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Cumulative Impacts of Natural Resource Development on Ecosystems and Wildlife:

An Annotated Bibliography for British Columbia

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ABSTRACT

Natural resource activities at different spatial and temporal scales have cumulative effects on ecosystems and biodiversity that are not yet thoroughly understood. There is currently little information about the baseline conditions or ecological thresholds of ecosystems and how cumulative impacts affect ecosystem resilience. Nevertheless, projects regulated by the *Canadian Environmental Assessment Act* have been required to "consider" cumulative environmental effects since 1992 even though established communities of practice to address these impacts are lacking within the realms of research, policy, and natural resource management. This bibliography constitutes an initial step within a longer-term Forrex planning process to properly address extension needs concerning the cumulative impacts of natural resource development on ecosystems and wildlife. It does not represent an exhaustive list of research related to cumulative impacts, but instead draws on selected work from multiple disciplines and sectors to provide a holistic and critical view of impacts relevant to British Columbia's ecosystems. The bibliography is organized by resource sector and includes forestry, rangeland and grazing, agriculture and wineries, mining, oil and gas, water development, fisheries, urban and rural development, transportation and utility corridors, and recreation. This is followed by a section that organizes sources by a wildlife, ecosystem, or general approach to cumulative effects and concludes with a discussion of identified knowledge and research gaps together with recommendations for developing assessment guidelines of cumulative impacts for the province's natural resource sector. This bibliography illustrates the diversity of cumulative effects approaches, the breath of potential impacts, and the complexity of interactions that occur within a shared land base.

KEYWORDS: *biodiversity, criteria and indicators, cumulative effects, cumulative impacts, ecosystems, modelling, monitoring, natural resource development, wildlife.*

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LIST OF ACRONYMS

ALCES®	A Landscape Cumulative Effects Simulator
ATV	All-Terrain Vehicles
CCME	Canadian Council of Ministers of the Environment
DNA	Deoxyribonucleic acid
EPA	United States Environmental Protection Agency
GIS	Geographic Information System
NEPA	*United States National Environmental Policy Act*
OHV	Off-Highway Vehicle

CONTENTS

1 INTRODUCTION

The terms "cumulative impacts" and "cumulative effects" are both used to describe spatially or temporally accumulated changes that result from the perturbations of one or more resource sector activities. These changes may be positive or negative and endured by any number of wildlife and ecosystem elements in a manner that may be additive or synergistic, direct or indirect, continuous or sporadic. The cumulative impacts of natural resource development on ecosystems and wildlife are not yet thoroughly understood. There is currently little information about the baseline conditions or ecological thresholds of ecosystems and how cumulative impacts affect ecosystem resilience. Nevertheless, projects regulated by the *Canadian Environmental Assessment Act* have been required to "consider" cumulative environmental effects since 1992 even though established communities of practice to address these impacts are lacking within the realms of research, policy, and natural resource management.

Several reports have acknowledged our lack of methods and measures to address cumulative impacts and have highlighted the need to address this emerging issue. Some sources of information that led up to the initiation of this bibliography include:

- Austin, M.A., D.A. Buffett, D.J. Nicolson, G.G.E. Scudder, and V. Stevens (editors). 2008. Taking nature's pulse: The status of biodiversity in British Columbia. Biodiversity BC, Victoria, BC. ***www.biodiversitybc.org***
- Hollstedt, C. 2008. Forest Science Board/Forrex: British Columbia Provincial Forest Extension Program Business Plan 2008–2011. Forrex, Kamloops, BC. Unpublished.
- Forest Science Board. 2006. Sustainability Program Research Strategy 2006–2016. Forest Investment Account–Forest Science Program. ***www.fia-fsp.ca/d-comm-su-SPACst-24Sep06.pdf***
- Minutes of the Forrex Board Think Tank 2008 meeting. Unpublished.
- Forrex Team 2007 Work Planning Session Report. Unpublished.

A recent survey on biodiversity threats in British Columbia[1] identified impacts from natural resource activities (e.g., agriculture, forestry, urban and rural development, transportation and utility corridors, water development, and oil and gas), together with climate change, as elements of highest concern to biodiversity in the province. A need therefore exists to increase awareness and knowledge about the cumulative impacts on ecosystems and biodiversity arising from the activities listed above as well as those associated with grazing and other range uses, agriculture and wineries, mining, fisheries, recreation, and other resource-based undertakings. In its 2009–2014 Extension Plan, the Forrex Ecosystem Management and Conservation Biology cluster responded to the lack of knowledge and standard practice in this area by targeting cumulative impacts on British Columbia's ecosystems and biodiversity as one of its priority areas of focus. Cumulative effects are also considered in the new Forrex 2009–2014 Strategic Plan.

This bibliography constitutes an initial step within a longer-term planning process to properly address extension needs about the cumulative impacts of natural resource development on ecosystems and wildlife. It does not, however, represent an exhaustive list of research related to cumulative impacts. For instance, anthropogenic climate change, although acknowledged as one of the major cumulative impacts of human development, is not considered in this report because of the vast and abundant scientific information currently available on this topic. We instead draw on selected work from multiple disciplines and sectors to provide a holistic and critical view of natural resource-related impacts of relevance to British Columbia's ecosystems.

[1] Long, B. 2007. Biodiversity safety net gap analysis. Biodiversity BC, Victoria, BC. ***www.biodiversitybc.org***

2 SCOPE, OBJECTIVES, AND METHODS

Natural resource managers and decision makers in British Columbia are the targeted audience of this publication. The objectives of this annotated bibliography are to:

- Increase awareness of cumulative impacts from natural resource development on ecosystems and biodiversity;
- Increase access to available research, projects, studies, initiatives, and existing working groups in the area of cumulative impacts within various natural resource development sectors; and
- Identify knowledge gaps and key concepts to support the development of a community of practice for cumulative impacts.

We based the selection of information sources for this annotated bibliography on Forrex Partner guidance and searches of both the Internet and provincial libraries. Our goal was to include a wide range of information without becoming repetitive. We employed numerous combinations of terms using ***Scirus.net*** and ***Google™ Scholar*** as the primary basis of Internet searches. We were also guided by references from the annotated sources themselves, and searched the ***ISI Web of Knowledge℠*** to help fill in gaps and expand the search on some topics. Finally, guidance from the reviewers of this manuscript also led to the addition of a number of valuable insights and annotations.

Although a plethora of theoretical and practical information is available on traditional environmental impact assessments, this information is generally limited to single projects before operation. Instead, our focus here is on theories and methodologies that go beyond this traditional view and increase our understanding of cumulative (rather than individual) impacts. In accordance with the cited literature, the terms "cumulative impacts" and "cumulative effects" are used interchangeably throughout this publication.

The next section is organized by resource sector and includes forestry, rangeland and grazing, agriculture and wineries, mining, oil and gas, water development, fisheries, urban and rural development, transportation and utility corridors, and recreation. This is followed by a section that organizes sources by a wildlife, ecosystem, or general approach to cumulative effects. The report concludes with a discussion of identified knowledge and research gaps together with recommendations for developing assessment guidelines of cumulative impacts for the province's natural resource sector.

3 SECTOR-BASED CUMULATIVE IMPACT STUDIES

The individual sector studies included here provide background integral to understanding the cumulative impacts approaches used in multi-sector studies. Although few examples of cumulative impacts approaches for individual sectors are available, each sector subsection in this bibliography offers information from the available literature on the various (and sometimes specific) effects of that particular sector's activities. This increases awareness of the cumulative effects by acknowledging the multitude of individual effects.

