Managing Zone-of-Influence Effects of Oil and Gas Activities on Terrestrial Wildlife and Habitats in British Columbia

Discussion Paper

Steven F. ***Wilson****, EcoLogic Research*

Abstract

A "zone of influence" is the difference between an anthropogenic activity's spatial footprint and the extent of the activity's effects on surrounding habitat and wildlife. This article reviews studies that have measured zones of influence for site-level activities that are relevant to oil and gas activities in British Columbia in order to inform the development of policies and procedures to manage their effects on terrestrial habitats and wildlife. Creation of edges, as well as noise and activity associated with industrial sites and roads, are the major stressors that generate zones of influence. These stressors create cascading effects that can result in altered ecosystems through a variety of mechanisms. Stressors can create abiotic and floristic effects that generally extend < 100 m into surrounding intact habitat, but effects on wildlife can extend up to 5 km and sometimes farther. Mitigating stressors at their source should reduce zones of influence and the need to apply management buffers to separate industrial activities from ecological resources.

KEYWORDS: edge effects; oil and gas development; sensory disturbance; zones of influence

Introduction

Oil and gas exploration and development is a dominant land use in northeast British Columbia. The effects of industrial development on ecosystems that are common to the Northeast have been the focus of extensive research. Venier et al. (2014) reviewed > 600 studies that examined effects caused by habitat conversion, changes to forest age and patch size distributions, expanding road systems, and a variety of other human-caused alterations that vary in scope and persistence. Declines in species' abundance and range contractions have been correlated with the extent of these ecosystem changes (Robinson et al. 2010, Venier et al. 2014, Jones et al. 2015). Because effects on terrestrial wildlife can occur at multiple spatial scales, mitigating effects of industrial development requires scale-specific management responses.

Regulation of oil and gas activities in British Columbia is tied directly to land tenure. At the landscape scale, tenuring for exploration and development is prohibited or restricted in some areas (e.g., parks) to protect a variety of values. At the site level, permitted boundaries define areas where proponents are allowed to conduct specific activities. In

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only some circumstances (i.e., water consumption or redirection, as well as the release of deleterious substances into air and water) do regulations recognize that effects of projects may occur outside their direct footprints.

Reviewed in this article is the potential for site-level oil and gas activities to affect wildlife and habitats beyond project boundaries, as well as mitigation measures for managing these zones of influence.

Methods

A "zone of influence" is the difference between an anthropogenic activity's spatial footprint and the extent of the activity's effects on surrounding habitat and wildlife. Available scientific literature related to zones of influence on wildlife and habitats was reviewed; in particular, studies of differences in abiotic or habitat characteristics, habitat use by wildlife, species' abundance, species richness, and reproductive success at distances from industrial activity or similar disturbances. The review focused on site-level effects rather than on landscape-level effects (e.g., road density [e.g., Boulanger and Stenhouse 2014], well site density [e.g., Hethcoat & Chalfoun 2015], and habitat fragmentation [e.g., Saunders et al. 1991]) because landscape-level effects and mitigation measures have been discussed extensively elsewhere (e.g., Gilbert & Chalfoun 2011, Environment Canada 2012, Thomas et al. 2014).

Included in this study were reviews and meta-analyses from boreal and temperate ecosystems that addressed oil and gas development and other industrial activities with similar effects. Research that specifically addressed species and habitats associated with hydro-riparian ecosystems was omitted because oil and gas activities near these features are already regulated by management zones and practice requirements (BC Oil and Gas Commission 2015).

The article summarizes available research results regarding the extent of zones of influence of different activities, develops a conceptual framework to classify and characterize potential effects, and summarizes management actions to mitigate zones of influence.

Summary of research

Research on zone-of-influence effects on wildlife and habitat can be grouped into two major categories:

1. effects resulting from noise and/or activity associated with roads and industrial activities; or
2. effects on biotic and abiotic conditions that penetrate into surrounding intact ecosystems from edges associated with roads or industrial sites.

Light pollution may also be a stressor associated with oil and gas activity; however, assessments of these effects independent of the confounding factors of noise and activity have not been conducted (Jones et al. 2015). In a rare study of effect size, de Molenaar et al. (2006) found that road lighting reduced breeding bird density at distances of up to 300 m. Artificial lighting can have a variety of physiological and behavioural effects on many taxa, but understanding is limited, particularly in field situations (Longcore & Rich 2004). As a result, light pollution was on considered further in the review or framework.

