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Effect of Food Supply and Contaminants on Osprey Productivity in southern British Columbia, Canada

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ABSTRACT

Osprey productivity estimates can be an efficient means of monitoring environmental degradation; however, variation in food quality and quantity can potentially conceal contaminant related effects. We conducted a study to determine whether contaminants or other ecological factors such as variation in prey delivery rates and prey biomass were affecting Osprey productivity. In total, 68 Osprey nests from five lake sites across southern British Columbia, Canada, were surveyed for productivity in 2001, while 25 of those nests were intensively observed to identify prey deliveries. At the Lillooet and Nakusp reservoirs, Ospreys were found to take only a few key species; whereas other natural lakes at Oliver and Pitt Meadows had 11 and 13 fish species identified. Prey delivery rates (mean 1.73 to 4.72 fish/day/nest); prey size (mean 21.2 to 26.8 cm); and prey biomass (mean 218.4 to 874.7 g/day/nest) varied significantly by location and had an effect on Osprey productivity. The number of young/active nest was positively related to prey biomass/nest indicating Ospreys at some locations were capable of increasing their delivery effort to raise larger broods. Two sites, Lillooet and Nakusp, consistently had the lowest prey sizes, prey delivery rates and prey biomass per nest, and subsequently lower overall productivity and nest success. In addition, Lillooet Ospreys also experienced the largest reduction in brood size (63%). Differences in productivity among sites could not be explained by contaminants. Concentrations of organochlorines, PCBs and mercury in eggs collected from the same locations in 1999 or 2000 were below levels known to cause reproductive toxicity. In particular, Nakusp eggs had lower levels of both DDE and PCBs than the more productive Nicola and Oliver sites. This study highlights the importance of food availability to breeding Osprey that can confound the interpretation of contaminant related reproductive effects.

INTRODUCTION

Ospreys *Pandion haliaetus* will settle in a variety of freshwater habitats where suitable nesting sites and available fish prey are essential for sustained breeding rates (Poole 1989). In British Columbia, Canada, complex natural drainage systems and hydroelectric dams produce rivers, lakes and reservoirs of differing quality for breeding Ospreys. In particular, the abundance and type of fish prey available to Ospreys may vary considerably across sites and is a critical determinant of overall productivity in raptors (Newton 1979).

Breeding populations of Ospreys are now commonly used as an indicator of environmental health. Their conspicuous nests, high degree of nest site fidelity, and piscivorous diet make them an ideal monitor species (Elliott *et al.* 1998; Henny *et al.* 2003). Reproductive endpoints such as clutch and brood sizes, as well as breeding densities, are frequently used as a means of monitoring contaminant related effects (Wiemeyer *et al.* 1988; Ewins 1992; Martin *et al.* 2003). Given that reproduction is a critical phase in determining population stability, knowledge about variation in breeding success due to natural causes is critical for interpreting reproductive effects from other anthropogenic stressors.

Convincing evidence that food is limiting in Ospreys is rarely documented. Food availability during the breeding period will ultimately affect adult and chick body condition, their mobilization of lipid reserves, the size of broods, and the overall success in fledging young (Ewins 1992). Food stress and body condition can ultimately have a profound influence on contaminant effects (Keith & Mitchell 1993). Although Osprey pairs often take turns incubating and feeding away from the nest, breeding Ospreys (primarily males) frequently deliver prey to their mates at the nest (Poole 1989). In addition, once chicks have hatched, prey must be delivered to the nest at least until the chicks fledge. Therefore, the use of prey delivery observations is a useful technique for estimating food availability and feeding rates.