3.1 Forestry

Boyle, J.R., J.E. Warila, R.L. Besschta, M. Reiter, C.C. Chambers, W.P. Gibson, S.V. Gregory, J. Grizzel, J.C. Hagar, J.L. Li, W.C. Mccomb, T.W. Parzybok, and G. Taylor. 1997. Cumulative effects of forestry practices: An example framework for evaluation from Oregon, USA. Biomass and Bioenergy 13(4–5):223–245. *http://dx.doi.org/10.1016/S0961-9534(97)10011-3*

This article develops a framework for long-term cumulative effects evaluation in forestry using existing concepts and literature. The authors suggested approaching cumulative effects from a defined landscape-unit perspective (e.g., watershed or catchment), although these ecosystem boundaries were chosen for convenience and did not necessarily represent true natural complexity. "Scopes" of assessment are outlined to examine the cumulative effects of forestry practices on air, soils, water, aquatic organisms, and wildlife. Highlighted by conceptual diagrams of physical, biological, and chemical interactions, the framework involves maps and databases held in geographic information systems (GIS). The authors provided a step-by-step approach to: (1) define goals, indices, and landscape indicators; (2) conduct the assessment; and (3) write the final report. A useful article for both background and definitions of cumulative effects, it develops a well-outlined tool (with examples from Wilson River, Oregon) that can be applied to cumulative effects assessment within and beyond the forestry sector.

KEYWORDS: *baseline conditions, decision-making framework, forest productivity, monitoring, scale.*

D'Eon, R.G. 2007. Harvest block spatial configuration as a function of logging road density: Do larger more aggregated blocks create less road? BC Journal of Ecosystems and Management 8(1):50–60. *www.forrex.org/JEM/ISS39/vol8_no1_art4.pdf*

This article explores the relationship between harvest patch geometry and road density. Using spatial landscape-level data from southeast British Columbia, the author tests the hypothesis that long-term road densities depend on the spatial configuration (index) of forest harvest patches. Indices used in pattern analyses were core density, edge density, patch area, and the proportion of forested land. Principle component analysis and linear regression were used to test relationships between these indices and road density. Despite the seeming logic that aggregated or centralized cutblocks require less road, the author found planning and management practices limit the correlation between these variables. Minimizing the number and extent of roads should be the goal of all sectors and a potential outcome of any cumulative impact assessment. Similar analyses could also be performed for any natural resource sector using different indices. The results show relationships between sectoral practices and any physical or ecological variable.

KEYWORDS: *land use geometry, multivariate statistics, planning, road density.*

McGarigal, K., W.H. Romme, M. Crist, and E. Roworth. 2001. Cumulative effects of roads and logging on landscape structure in the San Juan Mountains, Colorado (USA). Landscape Ecology 16:327–349. ***www.springerlink.com/content/w12557624742tv77***

This article examines two pathways of effects in the forestry sector—roads and cutblocks. To analyze fragmentation, the authors developed landscape and class metrics with a combination of aerial photographs, databases, and GIS. Using measures such as edge density and patch size, the authors found that roads have a greater impact on landscape and habitat structure than do harvested areas. Predicted impact severity was also found to depend on spatial and temporal scales, with longer time scales (40 years) and intermediate spatial scales (100–10 000 ha) exhibiting the most significant habitat alterations and fragmentation effects. The authors stressed the importance of scale and assumptions/ considerations in cumulative effects assessment outcomes (e.g., calculating metrics based on total land-base versus land with suitable timber). This work elucidates factors that may complicate cumulative effects research, although acknowledging these factors can lead to more realistic assessments and management goals.

KEYWORDS: *diversity, edge effects, fragmentation, GIS, landscape indices.*

Quilty, E.J., J.S. Richardson, and T. Faramand. 2005. Assessing cumulative effects on streams using continuous water quality data, LOI Y05116. Forest Science Program, Victoria, BC. Annual Technical Report. ***www.for.gov.bc.ca/hfd/library/FIA/2005/FSP_Y051116.pdf***

This report analyzes continuous water quality variables (e.g., pH, temperature, and dissolved oxygen) as they vary diurnally, seasonally, and spatially. The variables were measured at three streams in the Interior of British Columbia between 2002 and 2004 to determine whether they could be used as chemical indicators of the cumulative effects from forest practices on stream productivity. Although the authors found that these measures were not useful in unproductive streams (such as those in the study) with pH and oxygen levels related mostly to water temperature, the results reveal some promise of using these variables as productivity measures in more naturally productive streams elsewhere. This illustrates the need to develop site or regionally specific chemical, physical, or biological measures of impacts. For instance, carbon dioxide is suggested as a potentially more relevant indicator of productivity in these streams.

KEYWORDS: *chemical indicators, monitoring, stream productivity, water quality measures.*

Shifley, S.R., F.R. Thompson III, W.D. Dijak, and Z. Fan. 2008. Forecasting landscape-scale, cumulative effects of forest management on vegetation and wildlife habitat: A case study of issues, limitations, and opportunities. Forest Ecology and Management 254:474–483.
http://dx.doi.org/10.1016/j.foreco.2007.08.030

This case study from the Ozark Highlands in the United States uses landscape disturbance and succession models in cumulative effects research and assessment. The authors employed the LANDIS model to estimate tree species presence or absence at 1- and 10-year intervals based on a set of stochastic rules and disturbances. Using GIS- and remote sensing-based forest data, a wildlife suitability model was developed and performed in conjunction with LANDIS. Although applied to primarily hardwood forests in this case, LANDIS is also of use in modelling landscape or species changes in coniferous or other forests with sufficient data, computer resources, and ability to link ecological factors of interest. The landscape model profiled here was not directly related to cumulative effects and requires further development; however, its algorithms may offer a starting point to create a cumulative effects model that integrates all the needs of such an assessment into one computer program.

KEYWORDS: *disturbance, GIS, historical records, landscape modelling, succession.*

Spies, T.A., K.N. Johnson, K.M. Burnett, J.L. Ohmann, B.C. McComb, G.H. Reeves, P. Bettinger, J.D. Kline, and B. Garber-Yonts. 2007. Cumulative ecological and socioeconomic effects of forest policies in coastal Oregon. Ecological Applications 17(1):5–17.
www.esajournals.org/doi/abs/10.1890/1051-0761%282007%29017%5B0005%3ACEASEO%5D2.0.CO%3B2?journalCode=ecap

The authors used GIS-based models to evaluate future (100 year) success of policies in forest management and biodiversity. The study area (Oregon Coast Range) has similar biological indicator species to parts of British Columbia—northern spotted owl (*Strix occidentalis*), coho salmon (*Oncorhynchus kisutch*), and lichens—but the evaluation of policy and practices is specific to Oregon. Nevertheless, the same methodology could be used to evaluate the future outcomes of any forest practice scenario. Socio-economically, the mixed ownership and wide variety of forest values over a small area has similarities to many parts of rural British Columbia. These forests require an assessment of cumulative impacts imposed by multiple interests that may not be apparent at an ownership or stand level, despite often overlapping forest values between ownership groups. Changes in edge and interior forest condition were found to result from these land-value mosaics, reducing the available (future) habitat of indicator species.

KEYWORDS: *biological indicators, GIS, land use policy, modelling, socio-economic factors.*

Sustainable Forest Management Indicator Knowledge Base. 2008. Sustainable Forest Management Research Group, University of British Columbia, Vancouver, BC. *www.sfmindicators.org*

This website project provides links to background information on the development of criteria and indicators of sustainable forest management with a British Columbia focus, as well as a searchable knowledge base. Indicators (and criteria) have the advantage of application to natural resource industries outside of the forest sector and to multiple sectors operating within the same land base (e.g., the area of forest permanently converted to non-forest land use is an indicator of species diversity). Each indicator includes rationale, history, methods, and examples; however, indicator use is limited by a lack of strict measures or thresholds.