Noise and activity

The effects of noise on wildlife have been studied extensively in laboratory and field settings, but no general framework for estimating effects has yet emerged (Francis & Barber 2013). Laboratory results are not applicable because experiments often involve noise intensities and durations that are uncommon in field settings (U.S. Environmental Protection Agency 1980), and animals cannot respond behaviourally by moving away from stimuli.

Field studies have used a variety of experimental designs to identify noise effects on wildlife species (e.g., U.S. Environmental Protection Agency 1980, Bowles 1995, Kaseloo 2005, Barber et al. 2009, Francis & Barber 2013). Birds and ungulates have been the focus of most research on terrestrial species due to their visibility and abundance. Documented effects have been variable because noise is difficult to characterize in field situations due to variations in the physical environment (e.g., wind, temperature, physical barriers, vegetation), as well as variation among species (e.g., hearing capability) and individuals (e.g., age, sex, group size, experience with stimulus). Many studies have failed to control for other confounding effects, such as the visual stimuli associated with noise (i.e., vehicles), habitat differences, and altered predator-prey communities (Reijnen et al. 1995, 1996, Kaseloo 2005, Barber et al. 2009, Ortega 2012).

Field studies of birds have commonly involved assessing differences in densities at various distances from roads. Effects have been detected 2–3.5 km from multi-lane highways (Kaseloo 2005) and at low ambient noise levels (42–48 dBA) (Forman & Alexander 1998). Kaseloo (2005) concluded that sound levels above 50 dBA could be "potentially deleterious" and that effect distances averaged 1000 m. Forman et al. (2002) found that breeding bird densities and breeding success were lower within 1200 m of roads that had very high traffic volumes (> 30,000 vehicles/day).

Bayne et al. (2008) found that bird densities were 1.5 times higher near oil and gas well pads, which are associated with little noise, than near compressor stations, which produce 75–90 dBA. Greater Sage-Grouse (*Centrocercus urophasianus*) lek attendance by males declined by 29% and 73% when exposed to experimental drilling and road noise, respectively (Blickley et al. 2012). The authors speculated that the intermittent noise of roads, or perhaps the association of road noise with dangerous vehicle traffic, was responsible for the difference.

Lower reproductive success can also be a consequence of noise exposure (Foppen & Reijnen 1994, Halfwerk et al. 2011). For example, pairing success of Ovenbirds (*Seiurus aurocapilla*) was lower near compressor stations than near well pads (Habib et al. 2007). The assumed mechanism was "masking," in which noise affects bird calls and disrupts breeding behaviour (Klump 1996, Barber et al. 2009). This suggests that apparently habituated individuals remaining near noisy sites may still be subject to fitness consequences, although some species have been shown to shift song frequencies to compensate (Ortega 2012).

Francis et al. (2009) found lower species richness but higher nest success for birds that remained near compressor stations compared to gas wells. This suggests that elevated noise can also have more nuanced effects; while most species shifted their use away from the noisy sites, some species were able to exploit the change in community structure and increase their nesting success (Barber et al. 2009).

Although the response of ungulates to noise has been studied extensively, most work has involved observing the behaviour of individuals to overflights of fixed-wing aircraft or helicopters. Most of these studies confound the effects of noise with the visual stimulus of an aircraft (e.g., Côté 1996, Goldstein et al. 2005), and those that have examined these effects separately have produced equivocal results (Frid 2003, Cadsand 2012). There is only weak evidence for habituation or sensitization to repeated exposure (Stankowich 2008, Côté et al. 2013). Animal responses likely depend on the intensity of the perceived threat rather than on the noise intensity (Barber et al. 2009).

Studies have detected avoidance of human-related infrastructure by some ungulates (e.g., caribou and reindeer [*Rangifer tarandus*] [Environment Canada 2011], and pronghorn [*Antilocapra americana*] [(Beckmann et al. 2012] but not others (e.g., white-tailed deer [*Odocoileus virginianus*] [Polfus & Krausman 2012]). Again, these studies have not isolated noise effects from other potential stressors of human-related activity. Few studies have linked human-related disturbance to population declines (Hebblewhite 2011, Johnson & St-Laurent 2011).