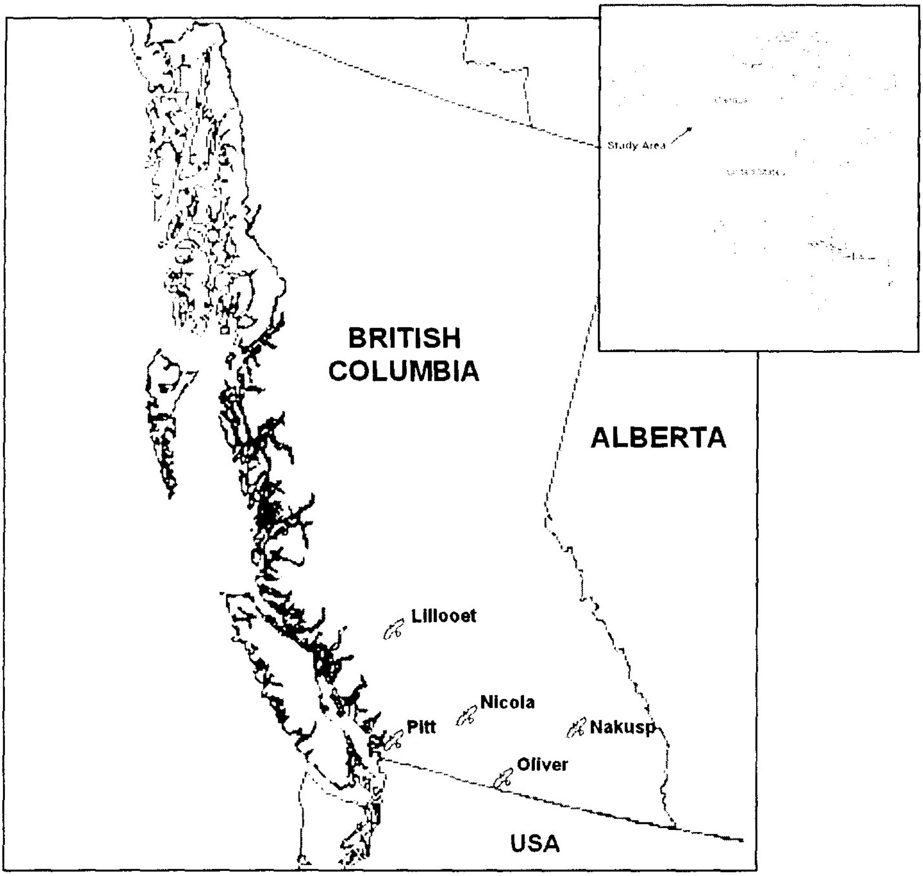
This study attempts to quantify the diet and productivity of nesting Ospreys at water bodies varying in hydrological characteristics at five unique locations in southern British Columbia. Through intensive nest observations over the course of the breeding period, we investigated inter-site variability in prey delivery rates and contaminant exposure to determine their relative effects on Osprey reproductive success. We hypothesized that increased prey delivery rates and prey biomass would have a positive effect on Osprey productivity while elevated contaminant levels may confound these results.

METHODS

Observations of prey delivery

Five study sites across southern British Columbia included Lillooet, Nakusp, Nicola, Oliver and Pitt Meadows (Figure 1). Study lakes were selected to represent a diversity of habitat characteristics in terms of elevation, hydrology, lake size and depth, in addition to biodiversity of fish species (Table 1). In total, 25 Osprey nests were selected for intensive prey delivery observations with five nests monitored at each of five sites. In May 2001, prior to the start of observations, all active Osprey nests were located at each site via ground and water surveys. Individual nests were selected for observation based on visibility of the nest, feeding perches and prey delivery routes. All prey observations were conducted by a single observer assigned to each site to monitor five nests for the duration of the study period.

Figure 1: Map of study area in British Columbia, Canada showing geographic locations of five sites where Osprey prey deliveries and productivity data were collected.



Over a 12 week period, from May to early August 2001, observations were conducted at each nest to encompass the major phases of Osprey breeding (incubation, chick rearing and fledging). The study was designed to render a total of 1,500 observation hours over the study period (with 300 hours at each of the five sites, and 60 hours at each of the 25 nests). A schedule was devised to ensure that each nest would be observed for equal amounts of time and at equal times of the day. The observations were separated into six time-blocks, each being two weeks long (Block 1: 14 to 27 May, Block 2: 28 May to 10 June, Block 3: 11 to 24 June, Block 4: 25 June to 8 July, Block 5: 9 to 22 July, Block 6: 23 July to 5 August). Within each time-block, all 25 nests were monitored twice, one five-hour morning observation (7:00-12:00) and one five-hour afternoon-evening observation (15:00-20:00) to represent one day of foraging. Morning and afternoon observations for a single nest were split over two separate days to account for natural variation caused by weather and other disturbances. The duration and times for the morning and afternoon-evening observations were selected based on identified peak Osprey foraging times derived from existing literature (Van Daele & Van Daele 1982; Poole 1989). If a nest failed during the observation period, another active nest in the same breeding stage was used as a replacement for the remainder of the study to ensure completeness of the dataset.

All species of fish known to be present within the five study sites were researched thoroughly. Since Ospreys are known to forage up to 10 km from the nest (Häkkinen 1978; Greene *et al.* 1983), suitable foraging sites within this radius were also investigated. Five site-specific fish identification packages were prepared, highlighting the fish species most likely to be caught by Osprey. Summaries of fish species known to exist in each reservoir, lake or river were added to the package, regardless of assessed probability of capture. Noted in each package were possible species colour and size variations, probable availability of each species, and illustrative keys to aid in distinguishing between fish on both the family and species level. Fish lengths were estimated using a 20-60x Bausch and Lomb spotting scope as comparison with the Osprey's tail length which is approximately 20 cm (Lloyd 1999; CWS unpubl. data). Prey were identified to species or family and sized to the nearest inch (2.5 cm). All observers were trained together prior to the start of observations to ensure consistency of prey identification and sizing.

