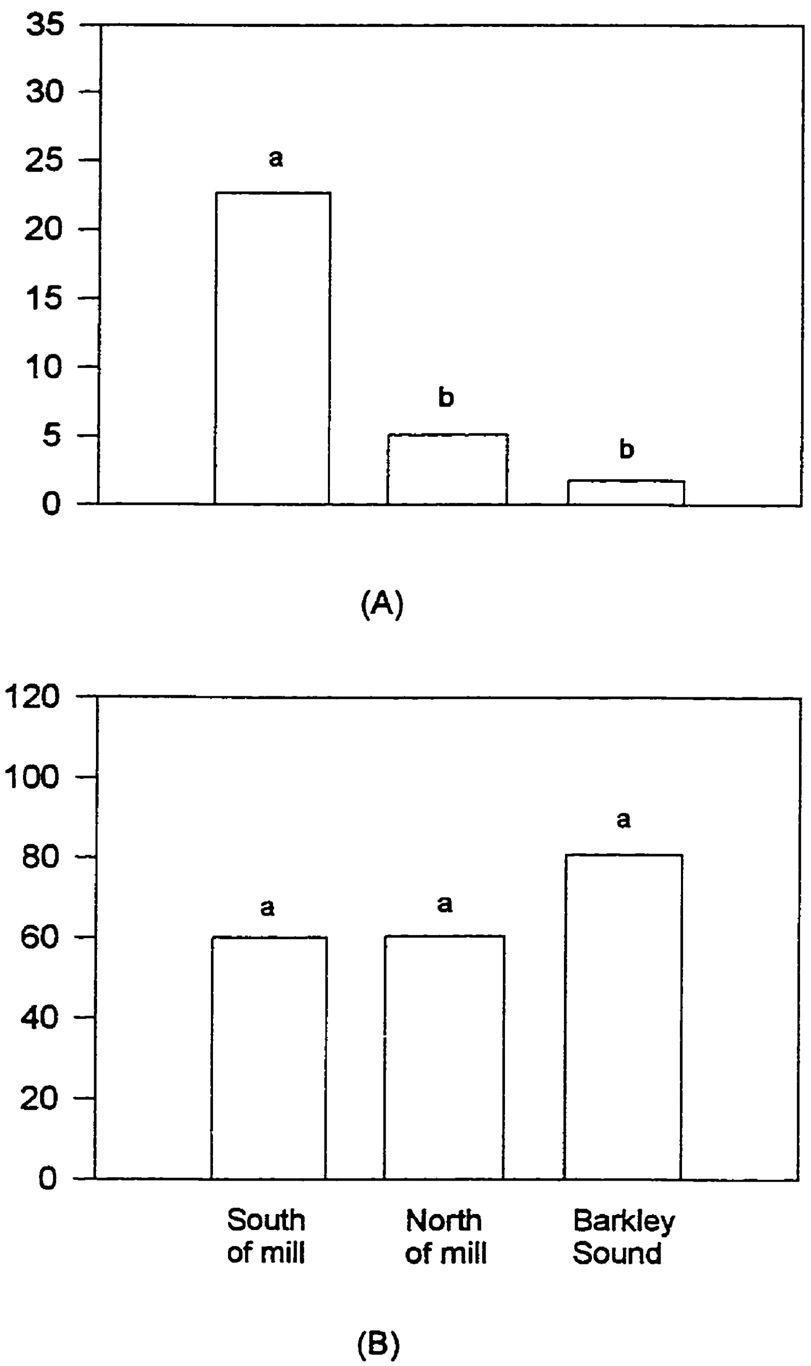

Figure 2.15. PCB-77 levels (ng/ kg, wet weight) in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

locations averaging 67.10 ng/kg, wet weight (Figure 2.15). Concentrations were slightly higher in Barkley Sound compared to the Crofton area but the difference was not significant. Adult levels were 3 - 50 times greater than eaglet levels from the same study area.

TEQs-WHO levels in blood plasma

Toxic Equivalents (TEQs-WHO) in eaglet blood plasma were highest south of the Crofton mill (17.04 ± 10.78 ng/kg, wet weight, Table 2.3, Figure 2.16). Levels north of the mill (2.59 ± 0.98 ng/kg, wet weight) did not differ from that found in Barkley Sound (0.81 ± 0.25 ng/kg, wet weight). Adult TEQ levels were similar among all study locations averaging 26.70 ng/kg, wet weight (Table 2.3, Figure 2.16). Levels tended to be higher south of the Crofton mill and in Barkley Sound but the difference was not significant.

PCB 126, 2,3,7,8-TCDF, 1,2,3,7,8-PnCDD, 2,3,7,8-TCDD, PCB-77, and 2,3,4,7,8-PnCDF were major contributors to the TEQs-WHO values determined for adult and eaglet contaminant data (Table 2.3).

Adult residue levels and mean 6-year productivity

No significant correlations were evident between mean 6-year productivity of individual nests near Crofton and in Barkley Sound for DDE, total PCBs or TEQs (Figures 2.17, 2.18, 2.19). South of the Crofton mill, productivity tended to decrease with increasing levels of DDE in eaglet plasma but the relationship was not significant.

Table 2.3. Geometric means and 95% confidence intervals for calculated TEQs-WHO levels in adult and eaglet blood plasma collected near Crofton and in Barkley Sound (1995-1997). Adult levels are lipid adjusted.

		TEQs-WHO Levels (ng/kg, wet weight)							
Location	N	2378-TCDD	12378-PnCDD	123678-HxCDD	123789-HxCDD	2378-TCDF	12378-PnCDF	23478-PnCDF	123678-HxCDF
<u>Eaglet Samples</u>									
South of mill	5	1.525 0.147-2.903	2.963 0.492-5.432	0.096 0.033-0.159	0.091 0.000-0.208	7.790 4.251-11.329	0.025 0.000-0.051	0.620 0.225-1.015	0.018 0.000-0.045
North of mill	9	0.152 0.095-0.208	0.436 0.261-0.611	0.016 0.008-0.024	0.023 0.014-0.031	1.169 0.563-1.775	0.009 0.006-0.012	0.133 0.077-0.188	0.012 0.009-0.014
Barkley Sound	4	0.150 0.033-0.267	0.145 0.059-0.231	0.001 *	0.009 0.006-0.011	0.151 0.085-0.217	0.009 0.003-0.015	0.093 0.030-0.155	0.010 0.002-0.017
<u>Adult Samples</u>									
South of mill	4	2.603 0.725-4.479	5.286 2.974-7.596	0.146 0.066-0.226	0.056 0.000-0.142	1.705 0.377-3.033	0.018 0.000-0.048	1.947 0.038-3.856	0.041 0.000-0.101
North of mill	3	2.013 0.000-4.062	5.322 0.802-9.842	0.120 0.000-0.293	0.021 0.000-0.051	1.403 0.000-3.660	0.027 0.000-0.066	1.101 0.488-1.714	0.016 0.000-0.038
Barkley Sound	3	1.651 0.000-3.574	5.167 1.715-8.618	0.060 0.021-0.099	0.038 0.015-0.060	1.149 0.856-1.441	0.026 0.009-0.043	0.739 0.000-1.697	0.034 0.023-0.047

*all values equal

Table 2.3. Continued.

Location	TEQs-WHO Levels (ng/kg, wet weight)								
	123789-HxCDF	234678-HxCDF	1234678-HpCDF	PCB-77	PCB-81	PCB-126	PCB-118	PCB-105	Total TEQs-WHO
<u>Eaglet Samples</u>									
South of mill	0.018 0.000-0.055	0.038 0.000-0.111	0.003 0.000-0.007	1.134 0.231-2.037	0.154 0.028-0.280	2.486 0.091-4.881	0.088 0.050-0.125	0.195 0.096-0.293	**17.047** 6.227-27.826
North of mill	0.013 0.009-0.016	0.024 0.013-0.035	0.001 0.001-0.002	0.258 0.096-0.419	0.031 0.014-0.048	0.298 0.150-0.446	0.015 0.012-0.017	0.033 0.029-0.037	**2.588** 2.160-3.016
Barkley Sound	0.010 0.002-0.017	0.020 0.000-0.048	0.001 0.000-0.002	0.087 0.041-0.133	0.027 0.004-0.049	0.093 0.000-0.197	0.005 0.004-0.005	0.010 0.004-0.016	**0.808** 0.729-0.886
<u>Adult Samples</u>									
South of mill	0.041 0.000-0.101	0.069 0.013-0.124	0.004 0.000-0.010	3.004 1.595-4.413	0.588 0.396-0.779	11.930 7.095-16.765	0.541 0.369-0.713	1.862 1.037-2.686	**29.841** 20.791-38.891
North of mill	0.016 0.000-0.038	0.041 0.000-0.105	0.002 0.001-0.003	3.020 0.096-5.943	0.675 0.228-1.125	6.711 0.0003-13.41	0.475 0.000-1.079	1.736 0.000-3.710	**22.698** 4.709-40.694
Barkley Sound	0.034 0.023-0.047	0.068 0.000-0.122	0.003 0.000-0.009	4.043 0.442-7.644	0.998 0.346-1.650	12.005 1.235-22.778	0.331 0.153-0.509	1.226 0.732-1.754	**27.573** 7.502-47.642

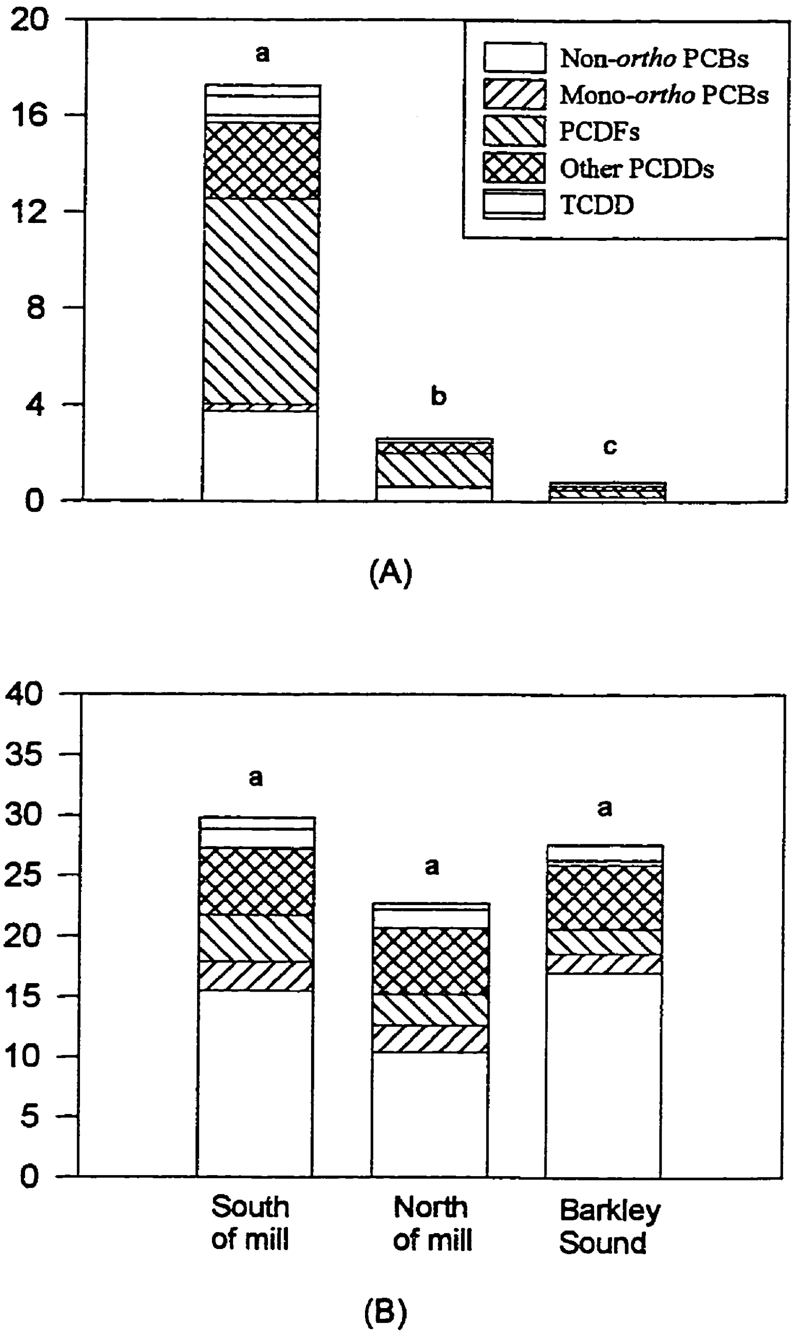

Figure 2.16. The contribution of various chlorinated hydrocarbon groups to the TEQs-WHO levels in blood plasma of (A) eaglets from nests near Crofton and in Barkley Sound and (B) breeding adults captured within active territories in each area. Adult do levels are lipid adjusted. Means that do not share the same lower case letter are significantly different ($p < 0.05$).

