A specialist in the city: the diet of barn owls along a rural to urban gradient

Sofi Hindmarch · John E. Elliott

Abstract We investigated the variations in the diets of barn owls (*Tyto alba*) along a rural to urban gradient in the Lower Fraser Valley of southwestern British Columbia, Canada. Our objectives were to determine the food preferences of barn owls in different habitat types and to assess both seasonal and annual variations in their diets. In particular, given the increased incidences and concentrations of second generation anticoagulant rodenticide (SGAR) residues in barn owls, we were interested in determining whether there was any relationship between the degree of urbanization surrounding their nest/roost sites and the proportion of commensal rodents (*Rattus norvegicus, Rattus rattus, Mus musculus*) in their diet. In total, 8,941 individual prey remains were identified. The proportion of rats consumed increased significantly with the amount of urbanization within home ranges. However, voles (primarily field voles, *Microtus townsendii*) were the main prey item for all sites irrespective of surrounding land use within home ranges. Shrews were the second most consumed prey species (10.8±8 %), and were found predominantly in the diet of barn owls nesting in more rural landscapes. The dominance of field voles in the diet was also reflected in the food-niche breadth, which was consistently low for all sites across the rural to urban gradient. Interestingly, barn owls were found nesting in highly urban environments (66–95 % urbanization), where bait stations containing SGARs were regularly used. This, combined with the increased consumption of rats in more urban environments, illustrates why the SGAR exposure rate in barn owls is substantial and rising.

Keywords Barn owl · Diet · Rodenticide · Rural–urban gradient

Introduction

The barn owl (*Tyto alba*) is a bird of prey with a worldwide distribution. Like many other cosmopolitan raptors, it has adapted to living in close proximity to humans, and commonly

S. Hindmarch (✉)
Langley, British Columbia, Canada
e-mail: sofi.hindmarch@gmail.com

J. E. Elliott
Environment Canada, Science and Technology Branch, Delta, British Columbia, Canada

🍾 Springer

nests in man-made structures. Barn Owls have also shown considerable resilience to land use changes by adapting and persisting in landscapes which are becoming increasingly urbanized. Inhabiting urbanized landscapes comes with an increase in anthropogenic threats such as trauma from collisions with vehicles and buildings (Hager 2009). Exposure to chemical contaminants like lead, persistent organic pollutants and polycyclic aromatic hydrocarbons can also be greater in urban environments (Van Metre et al. 2000; Li et al. 2001; Newsome et al. 2010; Henny et al. 2011). High density human developments also attract traditional commensal pest species, such as rats (Rattus sp.) and house mice (Mus musculus) (Feng and Himsworth 2013). Consequently, the need for pest control, particularly for rats, may be greater in urban settings (Riley et al. 2007; McMillin et al. 2008). The primary method for controlling commensal rodent infestations worldwide is the use of antico-agulant rodenticides (AR). Second generation ARs (SGAR) in particular are persistent, bioaccumulative and highly toxic compounds. Their spread as contaminants to birds of prey has been increasingly documented (Merson et al. 1984; Stone et al. 1999; Lambert et al. 2007; Walker et al. 2008; Albert et al. 2010; Lima and Salmon 2010; Murray 2011; Christensen et al. 2012; Thomas et al. 2011).

In southwestern British Columbia, regular measurement of rodenticide residues in barn owls did not begin until the mid-2000s, but data were obtained from retrospective analysis of archived samples from as early as 1988. The data shows that the exposure rate is on an upwards trend, with 62 % of carcasses collected between 1988 and 2003 testing positive for one or more ARs, compared to 75 % of carcasses collected between 2005 and 2011 (Albert et al. 2010; Elliott et al. unpubl. data). Similarly, data from Britain, corrected for changes in analytical methodology, also shows increased incidences of SGAR exposure in barn owls (Walker et al. 2012). Elliott et al. (2014) tested for AR residues in small mammals typically consumed by barn owls such as field voles (Microtus townsendii), shrews (Sorex sp.), deer mice (Peromyscus maniculatus) and rats and found rodenticide residues almost exclusively in rats. This result supports the notion that rats are an important, if not the main vector responsible for secondary exposure of non-target predators.

Barn Owls' close association with agricultural landscapes and structures have made them excellent candidates for dietary studies and this is reflected in the extensive dietary literature for the species (Marti et al. 2005). The majority of these studies have demonstrated that barn owls have a preference for small mammals (Campbell et al. 1987; Taylor 1994; Marti et al. 2005). However, in North America the majority of barn owl diet studies have been conducted in grassland and agricultural landscapes, and very few have investigated diets in more suburban to highly urban landscapes. Such data would be of particular interest for rapidly urbanizing regions such as the Lower Fraser Valley of British Columbia where the loss of grassland and agricultural lands surrounding urban centres is forcing wildlife to inhabit the remaining patchwork of green space such as parks, suburban woodlots and fragments of undeveloped land.