Measurement of productivity

All Osprey nests found in the study areas were monitored for productivity using combinations of ground, boat and aerial surveys. Estimates of productivity for our intensively observed nests were based on pairs that initiated clutch incubation and were defined as "active" (Postupalsky 1977). The number of young per active nest was calculated for each time period when chicks were present (blocks 3-6 only) and then averaged to report site means. For nests that were not intensively observed for prey deliveries, at least two visits were scheduled based on published methods (Posutpalsky 1977) that are now widely used (Ewins 1992; Poole 1989). The first visit, between mid-May and early June, was timed to determine the number of pairs of Ospreys occupying territories in the study area. The second survey took place from late June to early July and was timed to count nestlings at five to eight weeks of age. Since mortality usually occurs among small chicks early in the nestling period, the number of young counted at 5-8 weeks is typically a good indicator of the number of young to fledge (Postupalsky 1977). To avoid potential bias towards higher productivity estimates, any nests detected with young that were not surveyed previously were recorded but not included in the final calculations of site productivity. Furthermore, nests which had an egg collected for contaminant analysis were also excluded from productivity estimates.

Egg collection and analysis

Osprey eggs were collected from individual nests at locations across B.C. in 1999 and 2000 including the five lake sites used for the prey delivery observations in 2001. Egg contents were homogenized and analysed at the

National Wildlife Research Centre (Hull, Quebec) using gas chromatography with electron capture detection (see Elliott *et al.* 2001 for details). Analyses included several organochlorine pesticides: p,p'-DDE, p,p'DDT, p,p'-DDD, dieldrin, heptachlor epoxide, trans-nonachlor, cis-nonachlor, oxychlordane, trans-chlordane, cis-chlordane, α-hexachlorocyclohexane (HCH), β-HCH, γ-HCH, tetrachlorobenzene, pentachlorobenzene, hexachlorobenzene, mirex, photomirex and 59 PCB congeners that were summed to represent total PCBs. Total mercury was analysed by cold vapour atomic absorption spectroscopy after sample digestion. All samples were analysed according to quality assurance guidelines with reference materials, blanks, replicates and internally spiked standards. Samples were not recovery corrected and minimum detection limits for all compounds were 0.0001 mg/kg wet weight.

Data treatment

Every effort was made to identify fish to the family and species level including collecting fish remains from below the nest. For fish that could not be identified, those observations were only used for accurate records of number of prey deliveries. For fish identified to family or species but size could not be determined, site and species averages were used to estimate length. Lengths of prey were converted to masses using regression equations of length and weight data from fish collected from the study sites or from published length-weight regressions for the identified species (Schneider *et al.* 2000). Statistical analyses included one-way ANOVAs for determining differences among sites followed by a Tukey multiple comparison procedure performed using JMP®v. 4.0 software.

RESULTS

Salmonids (30.1%) and Catostomids (22.8%) followed by Cyprinids (16.4%) were the most common prey groups taken by breeding Osprey across all sites. However, species composition varied widely among study locations (Table 2). Oliver and Pitt Lake had very high prey diversity with 11 and 13 identified species delivered to nests at each site respectively. In the Lillooet system, two species, Bridgelip Sucker *Catostomus columbianus* and Rainbow Trout *Oncorhynchus mykiss* accounted for 84.8% of the observed deliveries while at Nakusp, the majority of prey were salmonids (76%) especially Kokanee *Oncorhynchus nerka* and Rainbow Trout. Osprey at Nicola Lake took a broader prey base of salmonids, catostomids and cyprinids with four main species accounting for 73.6% of the diet (Kokanee, Largescale Suckers *Catostomus macrocheilus*, Longnose Suckers *Catostomus catostomus,* and Peamouth Chub *Mylocheilus caurinus*).

Table 1. Details of each of the five Osprey study locations in southern British Columbia including lake characteristics and relative diversity of fish species found at each site.

Location	*Lake Name*	*Latitude*	*Longitude*	*Lake type*	*Elevation (m)*	*Mean Depth (m)*	*Perimeter (km)*	*Surface Area (ha)*	*Fish Diversity*[a]
Lillooet	Carpenter Lake Downton Lake	50°51' 50°50'	122°30' 122°59'	Hydroelectric Reservoir	700	NA[b]	111	4625	Low
Nakusp	Upper Arrow Lake	50°35'	117°57'	Hydroelectric Reservoir	441	NA	345	22948	High
Nicola	Nicola Lake	50°10'	120°32'	Natural lake	637	24	51	6215	Moderate
Oliver	Okanagan River/ Osoyoos Lake	49°02'	119°27'	Natural lake/ river	276	14	48	2300	Moderate
Pitt	Pitt River/Pitt Lake	49°14'	122°46'	Natural lake/ river	4	46	71	5383	High