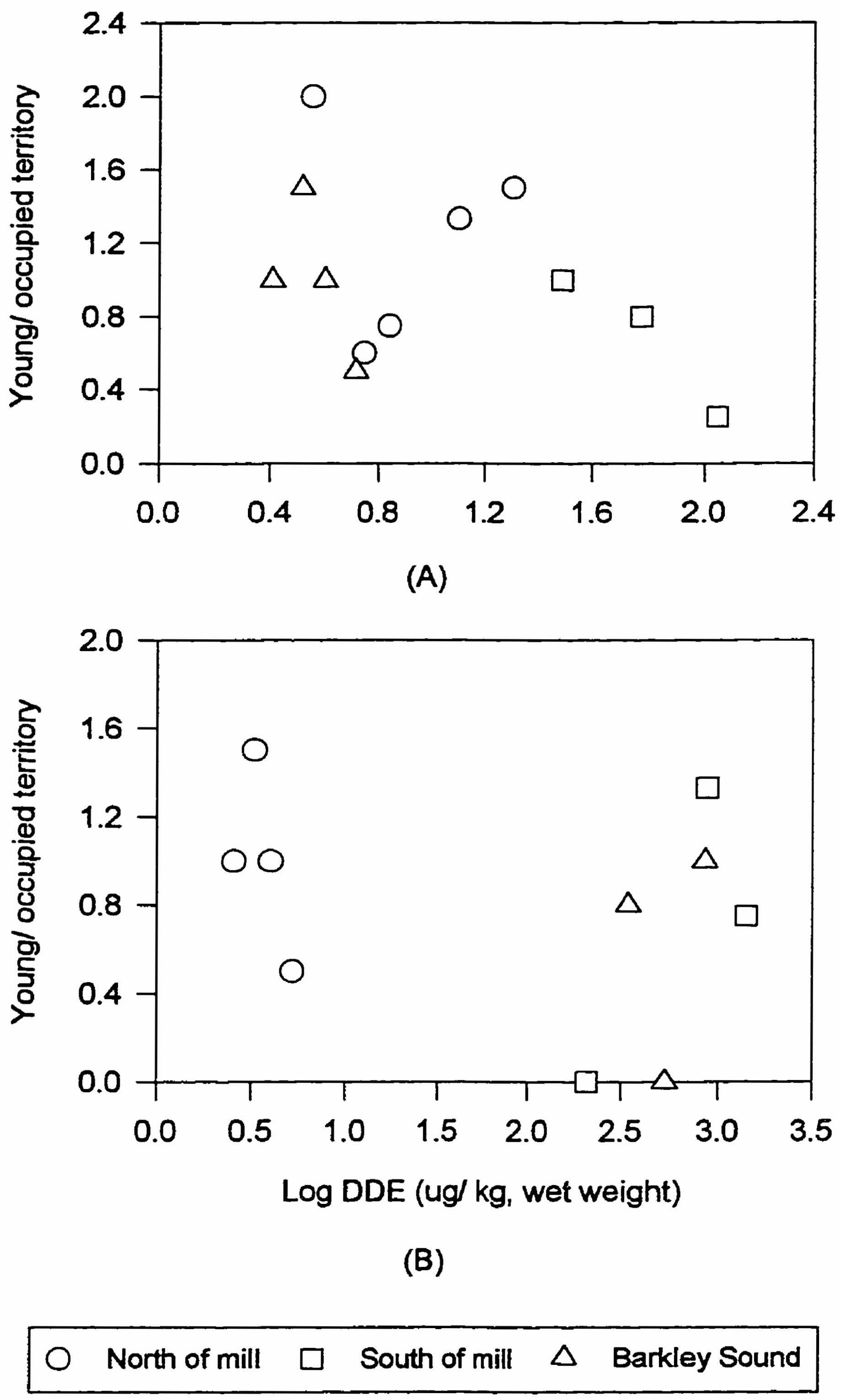

Figure 2.17. Productivity at nests near Crofton and in Barkley Sound in relation to (A) DDE levels in eaglet blood plasma raised in that territory and (B) DDE levels in blood plasma of breeding adults captured within that territory. Adult levels are lipid adjusted.

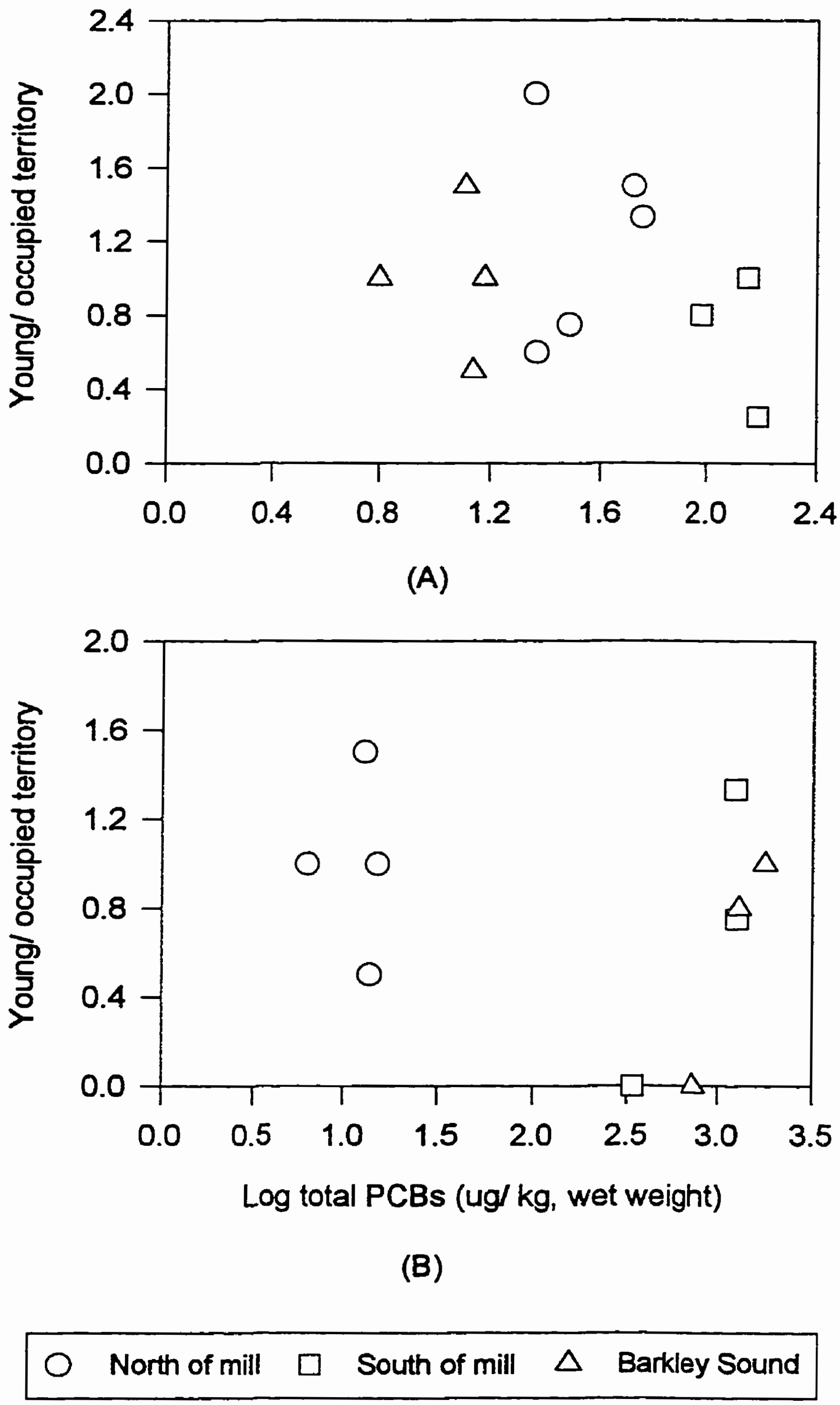

Figure 2.18. Productivity at nests near Crofton and in Barkley Sound in relation to (A) total PCB levels in eaglet blood plasma raised in that territory and (B) total PCB levels in blood plasma of breeding adults captured within that territory. Adult levels are lipid adjusted.

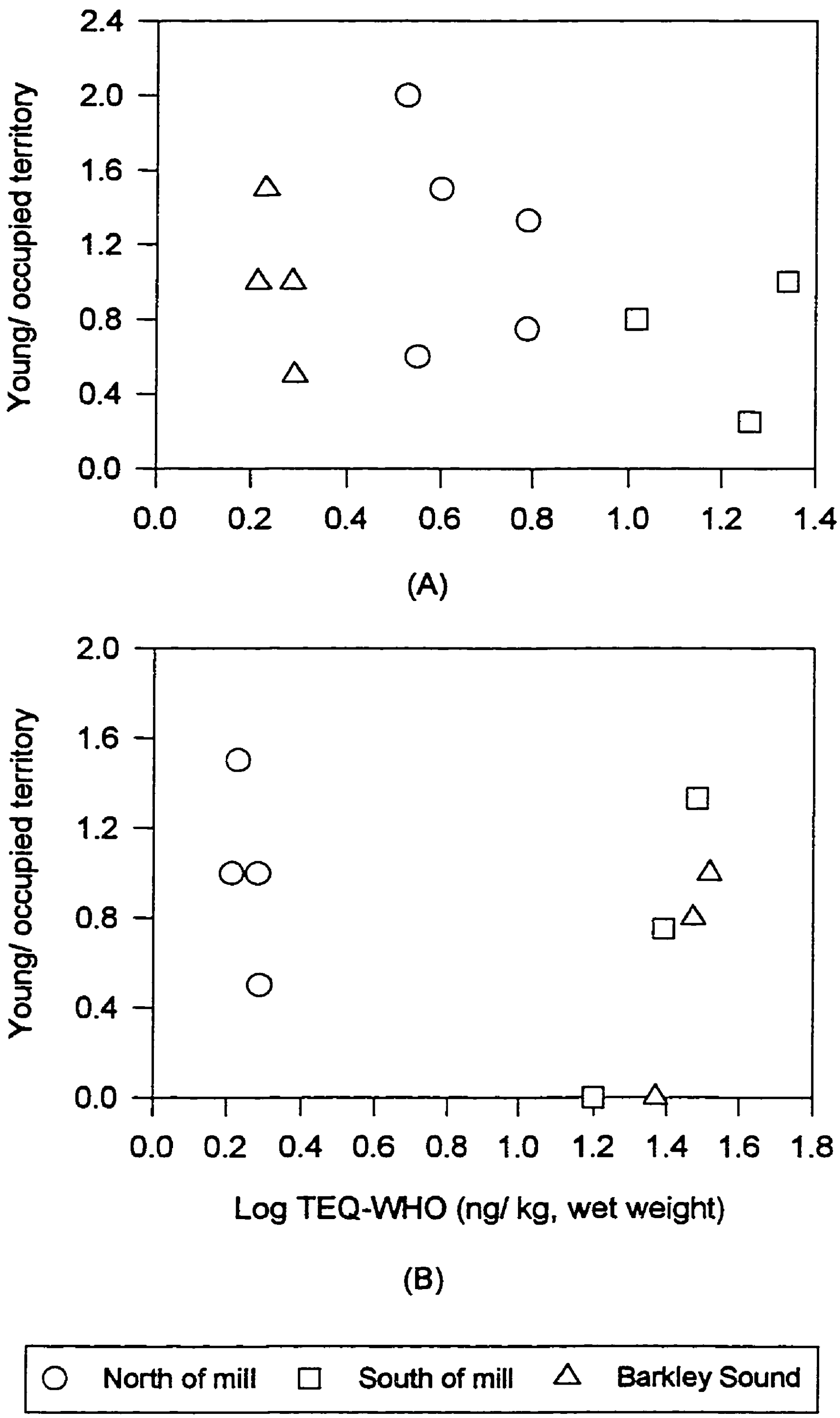

Figure 2.19. Productivity at nests near Crofton and in Barkley Sound in relation to (A) TEQ-WHO levels in eaglet blood plasma raised in that territory and (B) TEQ-WHO levels in blood plasma of breeding adults captured within that territory. Adult levels are lipid adjusted.