The objective of our study was to obtain information on the diet of barn owls on a rural to urban gradient in southwestern British Columbia. This data would document any changes in the diet of barn owls nesting in different habitats, and help us determine where barn owls fall on the generalist vs. specialist continuum in southwestern British Columbia. In particular, given the increased incidence and concentrations of AR residues in barn owls (Albert et al. 2010; Elliott et al. unpublished data), we were interested in determining whether there was any relationship between the degree of urbanization surrounding their nest/roost sites, and the proportion of commensal rodents (Rattus norwegicus, Rattus rattus, Mus musculus) in their diet.

Methods

Study sites

Surveys for barn owl nest and roost sites were conducted from November 2009 to April 2012 throughout the Lower Fraser Valley in the municipalities of Richmond, Vancouver, New Westminster, Burnaby, Delta, Surrey and Coquitlam (1,027 km^2) in southwestern British Columbia, Canada (49°8′0″ North, 122°18′0″ West; Fig. 1). The area includes some of the main stopover sites for birds migrating on the Pacific flyway and encompasses important wildlife areas such as the Alaksen National Wildlife Area, Burns Bog, Stanley Park and Boundary Bay.

Prior to European settlement the low lying floodplains were dominated by grassland and low shrub vegetation while higher elevations were covered primarily by coniferous forest (North and Teversham 1983). Today, the landscape ranges from agricultural land to suburban to highly urban, with the remaining lower grassland and forested habitats facing ongoing development pressure as the projected human population in the region is expected to increase 50 % by 2036 (Storen 2011).

Owl surveys and pellet collection

We surveyed for barn owls in semi-urban to urban areas of the Lower Fraser Valley. Barn owls tend to seek tall structures with permanent openings near the roof for nesting and roosting, so
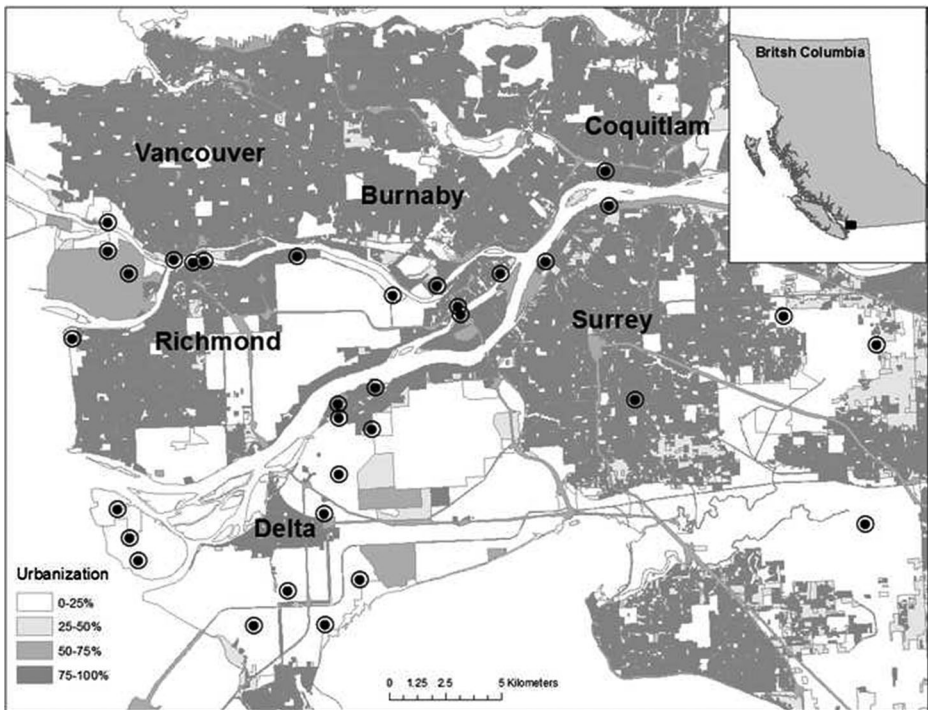

Fig. 1 Study area, the Lower Fraser Valley, British Columbia, Canada, used for assessing barn owl diet along a rural to urban gradient. The map includes nest and roost site locations, and the percentage of urbanization

we targeted industrial buildings and bridges/overpasses which appeared favorable for barn owl roosting/nesting. If permission was obtained from the property owner we would inspect the inside and perimeter of the structures for barn owls or indications of their presence (pellets or feathers). If we found evidence of a barn owl roosting/nesting, we would revisit the site on a bi-monthly basis and collect more pellets. In addition, pellets were collected on the same interval from farms in more rural areas in the South Fraser Valley. Collecting pellets on a bi-monthly basis permitted the evaluation of seasonal and inter-annual trends in the diet. Diet data from each location were combined into one sample when assessing the proportion of commensal rodents in the diet in relation to land use, and food-niche breadth. We documented if breeding had taken place by listening for chicks, which become quite vocal after dusk beyond 3 weeks of age, and can be heard begging for food in their nests. We also searched for any evidence of rodenticide usage on site and around neighbouring buildings, specifically bait stations placed along-side the perimeter of buildings.