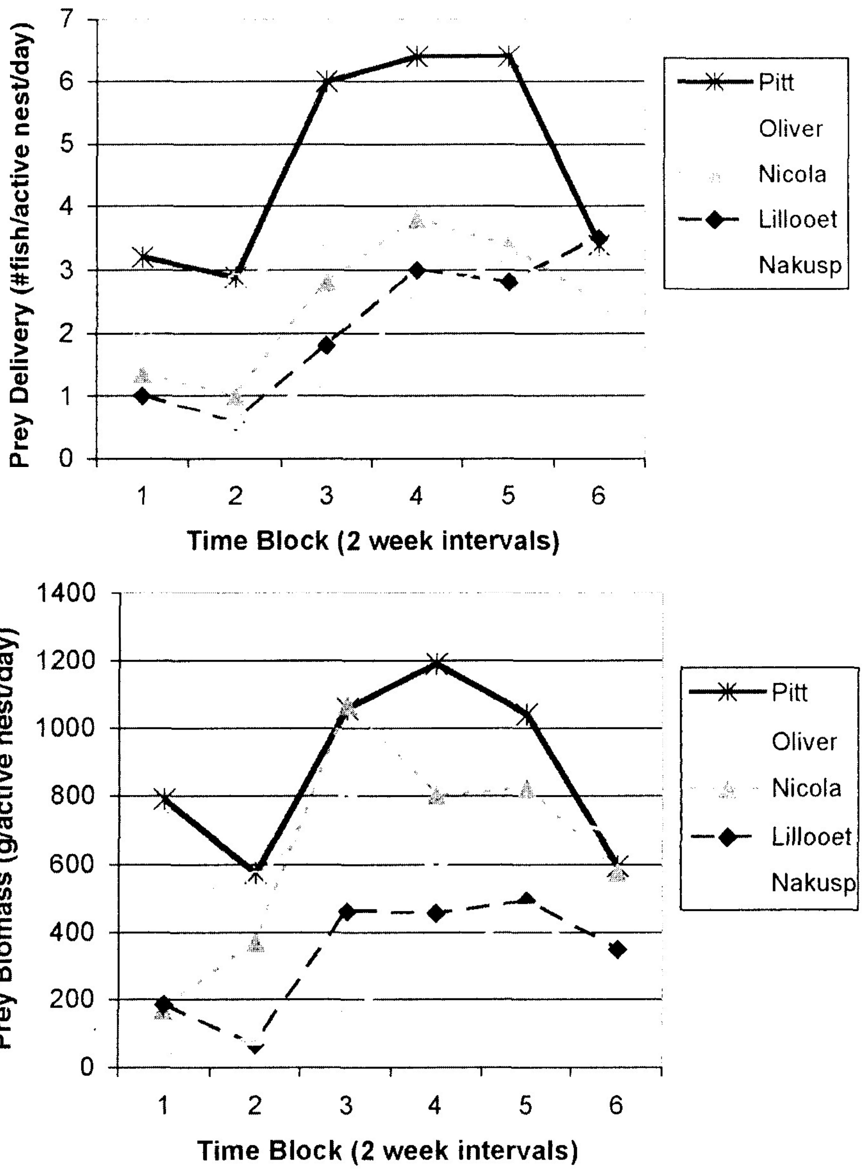
[a]Fish diversity defined as low <10 spp., moderate 10-20 spp., or high >20 spp. using data from B.C. Fisheries (**www.fishwizard.com**)
[b]NA = data not available

Table 2. Summary of fish prey delivered (% in diet) by family and species to Osprey nests at each of the five study lakes in southern British Columbia and for all sites combined, 2001.