Comparison of residue levels in adults and eaglets

No significant correlations occurred between adults and eaglets with DDE, total PCBs, or TEQs-WHO levels when all samples were pooled (Figure 2.20).

Adult nest attendance and chlorinated hydrocarbon levels

Adult nest attendance times were not correlated with DDE, total PCBs, or TEQs-WHO levels in adult blood plasma (Figure 2.21).

Exposure rates and estimated residue levels in eaglet plasma

Estimated exposure rates for selected PCDDs and PCDFs in eaglets near Crofton are found in Table 2.4. Calculated estimates of 2,3,7,8-TCDD and 2,3,4,7,8-PnCDF levels in eaglet blood plasma were similar to actual levels found near Crofton. Determination of other selected PCDD and PCDF concentrations, however, were less accurate. For example, calculated estimates of 2,3,7,8-TCDF were 4-fold higher than actual levels measured in eaglets near Crofton. Elliott *et al.* (1998a) also found that 2,3,7,8-TCDD concentrations in eagle eggs collected near Crofton were similar to that predicted by his bioaccumulation model but less accurate for other compounds such as 1,2,3,7,8-PnCDD.

Figure 2.20. Relationship between adult and eaglet: (A) DDE levels (ug/kg, wet weight) (B) total PCBs (ug/kg, wet weight) (C) TEQs-WHO levels (ng/kg, wet weight) near Crofton and in Barkley Sound. All residue levels are log normalized. Adult levels are lipid adjusted.

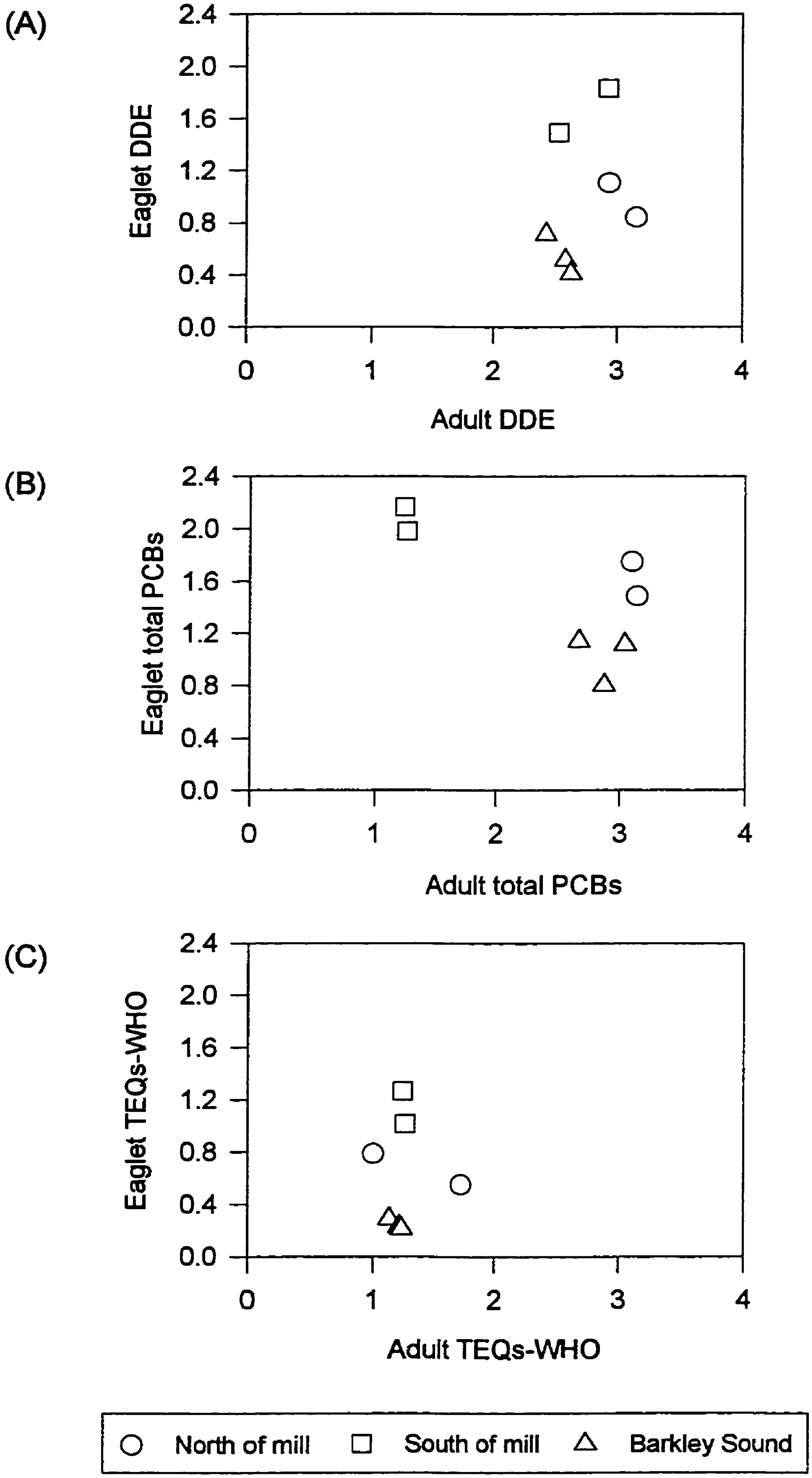
(A)
Eaglet DDE
Adult DDE
(B)
Eaglet total PCBs
Adult total PCBs
(C)
Eaglet TEQs-WHO
Adult TEQs-WHO
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0
1
2
3
4
○ North of mill
□ South of mill
△ Barkley Sound

Figure 2.21. Relationship between adult nest attendance and: (A) DDE levels (ug/kg, wet weight) (B) total PCBs (ug/kg, wet weight) (C) TEQs-WHO levels (ng/kg, wet weight) near Crofton and in Barkley Sound. All residue levels are log normalized and lipid adjusted.

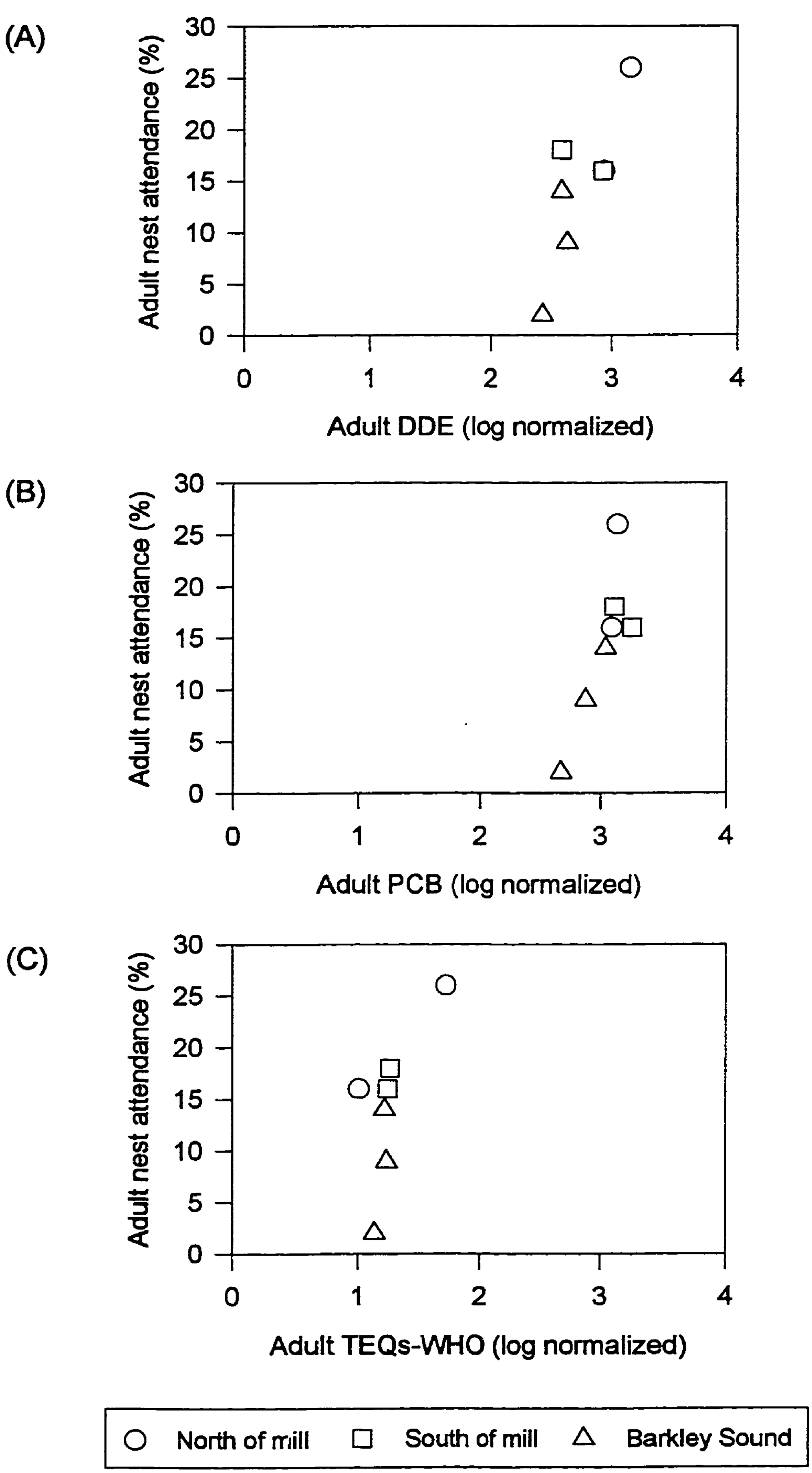
(A)
Adult nest attendance (%)
30
25
20
15
10
5
0
0
1
2
3
4
Adult DDE (log normalized)
(B)
Adult nest attendance (%)
30
25
20
15
10
5
0
0
1
2
3
4
Adult PCB (log normalized)
(C)
Adult nest attendance (%)
30
25
20
15
10
5
0
0
1
2
3
4
Adult TEQs-WHO (log normalized)
○ North of mill
□ South of mill
△ Barkley Sound

Table 2.4. Calculated estimates of selected PCDD and PCDF levels in eaglet blood plasma compared to actual values in eaglets from nests near Crofton (1995-1996).

Chemical	Residue levels in 3 fish species* (ng/kg, wet weight)	Exposure rate per eaglet (ng/kg/day)	Contaminant concentrations in eaglet blood plasma (ng/kg, wet weight)	
			Calculated value	Measured mean value
2378-TCDD	2	0.02	0.90	0.85
12378-PnCDD	2	0.02	0.90	1.73
123678-HxCDD	17	0.15	7.50	5.67
2378-TCDF	37	0.32	16.25	4.48
23478-PnCDF	0.5	0.01	0.35	0.36

*From Table 3.8, Elliott 1995.