Edge effects

Edge effects are the result of interactions between adjacent ecosystems (Saunders et al. 1991). Anthropogenic edges are created when habitat is cleared or altered, which results in adjacent ecosystems where originally there was only one. The resulting interactions can cause a series of abiotic and subsequent biotic changes that penetrate some distance from the new edge (Harris 1984, Murcia 1995). Both the contrast between the adjacent ecosystems and the permanence of the edge influence the magnitude and distance of effects (Kremsater & Bunnell 1999).

As with noise research, a common analytical framework to both characterize edges and measure their effects is lacking (Murcia 1995, Laurance et al. 2001, Cadenasso et al. 2003**,** Ries et al. 2004). This has led to a series of studies with inadequate or no replication to address confounding effects, and differences in methods that make comparisons among studies difficult (Murcia 1995).

Cleared or altered areas generally allow more solar radiation to reach the ground during the day and more to re-radiate to the atmosphere at night. This results in larger temperature and moisture gradients and higher variances near edges than in interior conditions. Where studied, differences in variables such as air temperature, air and soil moisture, and light intensity have been estimated to extend from 30 m to > 240 m of forest edges (Chen et al. 1995), although most studies have reported distances of < 100 m (Murcia 1995, Avon et al. 2010, Thomas et al. 2014). Effect distances vary among response variables and are particularly sensitive to edge orientation and weather (Chen et al. 1995, Murcia 1995).

Abiotic changes (e.g., temperature, wind, humidity) in areas adjacent to edges directly affect biotic processes such as plant desiccation, growth rates, and windthrow, but these effects can be complex. For example, forest edges might be associated with higher tree mortality rates but also higher rates of seedling establishment (Chen et al. 1992). This can lead to effects that do not decay monotonically with greater distances from edge but more complex "competition-induced waves of biomass" (Sprugel 1984, Reichman et al. 1993).

Introduction of invasive plants can occur where edge habitat is associated with human activities that facilitate the movement of seeds or other propagules (e.g., vehicles and road edges). Studies have demonstrated consistently that human-caused alterations of native ecosystems result in higher rates of invasion by non-natives (Evangelista et al. 2011).

With regard to animals, responses at distances from edges become more difficult to generalize than those of plants, with the numerical response of some species being positive and others negative, and sometimes but not always associated with corresponding changes in species richness or other measures of overall community structure. For example, Bayne and Dale (2011) reviewed 25 studies that compared songbird abundance between areas "near" and those "far" from edges created by energy sector activities and found that 10 species showed "typically negative responses to edge" while six showed "occasional negative responses to edge." Machtans (2006) found that in general, bird communities in boreal forests did not respond dramatically to the cutting of 6-m seismic lines, but Ovenbirds specifically moved their territories away from newly cut lines, declined in abundance, and were not observed crossing lines.

Many studies have correlated habitat use by mammals, bird density, and reproductive success with distances from edges created by linear features (Robinson et al. 2010) or by infrastructure in general (Benítiz-López et al. 2010). Fewer studies have controlled for the noise and activity associated with different types of infrastructure. Reported effect distances generally vary between 0 m and 5000 m, depending on species and feature type, but can extend farther (e.g., 14 km for barren-ground caribou [*Rangifer tarandus groenlandicus*]) (Boulanger et al. 2012). In general, large-bodied mammals with large home ranges in open habitats exhibit the largest avoidance distances, while density or reproductive effects on birds are limited to approximately 1 km (Benítez-López et al. 2010). Individuals can also differ in their response. For example, Johnson et al. (2015) found that different woodland caribou herds were not consistent in their avoidance of different types of infrastructure.

Increased mortality rates of wildlife have also been linked to areas adjacent to anthropogenic edges, either as a result of changes in predator abundance and/or predator efficiency in modified habitats (e.g., Paton 1994, Flaspohler et al. 2001, Malt & Lank 2009, Hethcoat & Chalfoun 2015), or as a result of increasing proximity to humans and resulting increases in hunting success (e.g., elk [*Cervus elaphus*] [Gratson & Whitman 2000], grizzly bears [*Ursus arctos*] [Mattson et al. 2002]). Most of these effects have been studied in relation to roads (Robinson et al. 2010).

Summarizing maximum reported zones of influence illustrates the extent of variability among systems (Table 1).