Prey Delivered		*Location*					*All Sites*	
Family	*Species*	*Lillooet (n = 46)*	*Nakusp (n = 51)*	*Nicola (n = 72)*	*Oliver (n = 94)*	*Pitt (n = 140)*	*Species Total*	*Family Total*
Salmonidae	Cutthroat Trout (*Oncorhynchus clarki*)					0.7	0.3	
	Kokanee (*Oncorhynchus nerka*)		37.0	31.9			10.4	
	Mountain Whitefish (*Prosopium williamsoni*)	2.2			4.3	7.9	4.0	
	Rainbow Trout (*Oncorhynchus mykiss*)	37.0	27.0	5.6	5.3		9.9	
	Unidentified Salmonids	2.2	12.0	4.2	1.1	7.9	5.5	30.1
Cyprinidae	Common Carp (*Cyprinus carpio*)				12.8	2.9	4.0	
	Goldfish (*Carassius auratus*)					0.7	0.3	
	Northern Pikeminnow (*Ptychocheilus oregonensis*)		7.8	1.4	3.2	10.0	5.5	
	Peamouth Chub (*Mylocheilus caurinus*)			12.5		2.9	3.2	
	Tench (*Tinca tinca*)				3.2		0.7	
	Unidentified Cyprinids					7.9	2.7	16.4
Catostomidae	Bridgelip Sucker (*Catostomus columbianus*)	47.8	3.9				6.0	
	Longnose Sucker (*Catostomus catostomus*)	2.2	3.9	12.5	1.1	5.7	5.2	
	Largescale Sucker (*Catostomus macrocheilus*)			16.7	4.3	2.1	4.7	
	Unidentified Catostomids	2.2	3.9	13.9	9.6	4.3	7.0	22.8
Centriarchidae	Black Crappie (*Pomoxis nigromaculatus*)				1.1	1.4	0.7	
	Smallmouth Bass (*Micropterus dolomieu*)				5.3	0.7	1.5	2.2
Ictaluridae	Brown Catfish (*Ameiurus nebulosus*)					30.1	10.7	
	Unidentified Ictalurids				1.1		0.3	10.9
Other Families	Prickly Sculpin (*Cottus asper*)					0.7	0.3	
	Yellow Perch (*Perca flavescens*)				1.1		0.3	
	Starry Flounder (*Platichthys stellatus*)					1.4	0.5	1.1
Unidentified	Unidentified Species	6.5	3.9	1.4	46.8	12.1	16.6	16.6

Prey delivery rates varied considerably over the breeding season. The first two time blocks encompassing 14 May to 10 June, when birds were incubating, had the lowest delivery rates ($F_{5,20}$ = 10.5, P < 0.0001) and the lowest prey biomass ($F_{5,20}$ = 7.88, P = 0.0003) (Fig. 2 a ,b). Although prey delivery peaked at different times for each site, there was a significant decline in prey biomass in the last two-week time block which coincided with the pre-fledging period.

Figure 2: Change in a) number and b) biomass of prey delivered to active Osprey nests that were observed at five locations in southern British Columbia over the course of the breeding season 2001. Observations were structured into six - 2 week time blocks (blocks 1, 2 = incubation; blocks 3, 4, 5 = chick rearing; block 6 = pre-fledging or fledging).

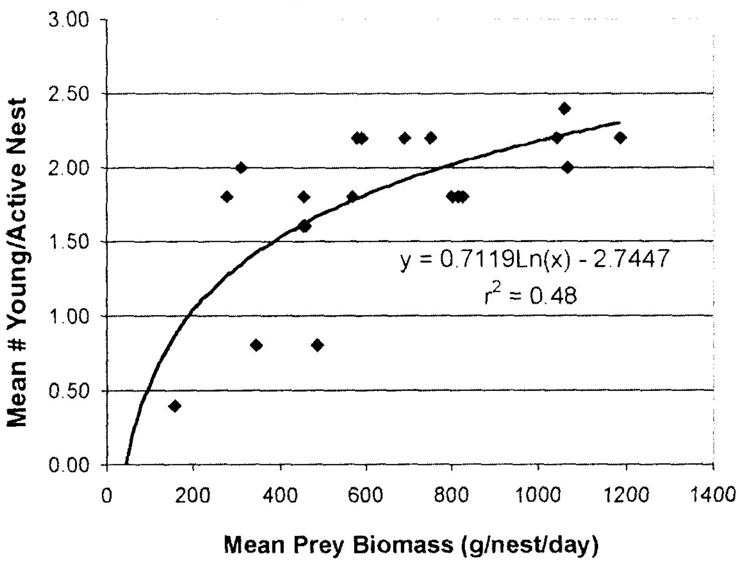


Osprey selected prey within a wide size range from 7.6 to 40.6 cm (mean 24.1 cm) which corresponded to masses of 5.1 to 917 g (mean 197 g). Significant differences existed between study sites in the size and mass of prey captured by breeding Osprey ($F_{4, 350} = 7.55$, $P < 0.0001$) (Table 3). The largest average prey was from Nicola Lake (258.6 ± 18.2 g) followed by Osoyoos Lake at Oliver (215.0 ± 12.4 g), while smallest prey was taken on average by Nakusp birds (126.1 ± 11.5 g).

Osprey prey delivery rates also varied across the five different study sites (Table 3). The mean number of prey delivered per day was generally highest at Pitt Meadows and lowest at Nakusp and Lillooet. Pitt Lake nests had higher delivery rates of 4.72 ± 0.40 fish/nest/day compared to all other sites ($F_{4,20} = 16.78$, $P < 0.0001$). Similarly, mean daily biomass of prey per active nest was significantly higher for Pitt, Oliver and Nicola over the Nakusp and Lillooet sites ($F_{4,20} = 20.16$, $P < 0.0001$). The estimate of biomass on a per nestling basis did not follow the same pattern. On average, individual chicks received similar masses of prey among sites ($F_{4,15} = 2.16$, $P = 0.1$).