DISCUSSION

Productivity and contaminants

Near Crofton, bald eagle breeding success was lowest south of the Crofton mill. Plasma samples from eaglets in this area also contained the greatest concentrations of chlorinated hydrocarbons from pulp mill effluent measured in this study. However, no correlations were evident between productivity and chemical residue levels in eaglets or adults.

Elliott *et al.* (1998a) also found no significant correlation between bald eagle productivity along the B.C. coast and levels of chlorinated hydrocarbons in eaglet plasma. They reported mean total PCBs and DDE levels from southeast Vancouver Island similar to that found north of the mill (30.0 and 11.0 ug/kg, wet weight respectively). In my study, levels south of the mill, however, were 4 - 5 times greater, but similar to PCB and DDE levels from a nest in this area that Elliott *et al.* (1998a) omitted from their analyses (153.0 and 110.6 ug/kg, wet weight respectively).

High levels of total PCBs and DDE have been shown to influence bald eagle productivity in several studies (Wiemeyer et al. 1972, 1984, Frenzel and Anthony 1992, Bowerman 1991, 1993). Bowerman (1993) suggested that the reduced productivity of bald eagles nesting in the Great Lakes Basin was due to high levels of PCBs and DDE in eaglet plasma. He reported that mean total PCBs in blood plasma of eaglets from this area regressed negatively with productivity (1977-1993). Applying total PCB levels found in eaglet blood plasma near Crofton to his regression resulted in productivity estimates of 0.4 young per occupied territory for adults breeding south of the mill and 1.0 young per occupied territory for those breeding north of the mill. These estimates were very similar to actual mean 6-year productivity in these areas. However, his regression estimated productivity of Barkley Sound eagles to be 2-fold higher than the observed value suggesting that other factors such as food stress may be influencing productivity in this area (see Chapter 1). Other studies have found no clear relationship between bald eagle productivity and concentrations of total PCBs, even at very high levels (Welch 1994, Donaldson et al. In press).

Bowerman (1993) also found that DDE levels in eaglet plasma regressed negatively with productivity of eagle nests throughout the Great Lakes Basin. Applying levels of DDE in eaglet blood obtained near Crofton and in Barkley Sound to this regression resulted in large differences between actual and estimated productivity. Nesting success south of the Crofton mill was much greater than that observed by Bowerman (1993) at the same DDE levels. North of the mill and in Barkley Sound, estimates were far below actual productivity in these areas.

Developmental deformities were observed in bald eagle populations where the greatest concentrations of PCBs in eaglet blood plasma were found (Bowerman 1993). Mean total PCB levels in eaglet plasma collected around Lake Michigan (154 ug/kg, wet weight) were similar to that found south of the Crofton mill. DDE levels however, were 2-fold higher here compared to that measured in eaglets from Lake Michigan (35 ug/kg, wet weight). In 1995, a deformed bald eagle nestling was found in a nest near the Harmac pulp and paper mill at Nanaimo, approximately 40 km north of Crofton on Vancouver Island (J. Elliott pers. comm.). Levels of DDE in blood plasma of this eaglet (127.0 ug/kg, wet weight) were 2 - 6 fold greater than that found for other eaglets in this area. Similarly, total PCB levels were 2 - 3 times greater than all other samples taken from this area (239.0 ug/kg, wet weight).

Other researchers have suggested that contaminants are not the main cause of low bald eagle productivity in the Great Lakes Basin. Dyksra (1995) found that bald eagle productivity was positively correlated with prey delivery rates to nests in her study rather than DDE and total PCB levels. Dykstra (1995) suggested that food availability, rather than contaminants was responsible for the reduced productivity along the shoreline of Lake Superior.

PCDDs and PCDFs

Very few studies on PCDD and PCDF levels in avian plasma have been published. Concentrations of TCDD in eaglets from southeast Vancouver Island (0.33 ng/kg, wet weight) reported by Elliott *et al.* (1998a) were comparable to levels north of the mill but significantly lower than the levels found south of the mill in this study. They obtained a blood sample from a nest south of the mill but omitted it from their analyses since the level of TCDD (1.71 ng/kg, wet weight) was significantly greater than any other result in this study area. This level however, is similar to that found in eaglet plasma from nests south of the mill in our study.

In both eaglet and adult blood plasma samples, PCDDs and PCDFs dominated the TEQ-WHO pattern near Crofton. PCBs contributed to most of the TEQ-WHO pattern for eaglets and adults from Barkley Sound. Similar trends were reported by Elliott and Norstrom (1998b).

No published data is available on levels of chlorinated hydrocarbons in plasma of adult bald eagles. PCDD and PCDF levels in blood plasma of adults caught within active territories in the three study areas tended to be highest south of the Crofton mill and lowest in Barkley Sound. For most PCDDs and PCDFs, however, levels north and south of the mill were not significantly different, possibly due to the small sample size. For example, only three nests south of the Crofton mill were included in this study. Several other nests occur farther south but were not included since no productivity surveys had been conducted in this area. North of the mill, nests were only included that were found within the dioxin fishery closure for comparison to Elliott *et al.'s* (1998a) results.

PCDDs and PCDFs levels in adults were significantly higher than that found for eaglets from the same area. The low concentrations in eaglets reflects a dilution of contaminants caused by rapid growth and low fat deposition rates in the young (Kozie and Anderson 1991). In a top predator such as the eagle, slowly metabolized chlorinated hydrocarbons such as DDE and PCBs can take up to 2 years to reach equilibrium (Anderson and Hickey 1976). This may account for the similar levels of most PCDDs and PCDFs in adult plasma samples from the three study areas.

Contaminant pooling in the Strait of Georgia

The difference in contaminant levels north and south of the mill may reflect tidal movement in the Strait of Georgia, which occurs in a north-south direction. The highest contaminant levels were found in a small bay approximately 4 nautical miles south of the Crofton mill. This bay is the main foraging area for most eagles breeding south of the mill and, because of its shape, may serve as a reservoir for mill effluent carried and deposited by tidal movement. Thus, prey items found in this bay may contain elevated levels of chlorinated hydrocarbons from pulp mill effluent which may be limiting eagle productivity in this area. However, no studies have determined the levels of chlorinated hydrocarbons in common prey species of eagles in this area. Bowerman (1993) and Giesy *et al.* (1993b) both suggested that concentrations of PCBs and DDE in eaglet blood plasma were a good measure of contaminant loads of common prey found within breeding territories.

There are no bays immediately north of the mill, therefore contaminants from pulp mill effluent may accumulate more gradually here. This lack of accumulated contaminants is reflected by the low concentrations of PCDDs and PCDFs in eaglet plasma samples taken from this area. Adult levels also tended to be lower north of the mill but the small sample size in this study failed to find differences in the levels of most PCDDs and PCDFs north and south of the Crofton mill.

Other studies in the Strait of Georgia have also found a difference in chlorinated hydrocarbon residues near a different bleached pulp and paper mill on Vancouver Island. Dwernychuck *et al.* (1994) reported that levels of PCDDs and PCDFs in invertebrates were significantly higher north of the Powell River mill. Coincidentally, bald eagle productivity from 1992 to 1995 in that area was low and may be possibly related to an accumulation of chlorinated hydrocarbons in small bays north of this mill (Elliott *et al.* 1998a).

It is possible that the reduced productivity south of the Crofton mill may be due to past exposure to high levels of chlorinated hydrocarbons (Elliott *et al.* 1998a). Residue levels were significantly higher in fish prey south of the mill before changes in the pulp bleaching process were made in the late 1980s. For example, concentrations of chlorinated hydrocarbons in great blue heron eggs collected from the Crofton colony decreased from > 200 ng/kg, wet weight in 1987 to < 4 ng/kg by 1994 (Elliott *et al.* 1996a). Elliott et al. (1996a) suggested that the reproductive failure of the heron colony in the late 1980s was possibly attributed to high levels of PCDD and PCDF in heron eggs. Productivity gradually improved as contaminant levels declined rapidly in the early 1990s. Elliott (1995) estimated that levels of TCDD and other contaminants would likely be even higher in a top predator like the bald eagle as compounds such as these persist longer in animals feeding at higher trophic levels. They estimated concentrations of TCDD in eagle eggs to be in the range of 250 ng/kg in the late 1980s. This value is much higher than that reported to affect the reproductive system of fetal male rats without causing any other health affects (single low maternal dose of 64 ng/kg, Mably *et al.* 1992) but below the acute embryotoxicity threshold for wild birds (Peterson *et al.* 1993).

Adults breeding south of the Crofton mill may have been exposed to high concentrations of contaminants which have damaged reproductive systems or influenced nesting behavior of these individuals.

Adult behavior and contaminant levels

Several studies have suggested that certain chlorinated hydrocarbons such as TCDD, DDE and PCBs can influence productivity through changes in adult behaviour and reproductive capabilities (Bowerman. 1993, Mably *et al.* 1992). A study of the reproductive failure of Forster's terns on Lake Michigan based on an inter-colony egg swap experiment suggested that PCBs caused a decrease in nest attendance and defense resulting in higher frequencies of egg disappearance and chick mortality (Kubiak *et al.* 1989). Similar results were found with organochlorine contamination in herring gulls in the Great Lakes (Mineau *et al.* 1984). In both studies, pollutant-induced endocrine dysfunction was suggested as the possible cause of aberrant parental behavior and decreased attentiveness to brooding.

In my study, adult nest attendance near Crofton and in Barkley Sound was not correlated with DDE, total PCBs, or TEQs-WHO levels in adults. Possible aberrant parental behavior was reported at one nest. Adults at Shoal Island nest, located within 200 m of the Crofton mill, reportedly ate their young in 1995 (L. Meier, pers. comm.). Although that nest was active for 5 of the 6 years that productivity surveys had been conducted there, no young were successfully raised. In 1996, a time-lapse video camera was mounted above this nest to record nesting behavior (see Chapter 1). Two eaglets were present during camera mounting in early May but disappeared 2 days later. No sign of either nestling was found in or around the nest. It is possible that these nestlings died or were killed and eaten by the Shoal Island adults or by another predator. Both eaglets were approximately 1-2 weeks of age at this time, significantly younger than all other nestlings in this area (4-6 weeks old).

The behavior of the Shoal Island eagles appears unusual. There are few cases of such active but unproductive territories elsewhere in the Strait of Georgia (Elliott *et al.* 1998a). Given the location of the Shoal Island nest and high bald eagle productivity at other nests here, it is very likely that PCDD/PCDF pollutants are affecting adult behavior at this nest. Decreased attentiveness to incubation and/or brooding by the Shoal Island birds may have contributed to the high eaglet mortality in this territory. Support for this conclusion is not available as no blood samples were obtained from either eaglets or adults at this nest.

During the 1997 breeding season, a second attempt was made at recording nesting behavior of the Shoal Island pair. Three alternate nests were located in this territory and time-lapse cameras mounted in each nest tree prior to the breeding season. However, no breeding attempts were made in this year.

Comparison of estimated and observed contaminant concentrations

Estimated concentrations of TCDD and PnCDF in eaglet plasma were similar to actual levels found in eaglets near Crofton. However, levels of other PCDDs and PCDFs (e.g. 2,3,7,8-TCDF) were less accurately predicted. It is possible that these compounds are more rapidly metabolized by eaglets resulting in significant differences between observed and estimated contaminant levels (R. Norstrom pers. comm.).