Table 1. Summary of selected literature that relates development activities to maximum zone-of-influence effects for terrestrial wildlife and temperate or boreal ecosystems.

Stressor	Proximate effects and outcomes	Maximum estimated radius of zone of influence (m)	References	Notes
Creation of edges	Changes in light, temperature, moisture in temperate forests	> 240	Chen et al. (1995)	Review of available literature for temperate and tropical forests found effects generally extended < 50 m (Murcia 1995), which has been corroborated by more recent studies (e.g., Avon et al. 2010)
	Vegetation characteristic changes in temperate forests	56	Murcia (1995)	Review of available literature for temperate and tropical forests
	Non-vascular plant changes in boreal forests	50	Moen & Gunnar Jonsson (2003), Hylander (2005), Esseen & Renhom (1998)	

Table 1. (continued)

Stressor	Proximate effects and outcomes	Maximum estimated radius of zone of influence (m)	References	Notes
	Structure and composition changes in mixed-wood boreal forests	60	Harper & Macdonald (2002)	
	Structure and composition changes among various forest types	< 100	Harper et al. (2005)	Review of 44 published studies
	Changes in songbird density in temperate deciduous forest	60	Kroodsma (1982)	Measured next to a powerline corridor, presumably without appreciable noise or activity
	Changes in avian nest success in forests and mixed habitats	50	Paton (1994)	Review of 26 papers focused on predation and brood parasitism of natural and artificial nests
	Changes in avian nest success in temperate forests	300	Flaspohler et al. (2001)	
Noise and activity	Avoidance of roads and single-bore and multi-bore well pads by grassland birds	350	Thompson et al. (2015)	Varied by species; largest avoidance distances for single-bore well pads
	Bird abundance changes in grassland and woodlands	3530	Kaseloo (2005)	Review of 19 studies; largest distances for grassland birds near highways with high traffic volumes
	Songbird abundance changes in boreal forest	700	Bayne et al. (2008)	Based on noise from compressor stations
	Grizzly and black bears avoidance of roads in interior wet belt forests	914	Kasworm & Manley (1990)	

Table 1. (continued)

Stressor	Proximate effects and outcomes	Maximum estimated radius of zone of influence (m)	References	Notes
	Ungulate avoidance of well sites	2000	Hebblewhite (2011)	Review of 8 studies
	Ungulate avoidance of roads	2700	Hebblewhite (2011)	Review of 8 studies
All	Bird responses to infrastructure in a variety of habitats	1000	Benítez-López et al. (2010)	Meta-analysis of studies related to 201 species
	Woodland bird responses in temperate forests near roads	800	Forman & Deblinger (2000)	Both edge and noise effects
	Mammal responses to infrastructure in a variety of habitats	5000	Benítez-López et al. (2010)	Meta-analysis of studies related to 33 species
	Boreal ecotype caribou responses to anthropogenic footprint	500	Environment Canada (2012)	Recommendation based on relevant literature
	Northern ecotype caribou avoidance of infrastructure	4250	Polfus et al. (2011), Johnson et al. (2015)	Highest for oil and gas features in South Peace region of British Columbia, as low as 1000 m for roads

Conceptual Framework

Zone-of-influence effects can be hypothesized in relation to causal relationships among anthropogenic stressors, proximate effects, and outcomes (Figure 1). Anthropogenic stressors are characteristics of development activities that can have negative effects on wildlife or habitats, and, as noted above, can be categorized into two main classes:

1. creation of edges, which result in abiotic and biotic changes that penetrate into adjacent ecosystems. Edges can be characterized by their contrast and permanence (Kremsater and Bunnell 1999); and
2. noise and activity, which alter the behaviour of some wildlife species without directly affecting components of their habitat. Noise intensity is characterized by its amplitude and frequency profile (Blickley and Patricelli 2010), and both noise and activity vary in duration, timing, and context (e.g., Frid 2003, Blickley and Patricelli 2010).