There was a declining trend in mean biomass delivered per chick for nests with one, two and three nestlings, such that single chicks were fed greater average biomass per individual than chicks with one or two siblings present ($F_{2,21} = 3.53$, $P = 0.048$). Although single chicks received more food on average, a positive relationship existed between prey biomass delivered/nest and the mean number of young/active nest ($r^2 = 0.48$, $P = 0.0007$), demonstrating that adult Ospreys could adjust their prey delivery effort at some sites to compensate for larger broods (Fig. 3).

Figure 3. Relationship between average biomass of fish prey delivered to the nest and mean number of Osprey young in active nests (n = 25) that were intensively observed during the chick rearing period (time blocks 3 to 6). All five study sites in southern British Columbia sampled in 2001 are combined for analysis.



Estimates of biomass delivered on a per chick basis did not appear to explain Osprey productivity. Instead, the biomass of prey deliveries on a per nest basis was closely related to the productivity of nests under observation and all the nests found at each site (Table 3). Lillooet and Nakusp had the lowest prey delivery rates and biomass on a per nest basis and subsequently had lower overall productivity ($F_{4,63}$ = 3.10, P = 0.02). Nest success was not significantly different among sites (χ^2 = 7.32, df = 67, P = 0.1), but notably lower at Lillooet and Nakusp relative to the other three locations. In addition, brood reduction was greatest for nests at Lillooet, while most other sites had little or no reduction in brood size. Productivity data collected from the same five sites over multiple years (1997, 1999, 2000 and 2001) did not vary significantly by year ($F_{3,116}$ = 1.55, P = 0.2). Mean productivity at each site over all years surveyed was as follows: Lillooet 1.13 ± 0.25, Nicola 1.63 ± 0.23, Oliver 1.90 ± 0.32, Pitt 1.20 ± 0.26, and Nakusp 0.82 ± 0.17.

Contaminant concentrations in Osprey eggs at the five study locations were generally low and showed few significant differences among sites (Table 4). Mean DDE concentrations were highest in Oliver eggs ($F_{4,21}$ = 5.71, P = 0.003) and mean total PCB levels were highest at Nicola Lake, but only significantly above Nakusp ($F_{4,21}$ =3.83, P = 0.02). Other organochlorines detected in eggs were low including DDT (range 0.001-0.114 mg/kg), DDD (range 0.006-0.245 mg/kg), HCB (range 0.0002-0.023 mg/kg), heptachlor epoxide (range ND-0.059 mg/kg), oxychlordane (range ND-0.043 mg/kg), trans-nonachlor (range ND-0.019 mg/kg), cis-nonachlor (range ND-0.071 mg/kg), and dieldrin (range ND-0.818 mg/kg). In general, Nicola and Oliver had the highest concentrations of all contaminants measured except mercury, which had no significant differences detected among sites ($F_{4, 21}$ = 1.40, P = 0.3). Therefore, differences in Osprey productivity among sites were not likely related to contaminant levels in eggs.

DISCUSSION

Prey size and prey delivery rates were found to differ significantly across sites in 2001. The highest estimates of prey delivery were from natural lake sites including Pitt Lake and Osoyoos Lake, where birds fed on a wide variety of prey. However, the length and mass of prey were greatest for Nicola Lake, where birds were feeding on primarily Kokanee (31.9%) and various sucker species (43.1%). Overall, the three most productive sites in terms of Osprey reproduction and food availability were Oliver, Pitt and Nicola. Those natural lakes appeared highly productive and resulted in greater numbers of prey captured, higher prey biomass per nest and ultimately increased productivity. In contrast, Lillooet and Nakusp were found to have low rates of prey delivery, smaller prey biomass, and lower overall estimates of productivity and nest success.

Although Ospreys are highly opportunistic feeders, they typically have an optimal size range of prey and are restricted to feeding in primarily shallow waters (Poole 1989). As a result, the species composition and associated biomass of their diet can vary widely among sites. Indeed, studies that examine Osprey foraging behaviour and diet show a high degree of disparity in diet composition across their breeding range (Swenson 1978; Van Daele & Van Daele 1982; Greene *et al.* 1983; Steeger *et al.* 1992). The five study locations were selected to cover a broad range of habitat conditions encountered by

Table 3. Summary of mean prey size, delivery rates, prey biomass and productivity estimates for nests that were intensively observed over 12 weeks in 2001. For comparison, additional data on the productivity estimates is shown for all nests surveyed at each of the five locations in the same year. Values are reported as means ± SE or percentages.