Elliott (1995) also found that his bioaccumulation model accurately predicted levels of 2,3,7,8-TCDD in bald eagle eggs collected on the coast of British Columbia but was less accurate for other PCDD/PCDFs. He suggested that biomagnification factors (BMFs) estimated for compounds other than TCDD were a possible source of error in his study. BMFs for these compounds were determined from a Lake Ontario food chain where levels of 2,3,7,8-TCDD in forage fish are much higher than other PCDDs and PCDFs, which where near the minimum detection limit. Therefore significantly large error in the estimated BMF would result from a small difference in forage fish residue levels (Elliott 1995). Additional error in his estimates of PCDD and PCDF levels may be due to estimated proportions of certain species in the eagle diet. Elliott (1995) used estimates of bald eagle diet composition from studies that collected prey remains from the base of nest trees (Knight *et al.* 1990, Vermeer *et al.* 1989, Watson *et al.* 1991). These studies estimated the putative diet of bald eagles to consist of 52.5% fish and 47.5 % birds. Mersmann *et al.* (1992) suggested that the collection of food remains may result in significant biases favoring birds and mammals. Prey items such as small to medium sized fish, reptiles, and amphibians are not well represented since many are entirely consumed. Additionally, this bias favoring mammals and birds may increase over time since large, bony prey items such as birds and mammals persist while softer bodied prey such as fish tend to decompose relatively quickly. Thus, nests that have remained active for several years may gradually accumulate prey remains. This was confirmed by Retfalvi (1970) who reported that very few prey items were found at the base of nest trees in the year following collection of prey remains. Our observations of prey types delivered to nests near Crofton and in Barkley Sound suggest that fish comprised 95% of all prey deliveries, while birds constituted less than 1% during the nesting period (Chapter 1). Levels of PCDDs and PCDFs in waterbirds can be extremely high compared to fish prey. Therefore, by overestimating the contribution of birds to the diet of bald eagles in his study, Elliott (1995) may have introduced a large source of error that resulted in significant differences between observed and estimated levels of PCDDs and PCDFs in bald eagle eggs.

The reduced productivity within the dioxin fishery closure area that surrounds the Crofton pulp and paper mill seems to be associated with adults breeding adjacent to or south of the mill outflow pipe. Levels of PCDDs and PCDFs produced in the pulp bleaching process are high in eaglet blood plasma collected south of the Crofton mill and may be affecting productivity in this area. No difference in contaminant levels was evident among adult samples taken near Crofton. However, sample size in this study is small and may have resulted in the failure to identify any relationship between adult or eaglet contaminant burdens and mean productivity there.

GENERAL SUMMARY AND CONCLUSIONS

The purpose of this study was to identify factors that may be contributing to the low bald eagle productivity near Crofton first reported by Elliott *et al.* (1998a). Bald eagle breeding success was measured between 1992-1997 at nests near Crofton and in Barkley Sound, a relatively uncontaminated control site on the west coast of Vancouver Island. Two hypotheses concerning the effects of food abundance in the local environment and contaminant output from the Timber West/Fletcher Challenge pulp and paper mill located at Crofton were tested.

Food availability

Dawn-to-dusk observations and time lapsed video recording were used to determine food abundance in the local environment near Crofton and in Barkley Sound. Prey delivery rates, prey biomass and energy per eaglet, brood size, eaglet activity, and adult nest attendance was recorded at several nests in each study area as measures of food availability in the local environment (Dykstra 1995).

Most measures of food availability were generally highest north of the mill and associated with high eagle productivity. In contrast, low food availability was indicated by most measures in the low productivity areas of south of the mill and in Barkley Sound. These results, supplemented by the willingness of adults to accept food supplementation, suggest that the level of food availability is contributing to the breeding success of bald eagles in these areas.

However, eaglet activity levels near Crofton and in Barkley Sound contradicted the results of other measures of food availability and did not support the conclusions of Dykstra' s (1995) study on Wisconsin bald eagles. The unexpected eaglet activity levels may be related to brood size and adult nest attendance, which limit nest space available for eaglet activity. Increased food availability would thus lead to an increase in brood size and adult nest attendance and consequently limit nest space and eaglet activity levels.

In addition, prey energy per eaglet determined for Barkley Sound nests was the highest of the 3 study areas. This contradicted the results of other measures of food availability, which suggested that prey is a limiting resource in Barkley Sound. The high prey energy per eaglet measured for Barkley Sound nests during this study may be explained by the unusual occurrence of Pacific mackerel in that area during the 1996 breeding season and may not be representative of normal prey availability. Thus, low productivity rates reported for previous years may still be related to low prey availability in this area.

Contaminants

To determine the effect of chlorinated hydrocarbons released in pulp mill effluent on productivity of bald eagles near Crofton, blood samples were obtained from eaglets and breeding adults there and also in Barkley Sound (control site). Plasma samples were analyzed for selected PCDDs/PCDFs, non-*ortho* PCBs, total PCBs, and DDE.

Highest concentrations of chlorinated hydrocarbons were found in eaglets south of the Crofton mill. Levels tended to be intermediate north of the mill and lowest in Barkley Sound. Residue levels in adults tended to be slightly higher south of the mill but the differences were not significant. In both eaglet and adult blood plasma samples, PCDDs and PCDFs dominated the TEQ-WHO pattern near Crofton. PCBs contributed to most of the TEQ-WHO pattern for adults and eaglets from Barkley Sound. No correlations were evident between mean 6-year productivity and levels of chlorinated hydrocarbons in eaglet plasma.

The difference in contaminant levels north and south of the mill may reflect tidal movement in the Strait of Georgia, which occurs in a north-south direction. The highest contaminant levels were found in a small bay approximately 4 nautical miles south of the Crofton mill. This bay is the main foraging area for most eagles breeding there and, because of its shape, may serve as a reservoir for mill effluent carried and deposited by tidal movement. In contrast, there are no bays immediately north of the mill, therefore contaminants from pulp mill effluent may accumulate more gradually there. This lack of accumulated contaminants is reflected by the low concentrations of PCDDs and PCDFs in eaglet plasma samples from that area.

Applying mean total PCB levels found north and south of the Crofton mill to Bowerman's (1993) regression resulted in productivity estimates similar to actual productivity in these areas. However, his regression overestimated productivity of Barkley Sound eagles suggesting that other factors such as food stress may be influencing productivity in this area. Breeding success was not accurately predicted by Bowerman's (1993) regression using DDE levels in eaglet blood plasma.

In conclusion, the low bald eagle breeding success south of the Crofton mill is responsible for the low productivity in the Crofton area first reported by Elliott *et al.* 1998a. The low reproductive success south of the mill may be caused by several factors. Results of my study suggest that food stress may be occurring in this area, as indicated by low prey delivery rates, prey biomass and prey energy per eaglet, and adult nest attendance.

Additionally, chlorinated hydrocarbon concentrations from pulp mill effluent tended to be highest in eaglets and adults south of the mill, which also may contribute to low productivity. Moreover, contaminants may be acting in conjunction with food stress to cause the low bald eagle productivity observed south of the Crofton mill. Studies have shown that productivity of raptors is influenced by both food abundance in the local environment and/or tissue concentrations of chlorinated hydrocarbons (Newton 1979, Dykstra 1995, Bowerman 1993). In addition, a study on the reproductive effects of DDE and food stress on ring turtle doves by Keith and Mitchell (1993) suggested that DDE alone did not influence breeding success, but, when combined with food restrictions, this contaminant caused a magnification of the effects of food stress.

The growing human population and industrial activity on Vancouver Island continue to threaten nesting and roosting habitat and important prey species utilized by bald eagles in that area. Additionally, contaminants discharged into the Strait of Georgia by pulp mills and other wood processing industries have possibly affected the reproductive health of adult eagles and the general health of eaglets that populate this area. Preservation of eagle habitat, continued monitoring of contaminants, and long term monitoring of bald eagle breeding success are necessary to insure population health around Vancouver Island and in other areas of North America.

MANAGEMENT IMPLICATIONS

Results of my food availability study suggest that bald eagles can readily adapt to alternate food sources. The shrimp fishermen working near Crofton may be having a positive impact on breeding success in this area. Large quantities of fish by-catch utilized by eagles breeding in this area possibly contributes to the larger brood size there. Variations in the intensity of this fishery may significantly impact bald eagle productivity near Crofton.

Pacific herring is an important food source for eagles and other animal species breeding on the British Columbia coast. Declines in herring stocks due to overfishing could likely have a negative affect on bald eagle population health. Efforts must be made to preserve the integrity of herring stocks in order to maintain the abundance and diversity of life along this coast.

Results from my contaminants study indicate that chlorinated hydrocarbons released in pulp mill effluent can have far reaching effects on wildlife. Most toxicological studies are limited to the immediate area surrounding an industrial site. Significant effects occurring in organisms far removed from the contaminant's source may therefore be missed. I suggest that future toxicological work should encompass not just the immediate area surrounding a contaminated site, but also a larger buffer zone, the size of which depends on the topography of the landscape (e.g. bays near an industrial site in which contaminants can concentrate) and natural conditions such as river or tidal flow.

Obtaining blood samples from adults and eaglets is a relatively non-invasive method of measuring concentrations of chlorinated hydrocarbons in addition to naturally occurring chemicals in the tissues of these animals. Further investigation into the relationship of eaglet lipid plasma levels, body condition, and productivity is needed. Additionally, residue levels in breeding adults needs to be examined more closely and related to concentrations in eaglet plasma and common prey items.

APPENDIX

Appendix Table 1.1. Length to mass conversion equations for fish species identified in this study.

Common Name	Scienific Name	Regression (M and W in g, L in mm)	Location	n	Length (mm)
Coho Salmon	*Oncorhynchus kisutch*	$\text{Log } M = -5.16+3.302*\text{Log } L$	Crofton, Barkley Sound	3	280-320
English Sole	*Inopsetta ischyra*	$W = 0.22 L^3$	Crofton, Barkley Sound	4	80-250
Ling Cod	*Ophiodon elongatus*	*	Crofton	3	250-330
Pacific Herring	*Clupea harengus*	$W = 330*10^{-8} L^{3.26}$	Crofton, Barkley Sound	38	80-250
Pacific Mackerel	*Scomber japonicus*	$W = 1.318 L^3*10^{-5}$	Barkley Sound	37	200-340
Plainfin Midshipman	*Porychthys notatus*	$W = 9.97*10^{-6} L^{3.16}$	Crofton	65	100-230
Pollock	*Theragra chalcogramma*	$W = 0.45 L^{2.25}$	Crofton	1	320
Silver Surf Perch	*Hyperprospon ellupticum*	$\text{Log } M = -5.49+3.239*\text{Log } L$	Crofton, Barkley Sound	3	80-200

*estimated from Figure 3, Chatwin 1956.

Conversion equations from: Ann 1973, Bilton 1985, Carlander 1969, Chatwin 1956, Craigie 1927, Hart *et al.* 1939, Gamboa 1991.

Appendix Table 1.2. Energy content of fish species identified in this study.

Common Name	Scienific Name	Energy Content (kJ/ gram)	Location
Coho Salmon	*Oncorhynchus kisutch*	5.2	Crofton, Barkley Sound
English Sole	*Inopsetta ischyra*	3.3	Crofton, Barkley Sound
Ling Cod	*Ophiodon elongatus*	1.9	Crofton
Pacific Herring	*Clupea harengus*	3.9	Crofton, Barkley Sound
Pacific Mackerel	*Scomber japonicus*	8.2	Barkley Sound
Plainfin Midshipman	*Porychthys notatus*	4.2	Crofton
Pollock	*Theragra chalcogramma*	3.4	Crofton
Silver Surf Perch	*Hyperprospon ellupticum*	4.2	Crofton, Barkley Sound

References: Bailey 1942, Food Composition and Nutrition Tables 1989, Hislop *et al.* 1991, Dykstra 1994.

Appendix Table 1.3. Correlation matrix (r and p-value) for selected behavioral data collected from nests near Crofton and in Barkley Sound (1996).