KEYWORDS: *criteria, indicators, Internet tool, searchable knowledge base.*

US Department of Agriculture Forest Service. Cumulative effects of forest management on hillslope processes, fishery resources, and downstream environments. Pacific Southwest Research Station, Albany, CA.
www.fs.fed.us/psw/programs/cumulative_effects

This US Forest Service interdisciplinary program examines cumulative effects and linkages at a watershed scale. The program is divided into "research emphasis areas" that explore stream flow, erosion, turbidity, etc., in southern California. The project's goal is to develop forest management strategies at the "ecoscape" level, following the argument that the integral nature of management impacts on watersheds means research cannot be broken down into individual projects. The two types of studies highlighted—"component studies" and "integrative studies"—each feeds the other's objectives. Results from monitoring and measurement provide government and industry staff with methods to determine compatibility between forestry and other natural resource sectors. Although lacking any results or definitive measures or limits for the monitored variables, the website is a valuable source of detailed information on the "hows," "whats," and "whys" of watershed monitoring for cumulative impacts. Similar methods can be applied using biologically relevant measures or limits of change for sites or regions anywhere in British Columbia.

KEYWORDS: *historical data, interdisciplinary research methods, monitoring, sector compatibility, thresholds.*

3.2 Rangeland and Grazing

Burkholder, J., B. Libra, P. Weyer, S. Heathcote, D. Kolpin, P.S. Thorne, and M. Wichman. 2007. Impacts of waste from concentrated animal feeding operations on water quality. Environmental Health Perspectives 115(2):308–312. ***www.ehponline.org/members/2006/8839/8839.pdf***

This article focuses on concentrated animal feeding operations and is also relevant to open grazing and rangeland animals moved indoors to feedlots in winter. The authors found current practices in the United States ineffective at protecting water resources from microbial, nutrient, or pharmaceutical contamination associated with livestock waste management. Wastewater enters natural water systems through high rainfall, improperly designed or overflowed manure lagoons, and from intentional application to the land. The authors suggested that waste containment and disposal not be carried out near water sources or flood-prone areas. Even at low density, range and grazing operations provide an influx of chemical elements into the environment, the long-term effects of which should be avoided and any cumulative impacts evaluated. This requires that thresholds for nitrogen, ammonia, and even penicillin, be set by watershed, stream size/flow, or distance from water body. These standards should be developed using existing information and updated as new research is completed.

KEYWORDS: *livestock operation, policy and practice, waste management, water quality.*

Donker, N.T. 2001. Impacts of ungulates on rangeland dynamics in aspen-boreal ecosystems of Alberta. PhD thesis. University of Alberta, Department of Graduate Studies, Edmonton, AB.

The author engaged in controlled clipping trials of native Alberta grasses to mimic ungulate grazing under different intensities and forage yields and found that forage yields were greatest when first defoliated in May and when defoliated to a 10 cm base height. When short-duration, intense grazing was practised instead of continuous grazing, no benefit to forage production or soil quality (aeration) was evident. The author developed a preliminary computer model specifically for wapiti (*Centus elaphus*) and bison (*Bison bison*) that may lead to a pasture simulator with very practical land use applications. Pasture dynamics likely depend on both ungulate- and vegetation-specific characteristics. This type of model could be beneficial in developing species-specific guidelines for grazing in particular areas to ensure continuously productive rangelands.

KEYWORDS: *field trails, grazing intensity, modelling, native grasses.*

Fowler, S., D. Frost, and C. de Carle. 2004. Environmental and biodiversity impacts of organic farming in the hills and uplands of Wales. University of Wales, Institute of Rural Sciences, Organic Centre Wales, Aberystwyth, UK. ***http://orgprints.org/10828/1/envimpactsuplands.pdf***

This article examines the conversion from conventional to organic practices on upland sheep and cattle farms in south Wales. The authors use a "whole system" approach to define and mitigate impacts associated with organic farming on both farmed and wildlife landscape components. To compare the benefit and impact pathways of organic versus conventional husbandry practices in the Welsh uplands, the authors examined impacts on biodiversity; non-renewable resource use; and soil, air, and water quality pathways for each individual farming practice (parasite control, soil pH balancing, etc.). Although most of British Columbia's agriculture and grazing land occurs at lower elevations and ecosystems differ greatly between the regions, this report clearly discusses the pathways of impacts from various practices and suggests how wildlife impacts could be minimized. It is not really a cumulative impact assessment, however, as relations to other sectors or grazing areas over the long term are not discussed.

KEYWORDS: *impact/benefit analyses, organic farming, Welsh uplands.*

Seabrook, L., C. McAlpine, and R. Fensham. 2006. Cattle, crops, and clearing: Regional drivers of landscape change in the Brigalow Belt, Queensland, Australia, 1840–2004. Landscape and Urban Planning 78:373–385. ***http://dx.doi.org/10.1016/j.landurbplan.2005.11.007***

This article presents a conceptual framework for regional landscape management that incorporates policy, science/technology, and population, cultural and economic values. Percent forest cover is found to have a sigmoidal time trend and is used as a measure of natural and human-induced landscape changes. The dominant human activity affecting forest cover is agricultural production. In addition to the quantitative analysis of the spatial cover of plant species over time, the authors describe a qualitative analysis of links between wildlife variables (indicated by native plant species) and the temporal human development variables in a tropical region. The authors show that non-physical human actions are also drivers of landscape change, and while this is not surprising, it is possible that landscape change or cumulative environmental effects could be predicted based on principles of population or even economics.

KEYWORDS: *conceptual model, historical data, landscape theory, vegetation loss.*

Seifan, M. and R. Kadmon. 2006. Indirect effects of cattle grazing on shrub spatial pattern in a Mediterranean scrub community. Basic and Applied Ecology 7:496–506.
http://dx.doi.org/10.1016/j.baae.2005.10.004

This article proposes a conceptual model to predict impacts of grazing on shrub distribution in a water-limited system. The authors assumed shrub "clumping" to depend on breeding dynamics of adult plants and palatability of the shrubs. They tested the model using 40 years of historical data and found that shrub clumping decreased in grazed areas in exchange for more uniform shrub patterns. Since this research took place in a hot and dry environment, the results are likely only relevant to the dry interior shrubland regions of British Columbia. The impacts of the change in shrub spatial dynamics on wild animal populations are only speculative; however, less clumping could influence predation on small mammals, nesting sites for ground birds, or the energy expenditure of wild grazing animals.

KEYWORDS: *grazing preference, historical data, modelling, vegetation patterns.*

Thrift, T.M. 2006. Effects of long-term winter–spring grazing on foothill rangeland. MSc thesis. Montana State University, Animal and Range Sciences, Bozeman, MT.
http://etd.lib.montana.edu/etd/2006/thrift/ThriftT0506.pdf

The author monitored a fescue (*Festuca campestris* Rydb.) and wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve) habitat in Montana for differences in vegetation community dynamics between sites heavily or lightly grazed by elk (*Cervus elaphus*). Field sampling showed grazing influences on basal diameter, leaf height, and seedheads per plant to vary both between and within plant species. The same would be true of any plant or animal family experiencing the effects from any natural resource sector activity. This illustrates the complexity of biological systems and reinforces difficulties in accurately assessing cumulative effects. Physical processes may be more predictable. The author found that soil compaction and a thinner Ah horizon characterized the heavily grazed rangelands compared to the lightly grazed rangelands.

KEYWORDS: *biological and physical effects, domestic elk, field sampling, vegetation dynamics.*

3.3 Agriculture and Wineries

Dale, V.H. and S. Polasky. 2007. Measures of the effects of agricultural practices on ecosystem services. Ecological Economics 64(2):286–296. ***http://dx.doi.org/10.1016/j.ecolecon.2007.05.009***

The authors present a framework by which the positive and negative impacts of agriculture and ecosystem services on one another may be measured. The selection and application of agricultural practice indicators are illustrated at various spatial scales. The dynamic relationship between ecosystems and agriculture is broken down into an economic relationship of goods and services—an analysis the authors suggested was limited by the absence of direct markets for ecosystem services. Definitive examples of potential indicators and their metrics are given (e.g., concentrations of suspended sediment, nutrients, or contaminants, in streams) and, although these measures relate to agriculture and ecosystem services, many can be applied to other sectors. This article is a useful tool for indicator development in any sector and for assessments at any scale, but does not provide a means of developing threshold limits for indicators.