Pellet analysis

Pellet analysis is considered a reliable and accurate method for determining barn owl prey intake (see Marti 1974 and references therein).

Pellets were processed by carefully taking them apart so that prey items could be identified based on the bone remnants, fur and other body parts using British Columbia small-mammal field guides (Nagorsen 1996, 2005). The number of individuals of any species within each pellet was determined by pairing each skull with the correct number of ischia, left and right mandibles, tibiae/fibulae, or in the case of birds each skull with sternum, gizzard sac and feet. The remaining bones contained within the pellet, were assembled to determine the minimum number of additional individuals whose skull may have been crushed. For smaller prey items (<100 g) the remains of each prey were assumed to be contained within a single pellet as it is rare that bones from one prey item to be mixed into two successive pellets (Raczynski and Ruprecht 1974). The majority of prey items were identified to species, but due to the lack of distinguishing features, most of the shrews could not be identified to species, so for the purpose of the food-niche breadth analyses all shrews were combined into one shrew category. Similarly, very few rat skulls were intact enough to be identified to species (Norway rat (*Rattus norvegicus*) or black rat (*Rattus rattus*)), and hence all rats were combined into one rat category. Weights of rats were estimated by measuring the length of their lower mandibles from the prey remains using a formula developed by Morris (1973). Songbird (Passeriformes) prey remains were allocated into two categories: a small bird category (less than 30 g) and a medium songbird category (30–60 g). All exoskeleton remains were considered to be in the order Coleoptera.

Land use and spatial analysis

We quantified the amount and type of land use within a 1 km radius (3 km^2) of each nest/roost site from digitized data layers using Geographic Information System (GIS) software (ArcMap 10). We used a 1 km radius around each site, as this approximates the average home range of a barn owl (3 km^2; Taylor 1994). Data on land use within these theorized home ranges were obtained from a 2006 Vancouver Regional District land use layer map which categorizes land parcels based on zoning (Metro Vancouver 2008). We compared the 2006 land use layer map with 2010 Bing Ortho photos (Bing Maps 2010) to control for any recent changes in land use or discrepancies in current land use and zoning. Within each 3 km^2 barn owl home range, we extracted and quantified the amount of urban land (residential and industrial land use) from the 2006 GIS data later.

Statistical analysis

We conducted a linear regression to evaluate whether there was any relationship between the proportion of commensal rodents in the diet and the proportion of urban land surrounding each nest/roost site.

An ANOVA was conducted to evaluate seasonal variations in the proportion of field voles, shrews and rats in the barn owl's diet across all sites. For this analysis, a "collection" consisted of all the pellets gathered from a specific site in 1 day. Data were only included from sites where a minimum of 15 pellets were collected on the collection date ($n=138$). Further, these data were grouped into a season (winter, spring, summer, autumn) based on the date.

For sites where we had identified ≥ 100 prey species ($n=31$) in total for the entire duration of the study, food-niche breadth: $FNB = 1/(\sum pi^2)$ where pi is the proportion of each species, was calculated. To allow for comparisons between samples, the standardized food-niche breadth was also calculated: $FNBst = (FNB - 1)/(N - 1)$, where N = the total number of prey species (Marti 1988). The FNBst variable was log-transformed to reduce skew.

Pearson correlation was used to evaluate the relationship between FNBst and the amount of urbanization (residential and industrial land use) within home ranges, and the association between FNBst and the proportion of the main prey consumed. All statistical analyses were carried out using IBM SPSS 19 (IBM SPSS, IBM Inc. Armonk, New York).

Results

Diet in relation to land use

We identified 13 structures in urban landscapes of the Lower Fraser Valley that were found to be used regularly by barn owls for nesting and roosting. We also monitored 20 barn owl roost/ nest sites located in more rural areas of the Lower Fraser Valley. The amount of urban land within home ranges (3 km^2) ranged from 0 to 95 % (Fig. 1; Table 1).

The diet data revealed that barn owls ate a variety of prey, with 18 different species found in the 3,589 pellets collected and a total of 8,941 individual prey remains identified. Voles (primarily field voles) were the main prey item for all sites regardless of the amount of urbanization within barn owl home ranges (range: 54.9–97.2 %, $\overline{X}=77.3\pm10.3$ %). Shrews were the second most consumed prey (10.8±8 %), and there was an inverse correlation between these two species ($r_p=-0.65$, $r^2=0.42$, $p<0.01$; Table 1).

There was considerable variation in the proportion of rats consumed by barn owls among sites (range: 0–36.6 %, $\overline{X}=6.0\pm7.6$ %). The consumption of rats increased significantly with increased urbanization within home ranges ($r=0.57$, $r^2=0.33$, $n=33$; $p<0.01$; Fig. 2). Barn owls consumed predominantly smaller rats, with an estimated average mass of 73.87±38.26 g (Range: 20–260 g, $n=336$; Fig. 3). House mice were negligible in the diet of barn owls, representing 0.26 % ($n=15$) of consumed prey and there was no relationship between land use and house mice consumption ($n=10$ sites).