	Eaglet age (weeks)	Brood size	Prey deliveries hour^{-1}eaglet^{-1}	Prey biomass day^{-1}eaglet^{-1}	Prey energy day^{-1}eaglet^{-1}	Adult nest attendance	Eaglet activity
Eaglet age		-0.4000 0.0001	0.1815 0.0492	-0.0303 0.7450	-0.04262 0.6467	-0.4570 0.0001	0.5164 0.0001
Brood size			0.2158 0.0331	0.5661 0.0550	0.3757 0.0001	0.6640 0.0185	0.1792 0.1821
Prey deliveries hour^{-1}eaglet^{-1}				0.4310 0.1619	0.1099 0.734	0.2798 0.0016	-0.5357 0.0726
Prey biomass day^{-1}eaglet^{-1}					0.7956 0.002	0.6852 0.0139	-0.6604 0.0194
Prey energy day^{-1}eaglet^{-1}						0.4056 0.1908	-0.3663 0.2415
Adult nest attendance							-0.8591 0.0003
Eaglet activity							

Appendix 2.1 List of the 42 PCB standards used for the quantification of PCB congeners (NWRC Laboratory Services Manual CWS-87-00).

Trichlorobiphenyls

PCB 28
PCB 31

Tetrachlorobiphenyls

PCB 42
PCB 44
PCB 49
PCB 52
PCB 60
PCB 64
PCB 66
PCB 70
PCB 74

Pentachlorobiphenyls

PCB 87
PCB 97
PCB 99
PCB 101
PCB 105
PCB 110
PCB 118

Hexachlorobiphenyls

PCB 128
PCB 129
PCB 137
PCB 138
PCB 141
PCB 146
PCB 149
PCB 151
PCB 153
PCB 158

Heptachlorobiphenyls

PCB 170
PCB 171
PCB 172
PCB 174
PCB 180
PCB 182
PCB 183
PCB 185

Octachlorobiphenyls

PCB 194
PCB 195
PCB 200
PCB 201
PCB 203

Nonachlorobiphenyls

PCB 206

Appendix Table 2.2. Percent lipid plasma levels and selected chlorinated hydrocarbon residue levels in blood plasma of eaglets from Crofton and Barkley Sound (1995-1996).

		Lipid (%)		Residue Levels													
Location, Nest	Year	gravi-metric	colori-metric	2378-TCDD	12378-PnCDD	123678-HxCDD	OCDD	2378-TCDF	23478-PnCDF	PCB-77	PCB-126	TEQs-WHO	PCB-118	PCB-105	PCB-153	DDE	Total PCBs
		(g/ ml)		(ng/ kg, wet weight)									(ug/ kg, wet weight)				
South of mill																	
Paddy Milestone	1995	0.130	3.339	2.50	4.45	14.20	0.30	10.73	0.77	28.59	44.97	25.03	9.90	1.90	24.10	52.20	136.44
Paddy Milestone	1996	ND	3.545	1.49	2.96	11.07	2.29	8.11	0.80	22.06	22.09	17.44	10.20	2.50	20.70	67.70	145.38
Maple Bay 1	1996	0.255	1.049	0.40	0.82	4.87	0.76	5.53	0.26	7.03	8.51	8.45	5.30	1.10	11.40	17.40	73.76
Maple Bay 2	1996	5.580	4.855	2.88	5.23	26.89	0.77	37.30	1.70	56.33	63.34	57.53	48.30	9.50	115.40	238.90	644.47
North of mill																	
Willy Is. South	1996	0.363	1.082	0.19	0.71	3.38	0.72	1.87	0.22	3.59	4.13	3.78	1.20	0.30	3.30	2.70	25.55
Willy Is. South	1996	0.089	0.698	ND	0.41	1.05	0.61	0.72	0.12	2.71	2.29	1.81	0.90	0.30	2.40	2.90	19.70
Willy Is. South	1996	0.165	0.821	ND	0.42	1.70	ND	0.92	0.09	3.12	2.56	2.06	1.00	0.30	2.70	4.40	22.60
Willy Is. North	1996	0.041	0.602	ND	0.48	1.11	ND	1.20	ND	10.62	0.07	2.63	1.60	0.30	4.40	6.60	30.90
Willy Is. North	1996	0.024	0.592	ND	0.19	0.73	ND	0.70	ND	13.54	5.69	2.51	1.50	0.30	4.30	5.30	28.67
Willy Island	1995	0.250	1.051	0.21	0.82	2.96	0.84	2.81	0.27	5.97	5.32	5.15	2.50	0.40	8.70	11.80	55.32
Pringle Farm	1995	0.170	0.980	0.13	0.51	2.05	0.29	1.48	0.15	3.41	4.00	2.98	3.00	0.60	9.30	19.30	51.80
Mouat	1996	0.304	1.045	ND	ND	1.07	ND	0.58	ND	2.36	1.86	1.49	1.10	0.30	2.40	3.20	26.87
Mouat	1996	0.063	0.549	ND	ND	ND	ND	0.24	ND	1.04	0.93	0.88	0.70	0.20	1.50	2.00	17.42
Barkley Sound																	
Ritherdon	1996	0.040	0.602	ND	ND	ND	0.17	ND	ND	1.84	0.73	0.95	0.50	0.20	1.50	4.20	12.87
Assits	1996	0.074	0.683	ND	ND	ND	ND	ND	ND	2.10	1.49	0.93	0.50	0.00	1.20	3.00	14.18
Sarita Bay	1996	0.082	0.632	ND	ND	ND	0.24	ND	ND	2.14	1.40	0.70	0.60	0.20	1.40	2.30	11.99
Sproat	1996	0.094	0.532	ND	ND	ND	0.54	ND	ND	0.90	0.09	0.64	0.30	0.00	0.80	1.60	5.36

Appendix Table 2.3. World Health Organization Toxic Equivalency Factors (WHO-TEFs) for birds, 1997.

Congener	Toxic Equivalency Factor (TEF)
2,3,7,8-TCDD	1
1,2,3,7,8-PnCDD	1
1,2,3,4,7,8-HxCDD	0.05
1,2,3,6,7,8-HxCDD	0.01
1,2,3,7,8,9-HxCDD	0.1
OCDD	<0.001
2,3,7,8-TCDF	1
1,2,3,7,8-PnCDF	0.1
2,3,4,7,8-PnCDF	1
1,2,3,4,7,8-HxCDf	0.1
1,2,3,6,7,8-HxCDf	0.1
1,2,3,7,8,9-HxCDf	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0001
3,4,4',5-TCB (81)	0.1
3,3',4,4'-TCB (77)	0.05
3,3',4,4',5-PnCB (126)	0.1
3,3',4,4',5,5'-HxCB (169)	0.001
2,3,3',4,4'-PnCB (105)	0.0001
2,3,4,4',5-PnCB (114)	0.0001
2,3',4,4',5-PnCB (118)	0.00001
2',3,4,4',5-PnCB (123)	0.00001
2,3,3',4,4',5-HxCB (156)	0.0001
2,3,3',4,4',5'-HxCB (157)	0.0001
2,3',4,4',5,5'-HxCB (167)	0.00001
2,3,3',4,4',5,5'-HxCB (189)	0.00001

Appendix Table 2.4. Percent lipid plasma levels and selected chlorinated hydrocarbon residue levels in blood plasma of breeding adults captured in active territories near Crofton and in Barkley Sound (1997).

	Lipid (%)		Residue Levels													
Location, Nest	gravi-metric	colori-metric	2378-TCDD	12378-PnCDD	123678-HxCDD	OCDD	2378-TCDF	23478-PnCDF	PCB-77	PCB-126	TEQs-WHO	PCB-118	PCB-105	PCB-153	DDE	Total PCBs
	(g/ ml)		(ng/ kg, wet weight)									(ug/ kg, wet weight)				
South of mill																
Maple Bay	0.595	0.137	0.65	3.25	12.61	1.34	0.45	0.91	25.57	71.98	17.12	32.00	11.00	165.00	206.00	766.00
Paddy Milestone	0.514	0.058	2.00	2.85	7.20	5.50	1.40	1.92	33.91	51.75	16.38	30.00	12.00	213.00	439.00	922.00
Osborn Bay	0.787	0.333	0.81	2.61	7.04	1.67	1.10	1.05	60.99	74.00	17.78	31.00	9.00	154.00	427.00	582.00
Octupus Point	0.849	1.314	2.35	5.79	12.26	1.52	1.65	1.01	58.69	137.14	30.68	55.00	18.00	293.00	562.00	1288.00
North of mill																
Willy Is. North	0.493	0.047	1.26	3.02	5.16	1.44	0.19	0.47	25.87	35.93	11.73	29.00	11.00	162.00	705.00	673.00
Willy Island	1.759	1.363	4.26	11.62	34.51	1.64	2.96	2.44	152.76	159.76	51.62	113.00	38.00	533.00	1532.00	2186.00
Shoal Island	0.612	0.095	0.65	1.98	3.55	1.85	1.31	0.59	25.57	23.03	9.15	12.00	5.00	42.00	127.00	208.00
Barkley Sound																
Nanat Island	0.690	0.065	0.62	2.94	3.22	1.31	1.31	0.23	33.90	48.65	12.59	19.00	7.00	65.00	188.00	328.00
Santa Maria Island	0.486	0.027	0.78	3.29	3.79	1.47	1.47	0.38	42.42	67.04	15.37	20.00	7.00	116.00	191.00	533.00
Poett Nook	0.490	0.070	1.20	2.19	2.74	1.39	1.39	0.54	52.03	74.33	16.10	15.00	6.00	73.00	213.00	370.00

Appendix Table 2.5. Correlation matrix (r and p-value) for selected chlorinated hydrocarbon levels in adult and eaglet blood plasma and behavioral data collected from nests near Crofton and in Barkley Sound (1996).

	Brood size	Productivity (1992-1997)	Prey deliveries hour^{-1}eaglet^{-1}	Prey biomass day^{-1}eaglet^{-1}	Prey energy day^{-1}eaglet^{-1}	Adult nest attendance	Eaglet activity	Eaglet residue levels			Adult residue levels		
								Total PCBs	DDE	TEQs-WHO	Total PCBs	DDE	TEQs-WHO
Brood size		0.6415 0.0031	0.2158 0.0031	0.5661 0.0550	0.3757 0.0001	0.6640 0.0185	0.1792 0.0190	0.1764 0.6040	0.0141 0.9672	0.0096 0.9777	0.5461 0.1614	0.5648 0.1447	0.3213 0.4822
Productivity			0.5436 0.0678	0.7726 0.0032	0.5596 0.0560	0.4664 0.0230	-0.6695 0.0172	-0.2557 0.4479	-0.4367 0.1793	-0.4017 0.2208	0.7259 0.0415	0.7390 0.0362	0.8375 0.0187
Prey deliveries hour^{-1}eaglet^{-1}				0.4310 0.1619	0.1099 0.7340	0.2798 0.0016	-0.5357 0.0726	0.4849 0.2233	0.4494 0.2639	0.5059 0.2008	0.9879 0.0990	0.4588 0.6965	-1.0000
Prey biomass day^{-1}eaglet^{-1}					0.7956 0.0020	0.6852 0.0139	-0.6604 0.0194	0.0855 0.8405	-0.0807 0.8493	-0.0407 0.9238	0.1577 0.8992	-0.8872 0.3053	1.0000
Prey energy day^{-1}eaglet^{-1}						0.4056 0.1908	-0.3663 0.2415	-0.4725 0.2371	-0.5183 0.1882	-0.5400 0.1671	0.2322 0.8508	-0.8497 0.3536	1.0000
Adult nest attendance							-0.8591 0.0003	0.3129 0.4505	0.0461 0.9136	0.1325 0.7545	-0.1176 0.9250	0.9052 0.2795	-1.0000
Eaglet activity								-0.2113 0.6154	0.0684 0.8721	-0.0086 0.9838	0.5870 0.6606	-0.5829 0.6039	-1.0000
Eaglet residue levels													
Total PCBs									0.9549 0.0001	0.9625 0.0001	0.6057 0.0450	-0.5913 0.4087	-0.9098 0.2725
DDE										0.9660 0.0001	0.6911 0.3089	-0.5293 0.4707	-0.8990 0.2874
TEQs-WHO											0.6749 0.3251	-0.5232 0.4768	-0.8692 0.3293
Adult residue levels													
Total PCBs												-0.0177 0.9823	0.5912 0.1621
DDE													0.7668 0.0443
TEQs-WHO													

LIST OF REFERENCES

Agavanov, A.V., D.S. Rezinko, A.A. Rozhkov, W.K. Semenov. 1957. Ecology of the steppe eagle (in Russian). Bull. MOIP Otd. Biology. 62:174-181.