KEYWORDS: *agricultural chemicals, effects framework, erosion, indicators, land use.*

Freemark, K. 1995. Assessing effects of agriculture on terrestrial wildlife: Developing a hierarchical approach for the US EPA. Landscape and Urban Planning 31:99–115.
http://dx.doi.org/10.1016/0169-2046(94)01039-B

This article discusses the importance of evaluating effects from agricultural practices over a hierarchy of spatial and temporal scales. Using research from Europe and North America, illustrative diagrams, and a focus on the midwestern United States, the author stressed the importance of linking GIS mapping techniques with spatially explicit models for future development scenarios and suggested that changes in institutional practices are required to fully incorporate these approaches into management. An existing program, MASTER (Midwest Agricultural Surface/Subsurface Transport and Effects Research), is discussed. The author argued that it lacks the broad range of biological information, metapopulation dynamics, and spatial explicitness necessary for a true understanding of agricultural/environmental dynamics. Although the approach presented is more theoretical than operational, this article does shed light on the various elements usually excluded from monitoring and assessment programs. Such exclusions often limit appropriate management at different spatial levels.

KEYWORDS: *effects hierarchy, GIS, public policy, scale, spatially explicit models.*

Freemark, K. and C. Boutin. 1995. Impacts of agricultural herbicide use on terrestrial wildlife in temperate landscapes: A review with special reference to North America. Agriculture, Ecosystems and Environment 52:67–91. ***http://dx.doi.org/10.1016/0167-8809(94)00534-L***

This review article examines the long-term effects of agricultural herbicides. From a North American (Canadian) wildlife perspective, the authors review research (primarily from Europe) that shows relationships between agricultural chemicals and non-target species. Although little research has been undertaken in North America, and few studies have examined the impacts of herbicides in non-crop habitats adjoining most fields, the authors argued that the use of agricultural chemicals, particularly herbicides, has dramatically altered habitats and landscapes throughout the continent. This article provides examples of the long-term (cumulative) impacts of herbicide use (not limited to the agricultural sector) on native plants, birds, and insects. Specific indicators and limits for herbicide use could be developed and used across sectors. Herbicides included are those commonly used in Canada. Since toxicity is chemical-specific, wildlife impacts may be partially mitigated through chemical selection.

KEYWORDS: *herbicides, non-target organisms, thresholds, toxicity.*

Mahler, P.J. 1972. Agricultural development and the environment. Geoforum 3(2):53–69. http://dx.doi.org/10.1016/0016-7185(72)90041-3

This article is an early example of reference to cumulative effects, focusing on the long-term effects of agriculture and its continued intensification. The author suggested that agricultural practices interfere with ecological pathways, reducing some components and processes (insects, trace soil nutrients, native vegetation, water tables), while increasing others (chemical residues, herbivores, invasive plants, soil erosion, waste, disease). Although this article is dated and geared to developing nations, similar effects are expected anywhere that agricultural production has increased, without increases in the productive land area. This practice does offer improved conservation and simpler management, but high-density agriculture also facilitates the spread of disease and pests, concentrates wastes, and requires more water and soil nutrients. The author argued that these issues should be approached cumulatively with integrated management of various land uses. This article gives a good "list" of the processes through which agriculture may affect wildlife, but does not measure the impacts or develop indicators to do so.

KEYWORDS: *agricultural intensity, disease, integrated management, waste, water usage.*

Mulvihill, P.R. and S.H. Ali. 2007. Disaster incubation, cumulative impacts, and the urban/ex-urban/rural dynamic. Environmental Impact Assessment Review 27(4):343–358. http://dx.doi.org/10.1016/j.eiar.2007.01.003

This article examines outcomes of cumulative impacts at two different scales: (1) a local water disaster, and (2) regional landscape change. The authors suggested that disaster incubation analysis is missing from traditional environmental assessments. They argued that through the pairing of disaster-based response with cumulative impact approaches, many unnecessary and often neglected impacts, particularly those of the "urban/ex-urban/rural dynamic," can be avoided, and incremental processes identified. Examples used are lengthy and do not illustrate the theory elegantly. This sort of risk analysis may be useful, in combination with cumulative impacts approaches, to undertake realistic and complete environmental assessments; however, the approach is not well described in this article. The key example is from Walkerton, Ontario, where groundwater was contaminated with *Escherichia coli* from farm runoff. Direct urbanization is also discussed (southern Ontario) in the context of agricultural land losses and fragmented wildlife habitats.

KEYWORDS: *disaster mitigation, habitat fragmentation, risk analysis, rural corridors, water contamination.*

Schreier, H. and S. Brown. 2004. Multi-scale approaches to water management: Land-use impacts on nutrient and sediment dynamics. **In** ***Scales in hydrology and water management. I. Tchiguirinskaia, M. Bonell, and P. Hubert (editors). International Association of Hydrological Sciences, Centre for Ecology and Hydrology, Wallingford, Oxfordshire, UK. Publication No. 287, pp. 61–75. http://books.google.com/books?hl=en&lr=&id=pj5tcO_8ikIC&oi=fnd&pg=PA61&dq=Schreier,+H.+and+S.+Brown.+2004.+Multi-scale+approaches+to+water+management:+land-use+impacts+on+nutrient+and+sediment+dynamics.+Scales+in+Hydrology+and+Water+Management.&ots=1KzrOKJmvn&sig=ab3iyGWgC_N-ZXP8CbAi0uU6y9Y#v=onepage&q=&f=false***

The authors applied a mass balance nutrient and sediment model at three spatial scales (the basin, small watershed, and farmer's field) to examine excess nutrient and sediment loads from agricultural practices. Using case studies from both Canada and Nepal, the authors found that the required input data was strongly related to the scale of application. For instance, stream water quality is related to surplus fertilizer application at the scale of the farm and the intensive agricultural watershed, but not at the basin scale. This mass balance approach can be used to identify areas of concern at larger scales, but estimates will not be absolute because of the non-linear nature of the relationships. Overall, the authors found that different scales require different approaches, which is an important lesson in cumulative impact assessment of agriculture or other natural resource practices contributing to nutrient or sediment inputs. This proceedings chapter is accessible through the Google™ books link provided.

KEYWORDS: *GIS, nutrient mass balance, scale, sediment loading.*

Smith, I., K. Hall, L.M. Lavkulich, and H. Schreier. 2007. Trace metal concentrations in an intensively used agricultural watershed in British Columbia, Canada. Journal of the American Water Resources Association 43(6):1455–1467. ***http://dx.doi.org/10.1111/j.1752-1688.2007.00121.x***

The water and sediment at 17 sites on the Sumas River in British Columbia were analyzed for metals, temperature, pH, and dissolved organic carbon, to assess the impacts of agriculture (copper and zinc in animal waste) and asbestos material slides (chromium and nickel) on stream ecosystems. Results show that nickel and zinc concentrations in sediments may be used as measures of landslide and livestock density. These measures may form the chemical basis to assess the impact of landslides and livestock on river ecosystems. Additionally, bioavailable water concentrations were often below the detection limits. Animal unit equivalents provided an index to estimate agricultural impacts from bioavailable metals on aquatic organisms. Sediment metal levels were strongly related to agricultural intensity and found at concentrations above standards set to protect aquatic health. Sediment concentrations of zinc and copper may prove useful measures of agricultural impacts in other parts of British Columbia.