Diet breadth

In comparison to other diet studies (see Marti et al. 2007; Teta et al. 2012), FNBst remained low across sites (Range: 0.003–0.089), and there was no evidence to suggest that the degree of urban development influenced food-niche breadth ($r_p=0.07$, $r^2=0.00$, $p>0.05$).

Table 1 The average proportion contributed by each prey taxon, including the total amount (*n*) of prey found in barn owl pellets collected from 2009 to 2012 at 33 nest/roost sites (*n*=8,941 prey items)

Landscape variable	% mean±SD (*n*)
Urban km^2	45.1±35.7 (33)
Prey	
Mammals	
Microtus townsendii	77.3±10.13 (6,924)
Microtus oregoni	0.2±0.5 (19)
Peromyscus maniculatus	2.8±2.4 (254)
Zapus trinotatus	0.1±0.2 (8)
Mus musculus	0.3±0.5 (29)
Rattus sp.	6.0±7.6 (481)
Sylvilagus floridanus	0.2±0.6 (26)
Scapanus oriarius	0.4±0.5 (40)
Neurotrichus gibbsi	0.4±0.8 (33)
Sorex sp.	10.8±8.0 (984)
Aves	
Sturnus vulgaris	0.2±0.5 (14)
Corvus brachyrhynchos	0.02±0.1 (1)
Colaptes auratus	0.01±0.1 (1)
Calidris sp.	0.04±0.1 (4)
Small unidentified passerines (>30 g)	0.7±0.8 (69)
Unidentified passerines (30–65 g)	0.5±0.6 (48)
Anurans	
Anura sp.	0.03±0.2 (2)
Insects	
Insect remains	0.1±0.4 (5)

Rattus taxa included: *rattus* and *norvegicus*, *Sorex* taxa included: *cinereus*, *monticolus*, and *vagrans*

Conversely, there was a strong significant inverse relationship between FNBst and the proportion of field voles in the diet (r_p=−0.93, r^2=0.87, $p<0.01$), which suggests that when the availability of field voles declined, barn owls substituted field voles with an array of other prey species.

Seasonal variation in prey

The average temperatures were similar between years (2010–2013), and the fall and spring average annual temperatures fell within ±2 StDev of the Vancouver climate normal for 1981–2010, 10.4±1.3, 9.7±1.1 °C respectively. The winter and summer annual temperatures were within ± 1 StDev of the Vancouver climate normal for 1981–2010, 4.4±1.8, 16.5±0.8 °C respectively. Total precipitation varied slightly more. Notably, fall 2009 was particularly wet compared to the seasonal average (171.9 vs. 127.0 mm). However, irrespective of year and season, field voles were the primary prey for all 3 years (2010: 78.2±13.2 %, 2011: 78.1± 14.9 %, and 2012: 76.7±12.0 %). The seasonal fluctuations in the consumption of field voles were consistent between years, but the ANOVA revealed that the consumption differed between seasons [F (3,134)=7.3, $p<0.05$]. A post hoc Tukey HSD test showed that there
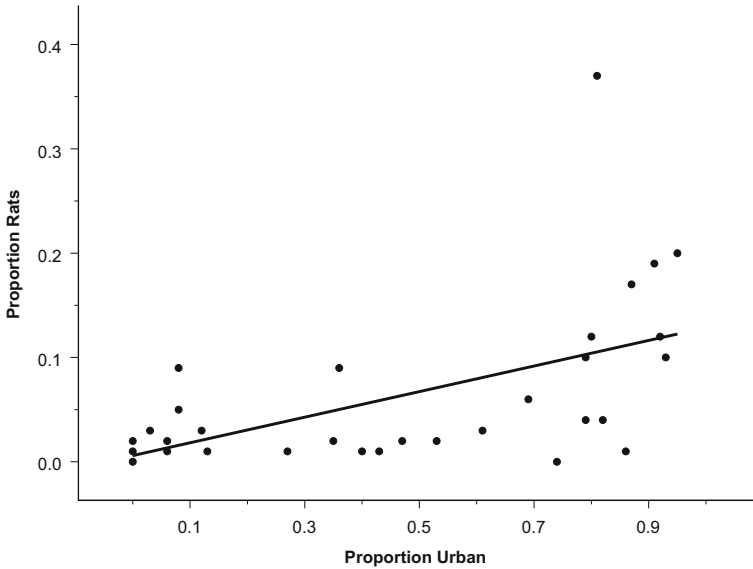
Fig. 2 The relationship between the proportion of urban land use within each home range (3 km^2) and the proportion of rats in the diet. Prop. Rats=0.01 + urban land use * 0.13, r=0.57 r^2=0.33, n=33, df=31, $p<0.01$

was a significantly higher proportion of field voles in the diet during fall and winter (0.83± 0.13, 0.85±0.08) compared to spring and summer (0.74±0.15, 0.72±0.12, $p<0.05$). The second most consumed prey species, shrews, exhibited opposing seasonal trends from the field voles, as the proportion of shrews in the diet was highest in the spring and summer (Fig. 4). However, this trend was different for highly urban sites (>66 % urbanization, n=13), where rats instead of shrews were the most important secondary prey item and there was a significant inverse seasonal correlation between rats and field voles (r_p=−0.81, r^2=0.66, $p<0.01$).