Anderson, D.W. and J.J. Hickey. 1972. Eggshell changes in certain North American birds. Proc. Int. Onrithol. Cong. 15:514-540.

Anderson, D.W. and J.J. Hickey. 1976. Dynamics of storage of organochlorine pollutants in herring gulls. Environ. Pollt. 10:183-200.

Ann, H.B. 1973. Studies on the age and growth of the jack mackerel (*Trachurus japonicus*). Bull. Fish. Res. Dev. Agency. 10:73-82.

Anthony, R.G., M.J. Garrett, and C.A. Schuler. 1993. Environmental contaminants in bald eagles in the Columbia River estuary. J. Wildl. Mannage. 57:10-19.

Bailey, B.E. 1942. Chart of the nutritive values of British Columbia fishery products. Can. Fish. Res. Bd. Prog. Rep. Pacific Issue. 53:9-11.

Bensadoun, A. and A. Rothfield. 1972. The form of absorption of lipids in the chicken, *Gallus domesticus*. Proc. Soc. Exp. Biol. Med. 141:814.

Bilton, H.T. 1985. Length-weight relations for adult sockeye, chum, and pink salmon. Can. Manuscr.-Rep. Fish. Aquat. Sci. 1846:11pp.

Blem, C.R. 1990. Avian energy stores. In: R.F. Johnston (ed.). Current ornithology. Volume 7, Plenum Press, New York, pp 59-114.

Blood, D.A. and G.G. Anweiler. 1994. Status of the bald eagle in British Columbia. Wildlife Branch, Ministry of Environment, Lands and Parks, Wildlife Working Report No. WR-62. 77 pp.

Bortolotti, G.R. 1984. Criteria for determining age and sex of nestling bald eagles. J. Field Ornithol. 55:467-481.

Bowerman, W.W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. Unpubl. M.A. thesis, Northern Michigan University, Marquette, Michigan.

Bowerman, W.W. IV. 1993. Regulation of bald eagle (*Haliaeetus leucocephalus*) productivity in the Great Lakes basin: an ecological and toxicological approach. Unpublished P.hD. dissertation, Michigan State University. East Lansing. 291 pp.

Bowman, R.E., S.L. Schantz, N.C.A. Weerasinghe, M. Gross, and D. Barsotti. 1989. Chronic dietary intake of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) at 5 or 25 part per trillion in the monkey: TCDD kinetics and dose-effect estimate of reproductive toxicity. Chemosphere. 18:243-252.

Braune, B.M. and R.J. Norstrom. 1989. Dynamics of organochlorine compounds in herring gulls. 3. Tissue distribution and bioaccumulation in Lake Ontario gulls. Environ. Toxicol. Chem. 8: 957-968.

Broley, C.L. 1958. The plight of the American bald eagle. Audubon 6:162-171.

Butler, R.W. and R.W. Campbell. 1987. The birds of the Fraser River delta: populations, ecology and international significance. Canadian Wildlife Service, Occasional Paper, Ottawa, No. 65.

Cain, S.L. and J.I. Hodges. 1989. A floating-fish snare for capturing bald eagles. Journal of Raptor Research. 23(1):10-13.

Carlander, K.D. 1969. Handbook of freshwater fishery biology. Volume I. Iowa Cooperative Fishery Unit. Iowa State Univerisity Press, Ames, Iowa. 752pp.

Chatwin, B.M. 1956. Age and growth of lingcod. Can. Fish. Research Bd. Prog. Rep. Pacific Issue. 105:22-26.

Clum, N.J. 1986. The effects of prey quantity on reproductive success of osprey (*Pandion haliaeetus*) in the Adirondack mountains. Unpublished M.S. thesis. Cornell University. 149 pp.

Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. J. Toxicol. Environ. Health. 33:395-453.

Collopy, M.W. 1984. Parental care and feeding ecology of golden eagle nestlings. The Auk. 101:753-760.

Collopy, M.W. 1986. Food consumption and growth energetics of nestling golden eagles. Wilson Bull. 98(3):445-458.

Craigie, E. H. 1927. Notes on the total weights of the squirrel hake, the pollock, the winter flounder, and the smelt, and on the weights of the liver and gonads in the hake and in the pollock. Trans. Royal. Soc. Can. 21(5):153-173.

Diaz, H.F. and V. Markgraf (eds.). 1992. El Nino: historical and paleoclimatic aspects of the southern oscillation. Cambridge University Press, New York. 476 pp.

Donaldson, G., J. L. Shutt, and P. Hunter. Productivity and organochlorine contamination in nestling bald eagles (*Haliaeetus leucocephalus*) in the Canadian Great Lakes Basin (1990-1996). In press.

Dunning, J.B., Jr. 1992. CRC Handbook of Avian Body Masses. CRC Press, Boca Raton, Florida. 371pp.

Dwernychuck, L.W., D. Levy, and G. Bruce. 1994. Powell River environmental effects monitoring (EEM) pre-design reference document. Hatfield Consultants, West Vancouver, BC, Canada.

Dykstra, C.J.R. 1995. Effects of contaminants, food availability, and weather on the reproductive rate of Lake Superior bald eagles (*Haliaeetus leucocephalus*). Unpublished P.hD. dissertation, University of Wisconsin-Madison.

Elliott, J.E. 1995. Environmental contaminants in bald eagles on the coast of British Columbia: exposure and biological effects. Unpublished P.hD. dissertation, University of British Columbia, Vancouver, BC.

Elliott, J.E., R.W. Butler, R.J. Norstrom and P.E. Whitehead. 1989. Environmental contaminants and reproductive success of great blue herons *Ardea herodias* in British Columbia, 1986-87. Environ. Pollut. 59:91-114.

Elliott, J.E. R.J. Norstrom, and G.E.J. Smith. 1996. Patterns, trends and toxicological significance of chlorinated hydrocarbon and mercury contaminants in bald eagle eggs from the Pacific coast of Canada, 1990-1994. Archiv. Environ. Contam. Toxicol. 31:354-367.

Elliott, J.E., I.E. Moul, and K.M. Cheng. 1998a. Variable reproductive success of bald eagles on the British Columbia coast. J. Wildl. Manage. 62:518-529.

Elliott, J.E. and R. Norstrom. 1998b. Chlorinated hydrocarbon contaminants and productivity of bald eagle populations on the Pacific coast of Canada. Environ. Toxicol. Chem. 17: In press.

Ellis, D.H. and C.H. Ellis. 1979. Development of behavior in the golden eagle. Wildlife Monographs. 70:1-94.

Food Composition and Nutrition Tables. 1989/90. 4th edition. Wissenschaftliche verlagsgesellschaft, Stuttgart, Germany. pp 319-361.

Fox, G.A., A.P. Gilman, D.B. Peakall, and F.W. Anderka. 1978. Behavioral abnormalities of nesting Lake Ontario herring gulls. J. Wildl. Manage. 42:477-483.

Fraser, J.D., L.D.Frenzel, J.E. Mathisen, F. Martin and M.E. Shough. 1983. Scheduling bald eagle reproduction surveys. Wildl. Soc. Bull. 11(1):13-16.

Frings, C.S., T.W. Fendley, R.T. Dunn, and C.A. Queen. 1972. Improved determination of total serum lipids by the sulfo-phospho-vanillin reaction. 18(7): 673-674.

Gamboa, D.A. 1991. Otolith size versus weight and body-length relationships for eleven fish species of Baja, California, Mexico. Fish. Bull. 89(4):701-706.

Gende, S. and Willson, 1997. Supplemental feeding experiments of nesting bald eagles in southeast Alaska. J. Field. Ornith. 68(4):590-601.

Goldstein, J.A. 1980. Structure-activity relationships for the biochemical effects and relationship to toxicity. In: Kimbrough, R.D. (ed.), Topics in Environmental Health: Vol. 4 Halogenated Biphenyls, Terphenysl, Naphthalenew, Dibenzodioxins and Related Products. North-Holland, New York, pp. 151.

Grier, J.W. 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Scinece. 218:1232-1235.

Hancock, D. 1964. Bald eagles wintering in the southern Gulf Islands, British Columbia. Wilson Bull. 76:117-120.

Hansen, A.J. 1984. Behavioral ecology of bald eagles along the Pacific Northwest coast: a landscape perspective. Unpub. PhD. Dissertation, Univ. of Tennessee, Knoxville, 161pp.

Hansen, A.J. 1987. Regulation of bald eagle reproductive rates in southeast Alaska. Ecology 68:1387-1392.

Harding, L.E. and Pomeroy, W.M. 1990. Dioxin and furan levels in sediment, fish, and invertebrates from fishery closure areas of coastal British Columbia. Environment Canada, North Vancouver, B.C., Rep. No. 90-09. 77pp.

Harmata, A.L. 1984. Bald eagles of the San Luis Valley, Colorado: their winter ecology and spring migration. Unpub. PhD. Dissertation, Mont. State Univ., Bozeman. 222pp

Hart, J.L., A.L. Tester, Beall, D. and Tully, J.P. 1939. Proximate analysis of British Columbia herring in relation to season and condition factor. J. Fish. Res. Bd. Can. 4(5):478-490.

Hebert, C.E. and K.A. Keenleyside. 1995. To normalize or not to normalize? Fat is the question. Environ. Toxicol. Chem. 14:801-808.

Helander, B. 1985. Reproduction of the white-tailed sea eagle *Haliaeetus albicilla* in Sweden. Holarctic Ecol. 8:211-227.

Hickey, J.J., and D.W. Anderson. 1969. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science. 162:271:273.

Hislop, J.R.G., M.P. Harris and G.M. Smith. 1991. Variation in the calorific value and total energy content of the lesser sandeel (*Ammodytes marinus*) and other fish preyed upon by seabirds. J. Zool., Lond. 224:501-517.

Jackman, R.E., W.G. Hunt , D.E. Driscoll and J.M. Jenkins. 1993. A modified floating-fish snare for capture of inland bald eagles. North American Bird Bander. 18(3)98-101.

Keith , J.O. and Mitchell, C.A. 1993. Effects of food stress on reproduction and body condition of ringed turtle doves. Arch. Environ. Contam. Toxicol. 25: 192-203.

Kirkley, J.S. and Gessaman, J.A. 1990. Water economy of nestling Swainson's hawks. Condor. 92:29-44.

Knight, R.L. P.J. Randolph, G.T. Allen, L.S. Young, and R.J. Wigen. 1991. Diets of nesting bald eagles, *Haliaeetus leucocephalus*, in western Washington. Can. Field. Nat. 104:545-551.

Kozie, K.D. and R.K. Anderson. 1991. Productivity, diet, and environmental contaminants in bald eagles nesting near the Wisconsin shoreline of Lake Superior. Arch. Environ. Contam. and Toxicol. 20:41-48.

Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty and T.C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forester's tern on Green Bay, Lake Michigan-1983. Arch. Environ. Contam. and Toxicol. 18:706-727.

Landers, J.P. and N.J. Bunce. 1991. The *Ah*-receptor and the mechanism of dioxin toxicity. Biochem. J. 276:273-287.

Maybly, T.A., R.W. Moore, and R.E. Peterson. 1992 I. *In utero* and lactational exposure of male rats to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. I. Effects on androgenic status. Toxicol. Appl. Pharmacol. 114:97-107.