KEYWORDS: *animal unit equivalents, natural contaminants, nutrient enrichment, sediment, water quality.*

3.4 Mining

Cardinal Rover Coals Ltd. and TransAlta Utilities Corporation. 1997. Report of the EUB–CEAA Joint Review Panel, Cheviot Coal Project, Mountain Park Area, Alberta. Alberta Energy and Utilities Board, Calgary, AB. Copies are available from CEAA Regional Office: ***ceaa.alberta@ceaa-acee.gc.ca***

This report examines, from the viewpoints of the applicant, the interveners (the Cadomin Environmental Protection Association), and the panel, all aspects involved in a coal mine application. These include the mine's need, description, and alternatives; societal and land use effects; and terrestrial, aquatic, and atmospheric environmental effects. The most relevant to wildlife are aspects of the latter (arbitrary) grouping. The Department of Fisheries and Oceans, in particular, was concerned with the cumulative impacts of introduced "end pit lakes." The cumulative impacts on groundwater flows were not considered because these would not be expressed regionally—a point on which the panel agreed. One could argue, however, that these impacts would be experienced incrementally over time, which may be evident through continuous regional groundwater monitoring. The benefit of the application, from a cumulative-effects perspective, was that it provided certain development alternatives, despite lacking a thorough assessment of the cumulative impacts of those alternatives.

KEYWORDS: *application review, development alternatives, end pit lakes, groundwater monitoring, stream habitat.*

Donato, D.B., O. Nichols, H. Possingham, M. Moore, P.F. Ricci, and B.N. Noller. 2007. A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife. Environment International 33:974–984. ***http://dx.doi.org/10.1016/j.envint.2007.04.007***

This literature review deals with direct wildlife death from cyanide used in gold mining with reference to the United States and Australia. The authors argued that the gold industry does not adhere to cyanide guidelines, and that wildlife mortality (especially avian) is extensively under-reported. They cited difficulties in measuring cyanide levels in the field and the lack of research relating to wildlife toxicity, and recommended that facilities (particularly tailing storage facilities) be made inaccessible or unattractive to wildlife. The authors referred to biologically significant cyanide levels in relation to particular biota and discussed biologically relevant chemistry, complexes with other elements, and cyanide bioavailability. Guidelines and mitigation measures suggested in this research may be deemed useful in minimizing or characterizing the cumulative impacts associated with gold mining; however, this article recognizes knowledge gaps rather than fills them.

KEYWORDS: *best practices, cyanide toxicity, gold, wildlife mortality.*

Earthworks™ Mining Impacts. Earthworks Organization, Washington DC.
www.earthworksaction.org/EnvironmentalImpacts.cfm

Earthworks is a not-for-profit organization that arose from the work of the US Mineral Policy Center. This multi-stakeholder group based in Washington, DC, is dedicated to reforming the *1872 Mining Law*, and protecting communities and the environment from the negative effects of mineral development. The main pathways through which mining may affect wildlife include the release of toxic substances and the surface/subsurface disturbance of land. The website provides evidence of direct impacts (death) to wildlife from particular mine sites and links to reports and other mine-specific groups or alliances. Although impacts to wildlife from land disturbance may be easier to predict using habitat mapping and methods common to other resource industries, the type and extent of environmental contamination (particularly water) is unique to mining and the type of mining. This industry therefore requires development exposure metrics based on either modelled or measured indices of likely exposure and susceptibility.

KEYWORDS: *habitat disturbance, multi-stakeholder, policy reform, toxic substances.*

Independent Environmental Monitoring Agency. Agency Resource Centre. Yellowknife, NT.
www.monitoringagency.net/ResoucreCentre/tabid/57/Default.aspx

An environmental review panel process of the proposed Ekati Diamond Mine™ recommended the formation of the Independent Environmental Monitoring Agency. Launched in 1996, the organization continues as “a public watchdog.” The resource centre offers information and publications, and also contains a monitoring summary, which is relevant here because ongoing monitoring of the now fully operational mine provides a basis from which to assess cumulative effects. Monitoring is conducted for compliance (permit and licences), aquatic effects (chemistry, sediment, plankton, fish habitat, etc.) and “specific effects” (particular problem sites). A wildlife monitoring program emphasizes caribou (*Rangifer* spp.), carnivores and mammals, habitat loss, and collision mortality. Although the agency does not carry out the monitoring, it reviews the design and results of these activities carried out by government or mine operators to ensure that a full suite of parameters subject to cumulative effects is represented.

KEYWORDS: *compliance, habitat values, monitoring, water quality.*

Stiff, K. 2001. Cumulative effects assessment and sustainability: Diamond mining in the Slave Geological Province. MSc thesis. University of Waterloo, Environment and Resource Studies, Waterloo, ON.
http://uwspace.uwaterloo.ca/bitstream/10012/986/1/klstiff2001.pdf

This thesis uses four criteria based on sustainability (integrated, comprehensive, participative, and enforceable) to evaluate cumulative effects assessment techniques and to make recommendations about including cumulative effects considerations in regional planning and environmental assessment in northern Canada. After first providing background in cumulative effects theory and practice, the author then focused on two diamond mine case studies using interviews and the Cumulative Effects Practitioner’s Guide (Hegmann et al. 1999; ***see below***). The author found that the sustainability criteria were not being met when cumulative effects were incorporated into planning processes. For example, regardless of the small proportion of caribou (*Rangifer tarandus groenlandicus*) range physically occupied by a mine, the author argued that the additive and synergistic effects of northern developments, when considered cumulatively, have a much greater impact on caribou range than the mine’s footprint might indicate. Similar impacts can be expected from any open-pit mining operation. This thesis does not develop criteria or indicators for measuring cumulative effects, but it does develop criteria for evaluating effects assessments.

KEYWORDS: *assessment criteria, caribou, diamonds, northern environments, regional planning.*

United States Environmental Protection Agency. 1994. Background for NEPA reviewers: Non-coal mining operations. Office of Solid Waste, Special Waste Branch, Washington, DC. Technical Document. ***www.epa.gov/compliance/resources/policies/nepa/non-coal-mining-background-pg.pdf***

This report provides background to assist regulators in the approval process of non-coal mining proposals on federal lands in the United States. It contains a thorough section on potential environmental effects, specifies impacts to surface and ground water, air, soils, and ecosystems, and discusses appropriate mandates and measures for monitoring in each of these classifications. Regarding cumulative impacts, it recommends that combined impacts should be viewed from the perspective of the whole ecosystem, and that these impacts should be defined over the entire life of the mine. Cumulative impacts may be estimated by comparing baseline condition data and modelled/monitored data. In addition, the document suggests using federal or state guidelines for water and air quality to compare with monitoring results. Its approach to future impacts, however, is vague, as these are only defined in terms of unspecified hydrological and atmospheric models.

KEYWORDS: *acceptable change, baseline conditions, best practices, monitoring, statutory regulations.*

3.5 Oil and Gas

AXYS Environmental Consulting Ltd., Salmo Consulting Inc., Diversified Environmental Services, Paragon Environmental Consultants, Linnotek Research and Development, and RWDI West Inc. 2003. A cumulative effects assessment and management framework (CEAMF) for northeast British Columbia: Final, Volume 1. Oil and Gas Commission and the Muskwa-Kechika Advisory Board. ***www.llbc.leg.bc.ca/public/PubDocs/bcdocs/365973/CEAMF_Final_Report.pdf***

This report presents a framework for managing and assessing cumulative effects in northeast British Columbia. Under the guidance of province's Oil and Gas Commission, the framework ("Sustainable Resource Management Strategy") begins at the oil and gas application stage, limiting regional-level effects by estimating the contribution of a single project to a particular regional "threshold." Thresholds, databases, and monitoring form an integral part of "adaptive resource management," whereas a project screener and regulatory review fall within the "sector-based regulation"—both of which require regional knowledge. Although the two-ended view is useful (i.e., working down from projects and up from wildlife indicators), it is not clear how (or where) the two tracks will meet. The framework lacks any predictive spatial context and has no recommendations for setting the scale of the cumulative effects assessment beyond project site approval. Additionally, factors such as wildlife risk ratings and sensitivities are presented as classes rather than absolutes, posing difficulty in parametric analysis. See, also, ***Volume 2***, below.