Site	*Observed Nests (n=25)*							*All Nests (n=68)*	
	Prey size (cm)	*Prey biomass (g)*	*# Prey (fish/nest/d)*	*Prey biomass (g/nest/d)*	*Prey biomass[a] (g/chick/d)*	*Mean # young/ active nest*	*% Brood reduction*	*Mean # young/ occup. territory*	*% Nest success*
Lillooet	23.0 ± 0.9	170.6 ± 20.2	2.12 ± 0.25	333.2 ± 20.2	403.4 ± 77.1	1.20 ± 0.23	64	0.67 ± 0.37	33.3
Nakusp	21.2 ± 0.7	126.1 ± 11.5	1.73 ± 0.18	218.4 ± 50.6	237.8 ± 56.0	1.50 ± 0.37	10	0.80 ± 0.18	48.0
Nicola	26.8 ± 0.7	258.6 ± 18.2	2.45 ± 0.10	633.0 ± 68.7	438.2 ± 45.0	1.85 ± 0.05	10	1.30 ± 0.40	60.0
Oliver	25.2 ± 0.5	215.0 ± 12.4*	3.10 ± 0.24	646.6 ± 47.3*	342.3 ± 39.8*	2.10 ± 0.10	0	2.11 ± 0.31	88.0
Pitt	23.5 ± 0.5	191.0 ± 14.5	4.72 ± 0.40	874.7 ± 62.2	431.0 ± 57.9	2.25 ± 0.05	8	1.20 ± 0.30	60.0

[a] chick rearing period only, time blocks 1 and 2 (incubation) excluded.

* Oliver biomass estimates should be interpreted cautiously since 46.8% of prey deliveries could not be identified and were not used for biomass calculations.

breeding Ospreys in British Columbia. Inter-site differences in prey availability, at least in the year of the study, were sizeable enough to have a marked effect on productivity. The results clearly show that local differences in prey diversity correspond with differences in prey size and species selection.

Analysis of prey biomass brought to a nest is typically the most meaningful measurement of daily food intake. After the model by Wiens and Innis (1974), Lind (1976) calculated the amount of food that Ospreys would require in the breeding season as 286 kcal/day for adults and 254 kcal/day for juveniles near fledging. Assuming fish contain 1 kcal/g body weight, nests with one adult female and two chicks would require approximately 794 g of food per day near fledging time (Van Daele & Van Daele 1982). Osprey from our five study locations ranged in mean daily intake during the later chick rearing period (time block 5) from lows of 453 g/day and 488 g/day at Nakusp and Lillooet respectively, to a high of 1042 g/day at Pitt Lake. Although Pitt, Nicola and Oliver nests achieved the minimum requirement of 794 g/day, those at Nakusp and Lillooet did not. The low prey biomass of Nakusp and Lillooet nests corresponded well to the lower productivity, lower nest success and higher degree of brood reduction (Lillooet only). The biomass of prey per chick was similar between locations, indicating that Ospreys at lower quality sites raise smaller broods to compensate for reduced food availability. Productivity estimates for all the nests at each site in 2001 further revealed that both the Lillooet and Nakusp Ospreys were at or below the published threshold of 0.8 young/active nest for maintaining stable populations (Spitzer *et al.* 1983). However, over multiple years of productivity estimates, only Nakusp bordered that critical threshold (0.82 ± 0.17).

Table 4. Summary of mean concentrations of total PCBs, DDE (mg/kg wet weight) and total mercury (mg/kg dry weight) measured in Osprey eggs from five sites in southern British Columbia, 1999 and 2000. Values are expressed as geometric means (ranges of concentrations).

Site	*Year*	*N*	*Moisture (%)*	*Lipid (%)*	*Total PCBs*	*p,p' DDE*	*Mercury*
Lillooet	2000	6	82.8	3.9	0.67 (0.31-1.91)	0.88 (0.31-2.59)	0.54 (0.17-1.18)
Nakusp	2000	5	81.1	3.6	0.12 (0.02-0.68)	0.33 (0.15-0.49)	0.26 (0.12-0.37)
Nicola	1999	6	84.0	5.0	1.42 (0.25-4.65)	0.64 (0.40-0.92)	0.33 (0.17-0.60)
Oliver	2000	4	81.3	4.1	0.49 (0.25-0.75)	2.57 (2.09-3.33)	0.37 (0.13-0.86)
Pitt	2000	5	81.9	4.0	0.38 (0.15-1.07)	0.69 (0.16-2.15)	0.52 (0.32-0.86)