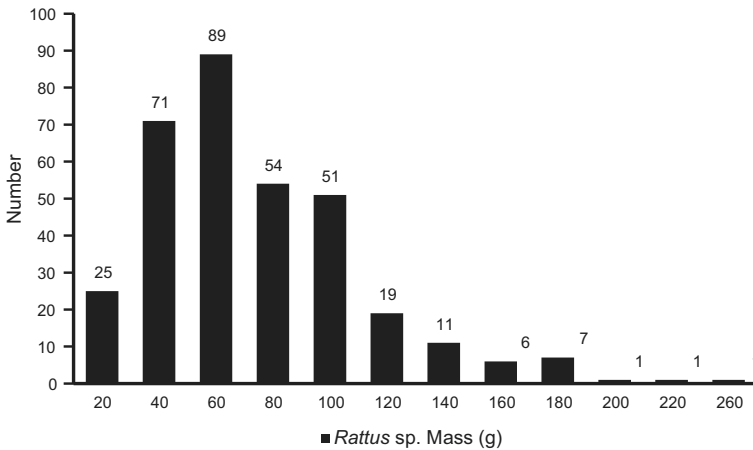**Fig. 3** Histogram representing the different weight classes of rats consumed by barn owls ($\overline{X}$=73.87±38.26 g, n=336)
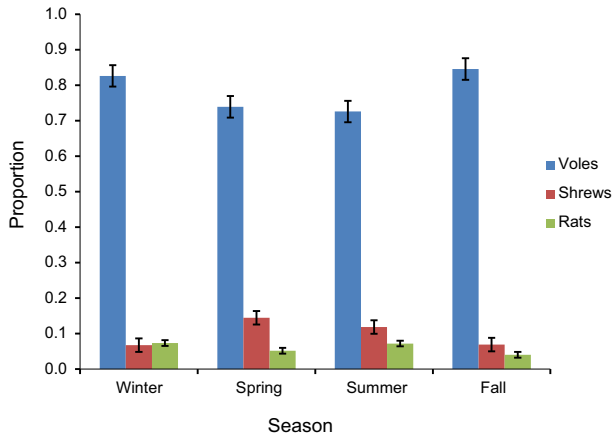
Fig. 4 Seasonal averages, including 1 StDev of the proportion of field voles, shrews and rats in the diet of barn owls

Discussion

Previous barn owl diet studies comparing the diet of rural owls versus owls inhabiting more urban landscapes found native small mammals to be the focal prey for barn owls residing in agricultural landscapes, and as home ranges became increasingly urbanized, birds and exotic rodents also became an important component of the diet (Campbell et al. 1987; Salvati et al. 2002; Teta et al. 2012). Similarly, we found an increase in the consumption of rats as the proportion of urban development within home ranges increased. However, field voles were the main prey consumed, irrespective of the site, amount of urbanization, year or season. The dominance of field voles in the diet was also reflected in the FNBst values which were consistently low for all sites regardless of surrounding land use. Shrews were the second most consumed prey, and their inverse relationship with field voles is typical for barn owls in southwestern British Columbia (Campbell et al. 1987). The switch towards rat consumption was, as expected, more evident for barn owls residing in highly urbanized environments (>66 % urbanization) where one would expect a higher abundance of rats, and field voles to be limited by the amount of suitable grass habitat which would mostly be confined to roadsides and railway track verges.

In southwestern British Columbia, field voles are the main prey for barn owls, with a large number of other prey species contributing only negligible amounts to their diet (Cowan 1942; Doerkson 1969; Dawe et al. 1978; Campbell et al. 1987). Unlike Teta et al. (2012), we found no peak in prey diversity at sites with intermediate levels of urbanization. Field voles were the main prey at all sites, and the consistently low FNBst values, irrespective of land use reflect this. However, the negative linear relationship between the proportion of field voles in the diet and FNBst values demonstrates that barn owls are adapted to supplement their diet with a wide array of alternate prey such as shrews, rats, birds, frogs, bats and fish when field voles are less available (Campbell et al. 1987; Marti et al. 2005).