KEYWORDS: *adaptive management, case studies, regional effects, thresholds, valued ecosystem components.*

Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope, National Research Council. 2003. Cumulative environmental effects of oil and gas activities on Alaska's North Slope. The National Academies Press. ***http://books.nap.edu/catalog.php?record_id=10639***

Created at the request of the US Congress, this book examines the multiple and cumulative environmental effects of past, present, and future oil and gas development on Alaska's North Slope and Arctic Ocean. Issues covered include the effects of physical structures on wildlife migration, as well as the impacts of exploration activities or hydrocarbon spills on marine, coastal, and tundra ecosystems. Identifying that unpredictable factors, such as oil markets and political agendas, have a strong influence on the location, timing, and intensity of future effects, the authors provided examples of the data and methodology required for this type of assessment. The approach presented is largely qualitative and does not necessarily represent a complete cumulative impact assessment, although the foundation and requirements for such are developed. This information has relevance for locations in the province experiencing the effects of past, present, or future proposals of oil and gas exploration and development.

KEYWORDS: *marine environments, planning, socio-economic factors, spills, tundra.*

Cumulative Environmental Management Association. Fort McMurray, AB. ***www.cemaonline.ca***

This multi-stakeholder association was formed in 2000 to confront the perceived environmental threats associated with the Alberta Oil Sands projects. It has produced hundreds of reports and eight management frameworks (including ecosystem management, land capability, and trace metals) in an effort to minimize the cumulative impacts associated with oil sands development in the regional municipality of Wood Buffalo. The frameworks (all available online) utilize traditional ecological knowledge, ecological indicators, and limits or measures. Using a combination of modelled and monitored data, each indicator is assessed within each of the frameworks. This provides an exceptional example of cumulative impacts "on-the-ground" at a multi-stakeholder level. It illustrates an approach that regions should work towards while ensuring (with appropriate review and funding) that results and recommendations are backed by quantitative scientific principles.

KEYWORDS: *indicators, landscape design, limits, pollutants, traditional knowledge.*

Cizek, P. and S. Montgomery. 2005. Cumulative effects modelling of the Mackenzie Gas Project: Scoping and development. The Canadian Arctic Resources Committee, Yellowknife, NT.
www.ngps.nt.ca/Upload/Interveners/Canadian%20Arctic%20Resources%20Committee/MGP_Development_and_Cumulative_Effects_Mapping.pdf

This report evaluates various models and predicts cumulative effects from the Mackenzie Gas Project. Maps of high, medium-high, and low-medium impact were produced using GIS and the United Nations' Environment Program's GLOBIO program to determine thresholds and wildlife "zones of impact" associated with different project activities. High-impact areas are associated with reduced bird abundance, medium-high impact corresponds to reduced mammal abundance, and low-medium impacts are expected to only cumulatively affect both flora and fauna. This methodology may be useful to determine cumulative effects of projects related to gas production and transmission. Spatial predictions of development were formulated randomly rather than from on geophysical realities, as recommended. Also, large projects such as the Mackenzie Gas Project will likely be associated with many new roads, and such linear disturbances should be included in any cumulative impact study.

KEYWORDS: *landscape simulation, pipeline, thresholds, zones of impact.*

Dogwood Initiative. 2010. Coalbed methane: Best practices for British Columbia. Victoria, BC.
http://dogwoodinitiative.org/publications/reports/coalbed-methane-best-practices-for-british-columbia

This report, produced by Dogwood Initiative, a Canadian non-profit group based in Victoria, draws on the experiences of other communities, which in many cases have incurred great environmental costs and considerable legal and political struggle, and on knowledge about the impacts of the coal-bed methane industry built up by other jurisdictions. It refers to existing developed frameworks that allow managing the range of adverse effects associated with this potentially high-risk industry while also maximizing local economic benefits. Background information on the resource extraction process is provided as well as short profiles of relevant experiences elsewhere that have spurred regulatory responses. Information on the best practices is presented in 10 key areas of coal-bed methane development, including water and air protection and cumulative impacts. The authors made a series of specific recommendations that, if adopted, would bring current provincial government policy to the level of best practices in coal-bed methane resource management. This report helps to raise the awareness among both the public and provincial legislators about the range of environmental, social, cultural, and economic aspects of coal-bed methane extraction.

KEYWORDS: *best management practices, coal-bed methane, policy, regulatory framework.*

Fisher, J.B. 2001. Environmental issues and challenges in coal bed methane production. Exponent, Inc., Tulsa, OK. Paper presented at 8th International Petroleum Environmental Conference. http://ipec.utulsa.edu/Conf2001/fisher_92.pdf

This report, presented at the 2001 IPEC conference, focuses on coal-bed methane developments in the Powder River Basin of Wyoming and Montana. Main environmental concerns revolve around issues of: water usage, disposal, and contamination; noise and air pollution; and linear/surface disturbances. Although the impact on water resources may be unique to this resource, noise and air pollution, road building, and habitat disturbance impacts are shared with other natural resource industries. The report cites landowner conflicts and lawsuits surrounding coal-bed methane development in the United States. Potential human health effects from contaminated drinking water are cited, and while wildlife would also be affected, the research is lacking. Increased salinity in irrigation water or surface water implies concentration limits should be set from a wildlife perspective. The report describes various avenues through which coal-bed methane may lead to cumulative effects; appropriate management measures and monitoring indicators can be developed from these.

KEYWORDS: *contamination, human health, limits, socio-economic factors, water resources.*

Regele, S. and J. Stark. 2000. Coal-bed methane gas development in Montana: Some biological issues. Montana Department of Environmental Quality, Industrial and Energy Minerals Bureau, Butte, MT. www.deq.state.mt.us/COALBEDMETHANE/pdf/fnl_cbm_txt3.PDF

This paper, presented at two workshops in 2000, analyzes the potential cumulative effects of developing numerous coal-bed methane wells along the Tongue River in Montana. Effects discussed include aquifer dewatering, decreased surface water availability, increased surface water flows, degraded water quality (salinity, contamination, dissolved solids, etc.), and surface disturbances. As such, coal-bed methane usage and discharge practices may have indirect impacts on agriculture, coal-mine reclamation, vegetation associated with ephemeral streams, fish, and invertebrate habitat. Particularly relevant information includes relationships between the numbers of coal-bed wells discharging water into the river and the changes in water quality. These relationships and their associated thresholds can be used to assess similar changes in British Columbia streams to prevent and/or minimize the impacts of coal-bed methane on aquatic wildlife.

KEYWORDS: *aquatic environments, operational measures, thresholds, water resources.*

Salmo Consulting Inc., Diversified Environmental Services, GAIA Consultants Inc., Forem Technologies Ltd., and AXYS Environmental Consulting. 2003. Cumulative effects indicators, thresholds and case studies: Final, Volume 2. Oil and Gas Commission and the Muskwa-Kechika Advisory Board. www.reviewboard.ca/upload/project_document/1138724528_BC%20Oil%20and%20Gas%20Commission%20Cumulative%20Effects%20Indicators%20Thresholds%20and%20Case%20Studies.pdf

Part 2 to *AXYS (2003)* described above, this document uses the Sustainable Resource Management Strategy framework and applies it to two study areas in northeast British Columbia using ecological indicators and thresholds of change. The authors narrowed the measurement field down to four "complementary" indicators relating directly to habitat and land use pathways. Other wildlife impact pathways from oil and gas development impose indicator requirements for water usage or divergence; waste stream emissions to air, land, or water; and impacts from noise, lights, and stack obstacles. Although factors such as core area and access density are related to population indices of large ungulates, these indicators oversimplify the dynamic and complex relationships that exist between the oil and gas sector and the ecological processes that form the environment within which it operates. "Core areas" may not necessarily be optimal habitat because of pollution, terrain, or forage availability for the wildlife taxon in question.