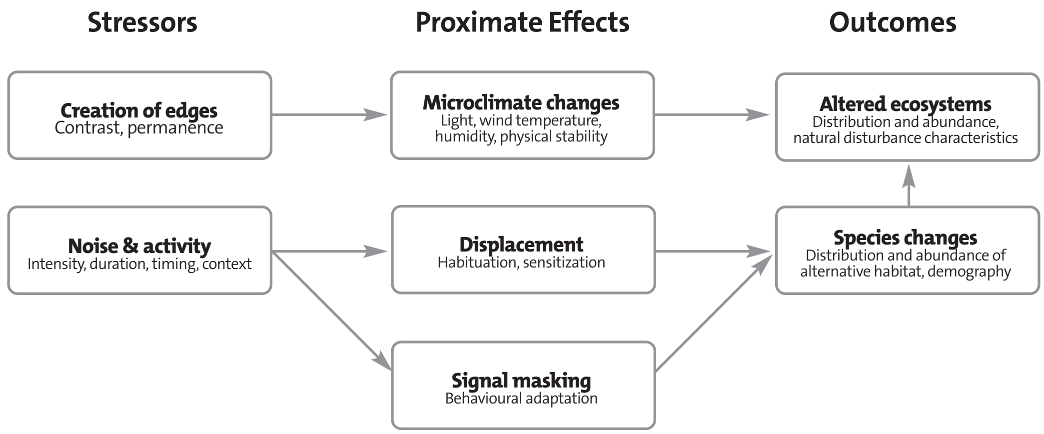

Figure 1. Conceptual framework of zone-of-influence effects characterized by potential anthropogenic stressors generated by oil and gas activities and their possible causal effects on wildlife and habitat.

These stressors, either independently or collectively, can generate the following proximate effects:

1. microclimate changes – physical changes to the environment that can favour some species over others. Effects depend on factors such as changes in light, wind, temperature, humidity, or other ambient characteristics that alter growing conditions for plants or residences of animals (e.g., Chen et al. 1995, Murcia 1995).
2. mortality – through both direct (e.g., desiccation, physical injury [Chen et al. 1992, Murcia 1995]) and indirect (e.g., nest predation [Paton 1994]) mechanisms.
3. displacement – temporary or permanent abandonment of preferred habitats by individuals, which may be affected by habituation or sensitization to stressors (Stankowich 2008).
4. signal masking – reduced audibility of important cues used by some wildlife species for breeding or anti-predator behaviour (Barber et al. 2009).

These proximate effects lead to changes in population densities, species composition, and ultimately, altered (e.g., Venier et al. 2014).

Mitigation Measures

Two general strategies can be used to mitigate zones of influence and reduce potential effects on important ecological features:

1. on-site mitigation measures, which are actions taken on permitted areas to reduce the size of zones of influence; and
2. application of a management buffer around an ecological feature, within which activity is restricted or prohibited, and which thereby separates activities from ecological features in order to reduce potential effects.

The effects of a stressor decline with distance, although the shape of the effect curve, the slope, and the intercept depend on the type of stressor, mitigating factors, and responses of species and ecosystems. Without on-site mitigation, management buffers can be applied to ecological features to reduce the risk of the stressor having an unacceptable effect. But implementing on-site mitigation can potentially reduce the size of the buffer, or perhaps even eliminate the need for one, depending on the effectiveness of the mitigation (e.g., Francis et al. 2011) (Figure 2).

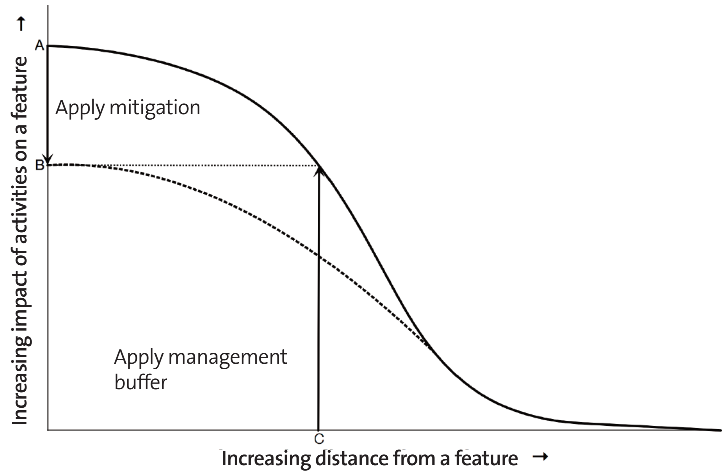

Figure 2. Hypothetical benefit of on-site mitigation and management buffers. Reducing effects from A to B can be achieved by applying on-site mitigation (to shift from the solid curve to the dashed) or by applying a management buffer of distance C. The shape of the effect curve and the relative benefits of mitigation measures and management buffers will vary for different activities

A number of on-site mitigation measures could be used to address both noise and activity stressors as well as effects resulting from anthropogenic edges. Not all mitigation measures are suitable or required for different types of activity (Table 2).