Urban development produces some of the greatest extirpation rates and frequently eliminates the large majority of native species (McKinney 2002). In addition, high density human developments also attract non-native commensal pest species such as rats and house mice. We were surprised to find barn owls nesting and roosting in structures that were situated in areas where >66 % of the landscape was covered with industry or housing. In addition, extensive

road networks severely fragmented the landscape and further reduced the available grassland habitat for foraging. In such a patchy and fragmented grassland habitat one would expect non-native predators such as rats and cats to alter the composition of native rodent species. Bock et al. (2002) demonstrated that the abundance of native rodents was reduced in grasslands where suburban habitat made up more than 10 % of the landscape. We observed many rats foraging in industrial and commercial locations situated within barn owl home ranges. Rats were particularly abundant around 24-h diners and grain storage facilities (Pers. Observ.). The increased consumption of rats in more urban environments suggests the barn owls were taking advantage of the more abundant rat population. However, rats were only consumed as subsidiary prey, and even for highly urban barn owl sites (>66 % urbanization) the consumption of rats averaged 11.7±10 % versus 76.8±9 % field voles (n=13). Hence urbanization did not influence the proportion of voles in the diet, suggesting that barn owls are able to compensate and maintain their preference for native voles even within a heterogeneous urban landscape (Teta et al. 2012). This would also suggest that a change in prey intake is driven more by the availability of their primary prey, (field voles) than by the availability of secondary prey, such as rats, a pattern that has also been demonstrated in other raptors (Steenhof and Kochert 1988).

The dominance of field voles in the diet of urban barn owls could imply that these owls are foraging in adjacent farmland outside the city limits, as was suggested by Charter et al. (2007) for urban nesting barn owls in Tel Aviv, Israel. However a radio telemetry study, which includes some of the individual barn owls whose pellets were gathered for the current study showed that these owls predominantly foraged within the city limits, making extensive use of grassy verges along roads and railways, remaining grass habitats on acreage properties, and empty fallow lots (Hindmarch and Elliott unpublished data). Being able to manoeuvre and forage in a highly urban landscape while avoiding collisions with buildings and vehicles demonstrates that barn owls are resilient and able to persist in a fragmented urban landscape. The high consumption of field voles within this urban landscape also shows that the remaining grass habitat is productive small mammal habitat, indicative of its past when the region was predominantly agricultural, no longer than 30 to 40 years ago. Unfortunately, the remaining grass habitat is disappearing rapidly due to urban densification, and given barn owls' preference for field voles as documented in this study, it remains questionable whether barn owls will be able to persist in these areas as the landscape becomes increasingly urbanized (Hindmarch et al. 2014, in press).

In temperate regions the annual and seasonal fluctuations in the abundance of field voles in the diet of barn owls are believed to reflect their availability (Campbell et al. 1987; Taylor 1994). Similar to other barn owl diet studies (Webster 1973; Campbell et al. 1987; Taylor 1994; Love et al. 2000), our data showed annual fluctuations in the proportion of voles consumed, but a consistent seasonal trend, irrespective of year. Seasonally, there was an increase in the consumption of field voles in the late spring and early summer, with a peak in the late fall and early winter and then a decline until spring again. Campbell et al. (1987) obtained similar trends when collecting seasonal diet data from barn owls in the Upper Fraser Valley, British Columbia in 1973 and 1978. Vole trapping in the Lower Fraser Valley confirms that the diet data does fluctuate in synchrony with overall vole abundance. Beecham (1979) and Taitt et al. (1981) showed that there is a spring decline in the field vole population followed by a peak in the late fall. However, even during low vole years, field voles constitute the main prey for barn owls in southwestern British Columbia (Campbell et al. 1987).

Owls are increasingly being exposed to SGARs in southwestern British Columbia (Albert et al. 2010; Elliott et al. unpubl. data), and the consumption of rats appears to be responsible for this exposure (Elliott et al. 2014). Documenting the presence of barn owls roosting and

nesting in industrial buildings or underneath highway overpasses in urban environments where bait stations containing SGARs, most commonly bromadiolone, are regularly being used, combined with the increased consumption of rats in more urban environments may explain why the exposure rate in barn owls is substantial and rising. Comparatively, within the same study area, Barred Owls, which have consistently had higher SGAR exposure and concentration rates than barn owls, were found to consume almost exclusively rats in urban environments (Hindmarch and Elliott unpublished data). Elliott et al. (2014) found that when bait stations were placed inside and along the perimeter of farm buildings, bromadiolone residues ranged from 2.87 to 4.26 ug/g ($n=5$) in trapped rats. While there is a lack of residue data for urban rodents, the scenario would likely be similar, the only difference being the increased density of buildings in an urban setting equating to an increased use of SGARs. This highlights the importance of conducting a residue study on target rodents in an urban setting, in particular due to the large number of cosmopolitan predators that could be negatively impacted by SGAR usage.