KEYWORDS: *core areas, habitat, land use, targets, tiered thresholds.*

Walker, D.A., P.J. Webber, E.F. Binnian, K.R. Everett, N.D. Lederer, E.A. Nordstrand, and M.D. Walker. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. Science 238(4828):757–761.
www.sciencemag.org/cgi/content/abstract/238/4828/757

This article looks at the combined (cumulative) impacts of multiple oil fields on Arctic tundra wildlife in Alaska, particularly in the Arctic National Wildlife Refuge. The authors give evidence of indirect impacts lagging many years behind project development with examples from the Prudhoe Bay oilfield. The most common impacts in the Arctic include flooding and thermokarst (sinking), making these areas undesirable locations for roads, wells, or permanent structures. The piled-gravel approach to structures limits melt, but causes damming and may create flooding of the land surface. The authors asked a series of questions about the natural and development history of the region, very similar to indicators of sustainable forest management. By developing regional or wildlife-specific quantitative measures for these indicators, cumulative impacts assessments may be performed. To minimize impacts on wildlife and ecosystems, the authors suggested the use of detailed "geobotanical maps" and comprehensive landscape planning.

KEYWORDS: *indirect effects, infrastructure, mapping, microclimate, permafrost.*

Western Governors' Association. 2006. Coal bed methane best management practices: A handbook. Western Governors' Association, Denver, CO.
www.westgov.org/wga/initiatives/coalbed/CoalBedMethane.pdf

This handbook analyzes the infrastructure and water usage associated with coal-bed methane extraction in an effort to develop the resource in an "environmentally responsible manner." The voluntary best-management practices in this handbook are the result of a multi-stakeholder advisory committee that created an adaptive framework to the management of coal-bed methane outside of the regulatory framework. This handbook stresses that Master Drilling Plans, consisting of multiple drilling applications in the same area (well pods), can significantly facilitate the identification and analysis of cumulative effects. The handbook provides alternatives to common practices that can reduce harm to environmental, human, or animal health. Particularly relevant to cumulative wildlife impacts are the planning, water, and infrastructure sections under which best-management practices are discussed from the perspectives of wildlife habitat, changes to soil and vegetation, and the management of produced, ground, or surface water. Companies operating in British Columbia could easily follow, or be guided by, these voluntary guidelines.

KEYWORDS: *adaptive framework, best practices, master plans, water resources, wildlife habitat.*

Wyoming Game and Fish Department. 2010. Recommendations for development of oil and gas resources within important wildlife habitats. Wyoming Game and Fish Department, Cheyenne, WY.
http://gf.state.wy.us/downloads/pdf/og.pdf

A working group of wildlife biologists prepared the recommendations in this report in response to rapid oil and gas development in Wyoming. The group drew on the available literature, including many practices already utilized by companies as well as those practices not always employed. The recommendations are presented as a "planning tool" to identify and mitigate wildlife impacts at the project planning stage, especially in areas of "high value" or "vital" wildlife habitats. The strongest element of this report is the presentation of wildlife impact thresholds and the resulting management/ mitigation options; however, these thresholds are based on quantitative measures of well density and land disturbance, which essentially equate to disturbance distances. Land use habitat surface indicators, while relevant, do not acknowledge other factors associated with oil and gas development. Additionally, thresholds are based on "moderate," "high," and "extreme" classifications, which lack precision, are difficult to analyze, and are qualitative.

KEYWORDS: *impact thresholds, management, mapping, mitigation, planning.*

3.6 Water Development

Braatne, J.H., S.B. Rood, L.A. Goater, and C.L. Blair. 2008. Analyzing the impacts of dams on riparian ecosystems: A review of research strategies and their relevance to Snake River through Hells Canyon. Environmental Management 41:267–281.
www.springerlink.com/content/k561104172521263/fulltext.pdf

This article evaluates seven research strategies (from existing literature) designed to assess the impacts of dams on riparian systems and river characteristics. Wildlife impacts from dams occur via three potential pathways: (1) changes to flow quantity/timing, (2) changes to sediment and alluvial material passage, and (3) fragmentation of river corridors. The authors concluded that the use of a combination of methods is the most effective technique for analyzing the impacts associated with dams. These methods include historical streamflow and reach information, current monitoring studies, progressive downstream pattern analysis, river manipulation, and biophysical modelling. Because all of these methods are influenced by confounding variables and unknowns, there is no single correct way to monitor the impacts of dams on stream reaches. When more than one dam exists on the same river or reach, the authors recommended monitoring in spatial sequence from upstream to downstream to assess cumulative impacts, suggesting that some impacts may be additive as you move along the reach.

KEYWORDS: *dams, experiment, flow characteristics, method analysis, monitoring.*

Byrne, J., S. Kienzle, D. Johnson, G. Duke, V. Gannon, B. Selinger, and J. Thomas. 2006. Current and future water issues in the Oldman River Basin of Alberta, Canada. Water Science and Technology 53(10):327–334. www.iwaponline.com/wst/05310/wst053100327.htm

This article looks at natural and anthropogenic stresses on water resources in southern Alberta. The cumulative impacts of natural variation, urbanization, irrigation, climate change, recreation, and dams serve to decrease water supplies and water quality. These impacts occur indirectly through disruptions or decreases in water flow, whether from reduced snowpacks, increased water usage, or direct divergence. Chemical and biological contamination of water sources (largely from agriculture) is exacerbated by reduced dilution when flow is weakened. The authors attempted to shed light on the cumulative impacts of these water uses (changes) through references to previous studies that offer detail on modelling of hydrological regimes, and the analysis of climate, synoptic meteorology, streamflow measurements, and water quality data. Despite the lack of monitoring of any true "cumulative impacts," concepts of interactions among land uses are well described. In addition, the authors made recommendations for water managers to help limit incidences of poor water quality and ensure an adequate supply.

KEYWORDS: *animal health, contamination, divergence, human health, water use.*

Cooper, K., S. Boyd, J. Aldridge, and H. Rees. 2007. Cumulative impacts of aggregate extraction on seabed macro-invertebrate communities in an area off the east coast of the United Kingdom. Journal of Sea Research 57(4):288–302. ***http://dx.doi.org/10.1016/j.seares.2006.11.001***

The authors collected sediment samples within and outside of aggregate extraction areas in the North Atlantic, UK, to be analyzed for macrofauna, particle distribution, and dredging history. The potential "sediment plume" or "screening" was predicted through fluid-dispersion modelling. Data measurements were analyzed using multivariate statistics and cluster analysis. The authors found higher ratios of sand to gravel and lower numbers of macrofaunal species and individuals in areas that had historically been subjected to direct dredging. They concluded that tidal currents have a greater influence on both sediment distribution and faunal diversity, although dredging definitely has sediment impacts that extend beyond the individual licence area. This is true of most industries, particularly those making emissions to air or water. In these cases, transport through the fluid medium becomes the defining factor in extent, scale, or reach of a particular activity.

KEYWORDS: *benthic communities, dispersion modelling, dredging, multivariate statistics, zone of influence.*

Gergel, S.E. 2002. Assessing cumulative impacts of levees and dams on floodplain ponds: A neutral-terrain model approach. Ecological Applications 12(6):1740–1754. ***http://dx.doi.org/10.1890/1051-0761(2002)012[1740:ACIOLA]2.0.CO;2***

This article develops a "neutral terrain model" to examine the cumulative impacts of multiple disturbances on temporary and permanent floodplain ponds. The primary disturbances explored are levees and dams. The model examines and simulates statistical distribution within gridded spatial data (maps) and incorporates three-dimensional topography and fractal dimensioning to simulate floodplain dynamics and pond-size distribution. Hydroperiod length is used as a quantitative indicator linked to wetland habitat function and four scenarios of dam/levee influence and flood period are modelled. The author found that both dams and levees affected the area of floodplain occupied by a pond in relation to flow levels and extreme events. These effects were predictable, as well as additive, antagonistic, or synergistic, depending on flood frequency and magnitude. The modelling method used here may be replicated or built upon for similar studies involving floodplain and wetland pond dynamics. The author noted that the results should only be extrapolated on a qualitative basis.