Table 2. Potential on-site actions to mitigate oil and gas activities that generate zones of influence.

Stressors	On-site mitigation	Relevant infrastructure	Relevant activities	Target wildlife and habitat	Examples of actions
Noise and activity	Noise abatement	Compressor stations, gas plants, other facilities	Construction, operation	Breeding birds and mammals	Silencers, walls, sheds
	Timing restrictions	Roads, well sites, facilities	Construction, maintenance, operation	Breeding birds and mammals	Seasonal or time of day prohibitions
Edge effects	Minimum disturbance techniques	Roads, pipelines, wells, facilities	Construction, maintenance	Rare and sensitive ecosystems, protected wildlife habitat	Minimizing disturbed area (relative edge length), hand-cutting and tree retention (edge contrast), revegetation, winter construction (less soil disturbance)
	Invasive species control	Roads, pipelines, wells, facilities	Construction, operation maintenance	Rare and sensitive ecosystems, protected wildlife habitat	Machinery cleaning and transport guidelines, herbicides, reseeding

Application

Mitigating effects by requiring on-site actions or by applying management buffers involves different trade-offs. On-site mitigation can increase costs for project proponents, while application of management buffers can increase opportunity costs by limiting development. A mix of both strategies can be appropriate. For example, timing restrictions during critical periods might address effects of some stressors associated with relatively large zones of influence (e.g., noise and breeding birds), but management buffers might still be required to manage effects of stressors with smaller zones of influence (e.g., biotic and abiotic changes due to creation of anthropogenic edges).

An important management consideration is the level of acceptable impact. A decision to avoid all potential effects would require more aggressive on-site mitigation and/or relatively large management buffers. But a zone of influence does not imply a total loss of habitat (Hebblewhite 2011). Effects are not uniform throughout zones, and while measurable, they might be acceptable to decision-makers, considering the multiple values being balanced by a management decision.

Limitations

Prohibiting or limiting activity within management buffers can be an effective strategy for discrete features (e.g., a nest colony, hibernaculum, sensitive ecosystems), but less so for wide-ranging species or more dispersed guilds, communities, or common habitats that are nonetheless important for maintaining general biodiversity. In these instances, zones of influence can be used to estimate the cumulative landscape effect of industrial activity. Effects can then be reduced by use of on-site mitigation measures (e.g., Francis et al. 2011) or by altering the density or configuration of activities through broader landscape-level objectives (e.g., Gilbert & Chalfoun 2011, Environment Canada 2012, Thomas et al. 2014).

The effects on ecological systems of edge creation, noise, and activity have been the focus of significant research, but the lack of a common analytical framework among studies has contributed to the lack of a consensus on effects (e.g., Yahner 1988, Paton 1994, Murcia 1995, Parker et al. 2005, Frances & Barber 2013), and most research has necessarily focused on correlations rather than on isolating and testing causal mechanisms. In addition, effects are influenced by many factors (e.g., Chen et al. 1995) and species (e.g., Thompson et al. 2015), as well as groups or individuals within species (e.g., Johnson et al. 2015) can vary in their responses. Some species can also benefit from the ecological niche vacated by others (Francis et al. 2009), and some might exhibit apparent habituation but suffer lower fitness (e.g., Habib et al. 2007).

Despite variation in results and the paucity of research that has examined causal mechanisms, there are some general conclusions that emerge. Specifically, studies that have examined abiotic and floristic changes resulting from the creation of edges suggest that changes generally penetrate < 100 m into surrounding native ecosystems, but effects on wildlife populations extend much farther: effects on birds can reach 1 km, while effects on wide-ranging mammals can extend to about 5 km or farther in some circumstances (Benítez-López et al. 2010, Boulanger et al. 2012).

Managing effects of oil and gas activities requires application of management actions at multiple scales. While mitigating zones of influence addresses site-level concerns, integration with landscape-level approaches is required to address the issue comprehensively.

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Author information

Steven F. Wilson, EcoLogic Research, 302-99 Chapel Street, Nanaimo, BC V9R 5H3. Email: steven.wilson @ecologicresearch.ca