Surprisingly, very few house mice ($n=15$) were found in the barn owls' diet, even though all nests were in man-made structures, and often in close proximity to other industrial buildings and residential homes. This result supports the notion that house mice seldom venture outdoors, and are therefore not a likely vector of AR to owls. Although rats appear to be the main exposure route, Cox and Smith (1990), Brakes and Smith (2005) and Elliott et al. (2014) showed that non-target small mammals can also be exposed to rodenticides, which suggests that there is a secondary rodenticide exposure pathway through the consumption of non-target small mammals. The latter exposure pathway is likely less common than exposure from the consumption of rats (Cox and Smith 1990; Elliott et al. 2014). However, given barn owls' strong preference for field voles irrespective of surrounding land use, future research should focus on rodenticide residue sampling of non-target small mammals in addition to rats in urban environments where we know barn owls and other urban raptors are nesting or roosting. In addition, we would recommend sampling of non-target small mammals, in particular field voles on adjacent farmlands, especially around berry crops, where farmers apply rodenticide to control field vole abundance.

References

Albert CA, Wilson LK, Mineau P, Trudeau S, Elliott JE (2010) Anticoagulant rodenticides in three owl species from Western Canada, 1988–2003. Arch Environ Contam Toxicol 58:451–459

Beecham TD (1979) Survival in fluctuating populations of the vole *Microtus townsendii*. Can J Zool 57:2375–2384

Bing Maps (2010) Search: southwestern B.C. http://www.bing.com/maps/?FORM=HDRSC4. Accessed 3 Dec 2012

Bock CE, Vierling KT, Haire SL, Boone JD, Merkle WW (2002) Patterns of rodent abundance on open-space grasslands in relation to suburban edges. Conserv Biol 16:1653–1658

Brakes CR, Smith CH (2005) Exposure of non-target small mammals to rodenticides: short-term effects, recovery and implications for secondary poisoning. J Appl Ecol 42:118–128

Campbell RW, Manuwal AD, Harestad AS (1987) Food habits of the common barn-owl in British Columbia. Can J Zool 65:578–586

Charter M, Izhaki I, Shapira L, Leshem Y (2007) Diets of urban breeding barn owls (Tyto alba) in Tel Aviv, Israel. Wilson J Ornithol 119:484–485

Christensen TK, Lassen P, Elmeros M (2012) High exposure rates of anticoagulant rodenticides in predatory bird species in intensively managed landscapes in Denmark. Arch Environ Contam Toxicol 63:437–444

Cowan I (1942) Food habits of the barn owl in British Columbia. Murrelet 23:48–53

Cox PR, Smith RH (1990) Rodenticide ecotoxicology: assessing non-target population effects. Funct Ecol 4: 315–320

Dawe NK, Runyan CS, McKelvey R (1978) Seasonal food habits of the barn owl (Tyto alba) on the Alaksen national wildlife area, British Columbia. Can Field Nat 92:151–155

Doerkson GP (1969) An analysis of barn owl pellets from Pitt Meadows, British Columbia. Murrelet 50:4–8

Elliott JE, Hindmarch S, Albert CA, Emery J, Mineau P, Maisonneuve F (2014) Exposure pathways of anticoagulant rodenticides to nontarget wildlife. Environ Monit Assess 186:895–906. doi:10.1007/s10661-013-3422-x

Feng AYT, Himsworth CG (2013) The secret life of the city rat: a review of the ecology of urban Norway and black rats (Rattus norvegicus and Rattus rattus). Urban Ecosyst. doi:10.1007/s11252-013-0305-4

Hager SB (2009) Human-related threats to urban raptors. J Raptor Res 43:210–226

Henny CJ, Grove RA, Kaiser JL, Johnson BL, Furl CV, Letcher RJ (2011) Wastewater dilution index partially explains observed polybrominated diphenyl ether flame retardant concentrations in osprey eggs from Columbia River Basin, 2008–2009. Ecotoxicology 20:682–697

Hindmarch S, Krebs EA, Elliott JE, Green DJ (2014) Urban development reduces the fledgling success of barn owls in the Fraser Valley, British Columbia, Canada. Condor (in press)

Lambert O, Pouliquen H, Larhantec M, Thorin C, L'Hostis M (2007) Exposure of raptors and waterbirds to anticoagulant rodenticides (difenacoum, bromadiolone, coumatetralyl, coumafen, brodifacoum): epidemiological survey in Loire Atlantique, France. Bull Environ Contam Toxicol 79:91–94

Li X, Poon CS, Liu PS (2001) Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem 16:1361–1368

Lima LL, Salmon TP (2010) Assessing some potential environmental impacts from agricultural anticoagulant uses. Proc Vertebr Pest Conf 24:199–203

Love RA, Webbon C, Glue DE, Harris S (2000) Changes in the food of British barn owls (Tyto alba) between 1974 and 1997. Mammal Rev 30:107–129

Marti CD (1974) Feeding ecology of four sympatric owls. Condor 76:45–61

Marti CD (1988) A long-term study of food-niche dynamics in the common barn-owl: comparisons within and between population. Can J Zool 66:1803–1812