Although Lillooet and Nakusp differ in several characteristics including elevation, prey species diversity and lake size, they are both hydroelectric reservoirs. Water levels in reservoirs are known to affect the hunting proficiency of Ospreys and have been linked to numerical increases in productivity during years of low water levels (Koplin *et al.* 1977; Van Daele & Van Daele 1982). It is possible that the reservoir sites had higher than average water levels in 2001 which may have caused the decline in productivity. Alternatively, those sites may have low nutrient availability, contain fewer key prey species of the required size or species that were more difficult to capture. Osprey dive success has been linked to the foraging strategy of their fish prey, such that benthic feeding fish were more easily captured than piscivorous fish (Swenson 1979). However, we failed to detect any trends between the sites with low productivity and Swenson's (1979) Prey Species Foraging Index. Weather may have accounted for some of the variation in prey deliveries and in reproductive success; however, the weight of evidence suggests that availability or abundance of key prey species was a more important component driving productivity results.

Osprey breeding data from many locations in Canada and the United States during the DDT era frequently showed low productivity of less than one chick per active nest (Henny *et al.* 1977; Poole 1989). Evidence from past studies primarily pointed to DDE residues and subsequent eggshell thinning as the cause of poor productivity (Spitzer *et al* 1978; Wiemeyer *et al.* 1988). Concentrations of common contaminants were below thresholds known to affect Osprey reproduction at our five study lakes (Noble & Elliott 1990). Reproductive effects such as shell thinning and lower productivity have been reported at critical DDE concentrations of 4.2 mg/kg (Wiemeyer *et al.* 1988). Reduced hatching success was detected in Osprey eggs from the Pacific Northwest at concentrations above 4.2 mg/kg DDE (Henny *et al.* 2004) and primarily at higher levels of 6 to 10 mg/kg (Elliott *et al.* 2001). The highest concentration of DDE in this study (3.3 mg/kg) was detected at an agriculturally dominated site in Oliver. However, DDE contamination was not sufficiently elevated to depress reproduction, as this site had among the highest productivity and nest success.

Although PCB concentrations have been correlated with embryonic biochemical responses such as hepatic cytochrome P4501A and retinolic products (Elliott *et al.* 2001); high PCB concentrations in Osprey eggs seldom cause effects on reproduction even at 25 mg/kg (Poole 1989). Therefore, PCB concentrations detected at our five sites in the range of 0.02 to 4.65 mg/kg were not expected to impact reproductive performance. Even the highest PCB concentrations found at Nicola Lake had productivity estimates at stable levels. In general, higher organochlorine and PCB concentrations were found at the most productive sites, Oliver and Nicola. In contrast, Lillooet and Nakusp had the lowest levels of contamination and still experienced lower reproductive success.

Mercury exposure has been of concern for Ospreys in some regions across North America, particularly on hydroelectric reservoirs (Hughes *et al.* 1997; DesGranges *et al.* 1998). Egg mercury levels in this study were slightly higher than those reported for Osprey nesting along other British Columbia rivers

(Elliott *et al.* 2000). However, levels were below known reproductive toxicity thresholds of 0.5 mg/kg wet weight, and were in the range of values detected at the other natural sites (Wiemeyer *et al.* 1975; Hughes *et al.* 1997; Henny *et al.* 2004). The highest value detected in this study of 1.2 mg/kg dry weight was at the Downton-Carpenter reservoir in Lillooet, which is consistent with other findings of Ospreys breeding on lakes and especially reservoirs having higher mercury levels than birds breeding along natural rivers (DesGranges *et al.* 1998).

Although failing reproductive health and numbers are generally warnings of contamination in Osprey fishing waters, other natural factors that limit reproduction should invariably be considered in assessing Osprey health. There is increasing evidence that environmental stressors, especially food stress can have synergistic or interactive effects with contaminants in birds (Keith & Mitchell 1993). Gervais & Anthony (2003) showed that even low levels of chronic *p,p'*-DDE exposure in wild Burrowing owls *Athene cunicularia* were associated with reduced productivity when in combination with low rodent biomass. Food supply in combination with contaminants was also attributed to reducing productivity of Bald Eagles *Haliaeetus leucocephalus* nesting near a pulp mill in coastal British Columbia (Gill & Elliott 2003). This combined effect may be caused by mobilization of lipid stores and associated contaminants during high stress periods (Frank & Lutz 1999) or the higher energy requirements of exposed individuals to activate their detoxification system (Heath 1995). Contaminants may also impose indirect effects through reduction in prey availability or abundance (Eeva *et al.* 2003). Given the substantial variation in prey delivery rates and the low levels of contamination at our study locations, we suggest that natural variation in food supply was probably a more important factor driving Osprey productivity. However, if contaminant levels increase, they may have greater impact on breeding birds under high food stress conditions. Therefore, consideration of daily prey intake on a per nest basis in addition to productivity estimates should provide a more accurate assessment of Osprey population effects from both natural and contaminant related stressors.

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