Maybly, T.A., R.W. Moore, R.W. Goy, and R.E. Peterson. 1992 II. *In utero* and lactational exposure of male rats to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. II. Effects on sexual behavior and the regulation of luteinizing hormone secretion in adulthood. Toxicol. Appl. Pharmacol. 114:108-117.

Maybly, T.A., D.L Bjerke, R.W. Moore, A. Gendron-Fitzpatrick, and R.E. Peterson. 1992 III. In utero and lactational exposure of male rats to 2,3,7,8-tetrachlorocibenzo-p-dioxin. III. Effects on spermatogenesis and reproductive capability. Toxicol. Appl. Pharmacol. 114: 118-126.

McArthur , M.L.B., G.A. Fox, D.B.Peakall, and B.J.R. Philogene. 1983. Ecological significance of behavioral and hormonal abnormalities in breeding ring turtle doves fed an organochlorine chemical mixture. Arch. Environ. Contam. Toxicol. 12:343-353.

McGarigal, K., R.G. Anthony, and F.B. Isaacs. 1991. Interactiona of humans and bald eagles on the Columbia River Estuary. Wildl. Monogr. 115:1-47.

Mersman, T.J., D.A. Buehler, J.D. Fraser, J.K.D. Seegar. 1992. Assessing bias in studies of bald eagle food habits. J. Wildl. Manage. 56(1):73-78.

Mineau, P., G.A. Fox, R.J. Norstrom, D.V. Weseloh, D.J. Hallett and J.A. Ellenton. 1984. Using the herring gull to monitor levels and effects of organochlorine contamination in the Canadian Great Lakes. In: Toxic Contaminants in the Great Lakes. J.O. Niragu and M.S. Simmons (eds.). J. Wiley and Sons, New York, pp. 425-452.

Moul, E. 1990. Environmental contaminants, disturbance, and breeding failure at a great blue heron colony on Vancouver Island. Unpub. MSc. Thesis, Univ. of British Columbia, Vancouver.

Newton, I. 1976. Population limitation in diurnal raptors. Canad. Field-Nat. 90:274-300.

Newton, I. 1979. Population Ecology of Raptors. Buteo Books, Vermilion, SD. 399pp.

Norman, D. A.M. Breault, and I.E. Moul. 1989. Bald eagle incursions and predation at great blue heron colonies. Colonial Waterbirds. 12:215-217.

Norstrom, R.J. and M. Simon. 1991. Determination of specific polychlorinated dibenzo-p dioxins and dibenzofurans in biological matrices by gel-permeation/carbon chromatography and gas chromatography-mass spectrometry. In C. Rappe, H.R. Buser, D. Dodet, and I.K. O'Neill (eds.). Polychlorinated dibenzo-p-dioxins and dibenzofurans. World Health Organization, Lyon, France. Pp. 281-297.

Ofelt, C.H. 1975. Food habits of nesting bald eagles in southeast Alaska. Condor. 77(3) 337-338.

Okey, A.B., D.S. Riddick, and P.A. Harper. 1994. The Ah-receptor: mediator of the toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and related compounds. Toxicol. Lett. 70:1-22.

Peterson, R.E., H.M. Theobold, and G.L. Kimmel. 1993. Developmental and reproductive toxicity of dioxins and related compounds: cross species comparisons. Crit. Rev. Toxicol. 23:283-335.

Phillips, D.L., J.L. Pirkle, V.W. Burse, J.T. Bernert, I.O. Henderson, and L.L. Needham. 1989. Chlorinated hydrocarbon levels in human serum: Effects of fasting and feeding. Arch. Environ. Contam. Toxicol. 18:495-500.

Postupalsky, S. 1978. The bald eagles return. Natural History. 87:62-63.

Ratcliffe, D. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. J. app. Ecol. 7:67-107.

Retfalvi, L. 1970. Food of nesting bald eagles on San Juan Island, Washington. Condor. 72:358-361.

Safe, S. 1987. Determination of 2,3,7,8-TCDD toxic equivalent factors (TEF): Support for the use of the *in vitro* AHH induction assay. Chemosphere. 16:791-802.

Safe, S. 1990. Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: environmental and mechanistic considerations which support the development of toxic equivalency (TEFs). Crit. Rev. Toxicol. 21:51-88.

Smrek, A.L., S.L. Head, and L.L. Needham. 1981. Comparison of two deproteinization methods for the determination of DDT and DDT metabolites in serum. Anal. Lett. 14:81-96.

Sprunt, IV, A. 1969. Audubon bald eagle studies-1960-1966. Proc. 22nd Ann. Conv. Natl. Audubon Soc., Sacremento, CA.

Sprunt, IV, A.,W.B. Robertson Jr, S.Postupalsky, R.J. Hensel, C.E. Knoder and F.J. Ligas. 1973. Comparative productivity of six bald eagle populations. Trans. No. Amer. Wildl. Nat. Resour. Conf. 38:96-106.

Stalmaster, M.V. 1987. The Bald Eagle. Universe Books, New York.227 pp.

Stalmaster, M.V., and Gessaman, J.A. 1982. Food consumption and energy requirements of captive bald eagles. J. Wildl. Manage. 46:646-654.

Stinson, C.H. 1978. The influence of environmental conditions on aspects of the time budgets of breeding ospreys. Oecologia. 36:127-139.

Thompson, H.V. and King, C.M. 1994. The European Rabbit. The history and biology of a successful colonizer. Oxford University Press, Oxford. 245pp.

Turle, R. and Norstrom, R.J. 1987. The CWS guidelines to practical quality assurance for contract analysis. CWS Technical Report 21.

Turle, R., R.J. Norstrom, and B. Collins. 1991. Comparison of PCB quantitation methods: re-analysis of archived specimens of herring gull eggs from the Great Lakes. Chemosphere. 22:201-213.

VanDaele, , J. and H.A. VanDaele. 1982. Factors affecting the productivity of ospreys nesting in west-central Idaho. Condor. 84:292-299.

Vermeer, K. 1983. Marine bird populations in the Strait of Georgia: comparison with the west coast of Vancouver Island. Can. Tech. Rep. Hydrogr. Ocean. Sci. 19, 18pp.

Vermeer, K, K.H. Morgan, R. W. Butler and G.E.J. Smith. 1989a. Population, nesting habitat, and food of bald eagles in the Gulf Islands. In: The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia. K. Vermeer and R.W. Butler (eds.). Canadian Wildlife Service, Special Publ., Ottawa, 123-130.

Waldichuk, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 14:321-486.

Watson, J.W. (ed.). 1997. The golden eagle. T& A D Poyser, London. 374pp.

Watson, J.W., M. Garrett, and R.G. Anthony. 1991. Foraging ecology of bald eagles in the Columbia River Estuary. J. Wildl. Manage. 55(3):492-499.

Welch, L.J. 1994. Contaminant burdens and reproductive rates of bald eagles breeding in Maine. Unpubl. MSc. Thesis, Univ. of Maine, Old Town, MA, U.S.A., 86pp.

Whitaker, J.O. (ed.) 1980. The Audubon Society Field Guide to North American Mammals. Chanticleer Press, Inc., New York. 745pp.

Whitehead, P.W. 1989. Toxic chemicals in the great blue heron (*Ardea herodias*) eggs in the Strait of Georgia. In: The Ecology and Status of Marine and Shoreline Birds in the Strait of Georgia, British Columbia. K. Vermeer and R.W. Butler (eds.), Canadian Wildlife Service, Special Publication, Ottawa, pp. 177-183.

Whitehead, P.E., , R.J. Norstrom and J.E. Elliott. 1992b. Dioxin levels in eggs of great blue herons (*Ardea herodias*) decline rapidly in response to process changes in a nearby kraft pulp mill. Organohalogen Compounds. 9:325-328.

Wiemeyer, S.N., T.G. Lamont, C.M. Bunk, C.R. Sindelar, F.J. Gramlich, J.D. Fraser and M.A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs-1969-79-and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

Wooster, W.S., and D.L. Fluharty (eds.). 1985. El Nino north: Nino effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington, Seattle. 312 pp.

IMAGE EVALUATION
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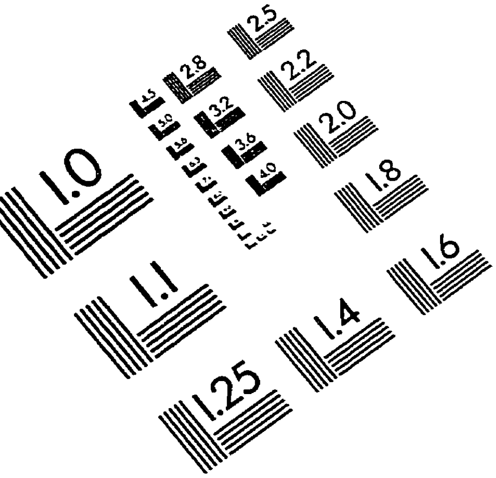

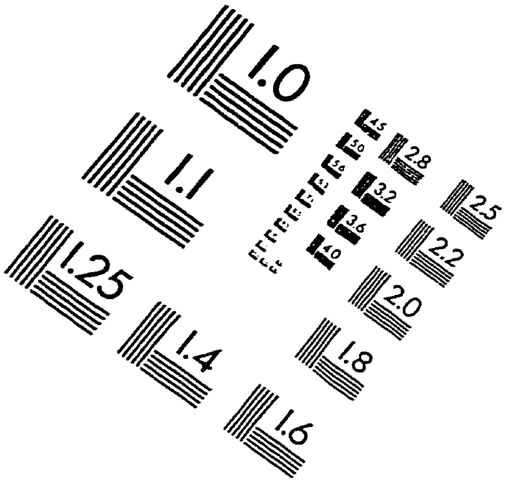

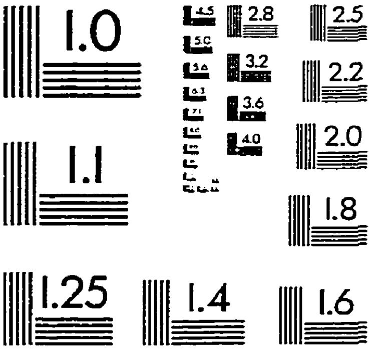

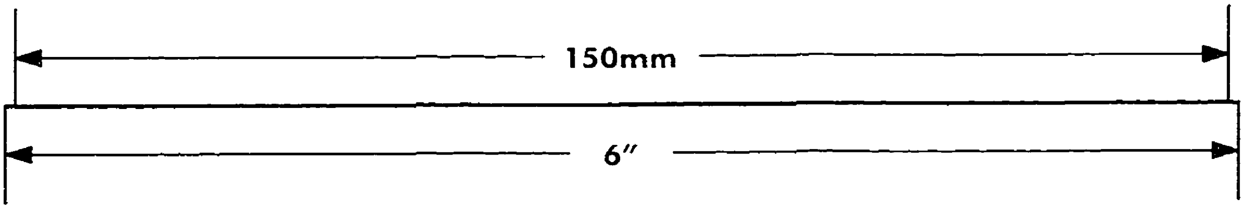

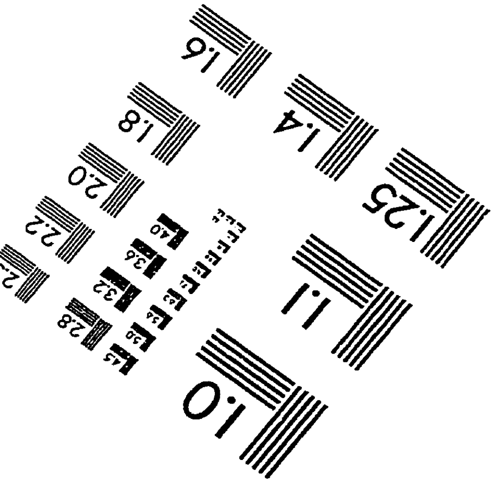

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989