Marti CD, Bechard M, Jaksic FM (2007) Food habits. In: Bildstein KL, Bird DM (ed) Raptor research and management techniques. 2nd edn. Raptor Research Foundation, Hancock House Publishers, Blaine, p 129–149

Marti CD, Poole AF, Bevier LR (2005) The birds of North America Online. In: Poole A (ed) Ithaca: Cornell Lab of Ornithology barn owl (Tyto alba) http://bna.birds.cornell.edu.proxy.lib.sfu.ca/bna/species/001. doi:10.2173/bna.1. Accessed 15 Nov 2012

McKinney ML (2002) Urbanization, biodiversity and conservation. Bioscience 52:883–890

McMillin SC, Hosea RC, Finlayson BF, Cypher BL, Mekebri A (2008) Anticoagulant rodenticide exposure in an urban population of the San Joaquin kit fox. Proc Vertebr Pest Conf 23:163–165

Merson MH, Byers RE, Kaukeinen DE (1984) Residues of the rodenticide brodifacoum in voles and raptors after orchard treatment. J Wildl Manag 48:212–216

Metro Vancouver (2008) Metro Vancouver http://www.metrovancouver.org/Pages/default.aspx. Accessed 29 Sept 2008

Morris WI (1973) Rats in the diet of the barn owl (Tyto alba). Notes Mammal Soc 39:540–545

Murray M (2011) Anticoagulant rodenticide exposure and toxicosis in four species of birds of prey presented to a wildlife clinic in Massachusetts, 2006–2010. J Zoo Wildl Med 42:88–97

Nagorsen DW (1996) Opossums and shrews and moles of British Columbia. University of British Columbia Press, Vancouver

Nagorsen DW (2005) Rodents and lagomorphs of British Columbia. University of Washington Press, Seattle

Newsome SD, Park JS, Henry BW, Holden A, Fogel ML, Linthicum J, Chu V, Hooper K (2010) Polybrominated diphenyl ether (PBDE) levels in peregrine falcon (Falco peregrinus) eggs from California correlate with diet and human population density. Environ Sci Technol 4:5248–5255

North MEA, Teversham JM (1983) The vegetation of the flood plains of the Lower Fraser, Serpentine and Nicomekl rivers, 1859 to 1890. Syesis 17:47–66

Raczynski J, Ruprecht AL (1974) The effect of digestion on osteological composition of owl pellets. Acta Ornithol 14:25–38

Riley SPD, Bromley Poppenga CRH, Uzai FA, Whited L, Sauvajot RM (2007) Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. J Wildl Manag 71:1874–1884

Salvati L, Ranazzi L, Manganaro A (2002) Habitat preferences, breeding success, and diet of the barn owl (*Tyto alba*) in Rome: urban versus rural territories. J Raptor Res 36:224–228

Steenhof K, Kochert MN (1988) Dietary responses of three raptor species to changing prey densities in a natural environment. J Anim Ecol 57:37–48

Stone WB, Okoniewski JC, Stedelin JR (1999) Poisoning of wildlife with anticoagulant rodenticides in New York. J Wildl Dis 35:187–193

Storen J (2011) British Columbia in 2036, People 2036. BC Stats. http://www.bcstats.gov.bc.ca/StatisticsBySubject/Demography/PopulationProjections.aspx. Accessed 31 March 2013

Taitt MJ, Gipps JHW, Krebs CJ, Dundjerski Z (1981) The effect of extra food and cover on declining populations of *Microtus townsendii*. Can J Zool 59:1593–1599

Taylor IR (1994) Barn owls. Predator–prey relationships and conservation. Cambridge Univ, Press, Cambridge

Teta P, Hercolini C, Cueto G (2012) Variation in the diet of western barn owls (*Tyto alba*) along an urban–rural gradient. Wilson J Ornithol 124:589–596

Thomas PJ, Mineau P, Shore RF, Champoux L, Martin PA, Wilson LK, Fitzgerald G, Elliott JE (2011) Second generation anticoagulant rodenticides in predatory birds: probabilistic characterisation of toxic liver concentrations and implications for predatory bird populations in Canada. Environ Int 37:914–920

Van Metre PC, Mahler BJ, Furlong ET (2000) Urban sprawl leaves its PAH signature. Environ Sci Technol 34:4064–4070

Walker LA, Turk A, Long SM, Wienburg CL, Best J, Shore RF (2008) Second generation anticoagulant rodenticides in tawny owls (*Strix aluco*) from Great Britain. Sci Total Environ 392:93–98

Walker LA, Chaplow JS, Llewellyn NR, Pereira MG, Potter ED, Sainsbury AW, Shore RF (2012) PBMS report on rodenticides https://wiki.ceh.ac.uk/download/attachments/134414860/PBMS_Rodenticide_2011_FINAL.pdf?version=1&modificationDate=1361181795000. Accessed Sept 15 2013

Webster JA (1973) Seasonal variation in mammal contents of barn owl castings. Bird Study 20:185–196