KEYWORDS: *flooding, fractal dimension, hydroperiod, wetlands.*

Mahoney, S.P. and J.A. Schaefer. 2002. Hydroelectric development and the disruption of migration in caribou. Biological Conservation 107(2):147–153. ***http://dx.doi.org/10.1016/S0006-3207(02)00052-6***

This article looks at the cumulative impacts of hydroelectric development on migratory caribou (*Rangifer tarandus caribou*) in west-central Newfoundland. The authors, using radiotelemetry, found that caribou migration was individual-specific, much like avian species. Migratory displacement of caribou was greatest during the construction phase, but reduced use of space adjacent to the project continued for a number of years following completion of the dam, powerhouse, and dyke. Although not a "true" cumulative impacts assessment (it only looks at one industry and one valued ecosystem component—caribou), this article reinforces the importance of monitoring wildlife populations over time. Long-term data sets of any chosen component can be used to establish baseline conditions and evaluate individual or cumulative impacts.

KEYWORDS: *baseline conditions, caribou, hydro, long-term monitoring.*

Railsback, S.F., G.F. Cada, C.H. Petrich, M.J. Sale, J.A. Shaakir-Ali, J.A. Watts, and J.W. Webb. 1991. Environmental impacts of increased hydroelectric development at existing dams. Oakridge National Laboratory, Oak Ridge, TN. Environmental Sciences Division Publication No. 3585.
http://hydropower.inel.gov/environmental/pdfs/ornltm-11673.pdf

This report looks at the impacts of upgrading existing hydropower facilities to increase capacity versus retrofitting of existing dams currently not producing hydropower. Upgrades occur through replacing or adding turbines, or through increasing flow or head to the turbines. Increases in capacity can lead to changes in downstream and reservoir water quality (particularly temperature and dissolved oxygen), changing fish populations, increasing fish mortality, and altering water levels. Retrofits of existing dams can have similar effects on water quality, dissolved oxygen, increased fish mortality, and altered recreational use. Retrofits, however, may also alter the flood regime. The authors stressed that the cumulative impacts of developing multiple hydropower projects in the same area have yet to be addressed. This becomes important in parts of British Columbia where numerous projects may be proposed within the same area or watershed. The measurement parameters and mitigation options discussed here may be useful in these situations.

KEYWORDS: *fish mortality, plant upgrades, turbine design, water quality.*

3.7 Fisheries

Field, J.C. and R.C. Francis. 2006. Considering ecosystem-based fisheries management in the California Current. Marine Policy 30(5):552–569. http://dx.doi.org/10.1016/j.marpol.2005.07.004

Through a review of current tools and knowledge systems, this article presents a means of progressively implementing ecosystem-based management of fisheries in California. The premise is that if fisheries managers are better informed about biological and physical marine ecosystem interactions, more realistic management decisions will be made. The authors argued that a more holistic approach to fisheries management, which employs ecosystem thresholds and limits, is necessary to ensure the future of the industry and to protect it from energy and food shortages, which cascade up trophic levels. To fully understand the physical and biological processes that determine commercial fish stocks, a cumulative impacts approach must be taken. Although cumulative effects are not the focus of this article, the evaluation of these impacts is considered very important within the context of ecosystem-based management. With incremental implementation, this form of management allows change to evolve within the current institutional framework, and to continue to evolve on the basis of new knowledge.

KEYWORDS: *ecosystem-based management, education, foodwebs, thresholds.*

Heaslip, R. 2008. Monitoring salmon aquaculture waste: The contribution of First Nations' rights, knowledge, and practices in British Columbia, Canada. Marine Policy 32(6):988–996.
http://dx.doi.org/10.1016/j.marpol.2008.02.002

This article looks at how traditional knowledge can be integrated into the necessary assessments of cumulative impacts of salmon aquaculture in coastal British Columbia. The First Nations perspective in this case represents wildlife values, specifically the health and vitality of clams and clam beach habitat. Local people have noticed beach changes and declines in the quality and number of clams over time, and speak of a strong tidal flow that can lead to "far-field damages" from fish pens (which makes sense for anything dispersed in a fluid). Like most industries in British Columbia, aquaculture operations have thus far only approached impacts on a "site-by-site basis." Cumulative impact relationships are not necessarily linear as are those of traditional cause-and-effect impact assessments. Instead, they require a holistic understanding of systems that can be based, improved, or built upon using traditional knowledge and concepts of change.

KEYWORDS: *aquaculture, clams, coastal habitats, monitoring, traditional knowledge.*

Poulsen, B., P. Holm, and B.R. MacKenzie. 2007. A long-term (1667–1860) perspective on impacts of fishing and environmental variability on fisheries for herring, eel, and whitefish in the Limfjord, Denmark. Fisheries Research 87:181–195.   http://dx.doi.org/10.1016/j.fishres.2007.07.014

This article deals with the impacts of historical fishing practices and environmental developments on three fisheries. Information on the cumulative wildlife effects of fisheries is limited, and these impacts can be viewed ecologically (rather than economically) as impacts to wildlife populations. Through an analysis of historical records, the authors determined that although declines in fish populations have largely been caused by poor management and practices, the decline of some species has also been influenced by the intrusion of saline water, following a storm in 1825. Although elements such as total catch and fishing methods can be controlled and their outcomes predicted, natural variability and extremes can have a dramatic and unforeseen impact on wild aquatic (or even terrestrial) populations. Though not a topic of this bibliography, climatic variability adds to both the uncertainty and complexity of cumulative impacts assessments and provides a basis for including natural variability (forest fires, flood frequency, etc.) into predictive tools.

KEYWORDS: *climate events, historical records, stressor interactions, trend analysis.*

3.8 Terrestrial and Off-shore Wind Farms

Bisbal Vigo, A. 2007. Impacts of offshore wind developments on birds. MSc thesis. Cranfield University, School of Applied Sciences, Bedfordshire, UK.   http://hdl.handle.net/1826/2304

This thesis evaluates current knowledge of the impacts from offshore wind-turbine developments on birds. When written, only a handful of the included sites were operational. Three main impact pathways are identified: (1) direct collision, (2) behavioural changes, and (3) physical changes (barriers) caused by turbine presence. The author used an impact matrix to illustrate the potential effects of developments on birds, classifying these effects as positive or negative, permanent or temporary. Disturbance significance is allocated based on the number of times a bird family was classified as experiencing effects through the three main disturbance pathways. Each bird family responded differently to different disturbances illustrating the importance of choosing indicator species wisely for the desired pathway. Because wind power is a relatively new development, little is known about the long-term or cumulative impacts from individual or multiple projects, or whether suggested impact mitigation measures (lighting, spacing, etc.) are effective.

KEYWORDS: *disturbance significance, environmental statements, impact matrix, offshore.*

Bright, J., R. Langston, R. Bullman, R. Evans, and S. Gardner. 2008. Map of bird sensitivities to wind farms in Scotland: A tool to aid planning and conservation. Biological Conservation 141(9):2342–2356. http://dx.doi.org/10.1016/j.biocon.2008.06.029

This article presents maps of sensitivities to wind farms for 16 different bird species of conservation concern. The sensitivities can be viewed as "thresholds" and the birds as "indicators"—both are important components of cumulative impacts assessments. Spatial sensitivities were derived from available literature on range, risk of tower collision, and overall sensitivity to habitat disturbances. As often is the case with thresholds, sensitivities were based on classes (low, medium, and high sensitivity), which limits levels of statistical analysis and accuracy. The authors identified the cumulative impacts of multiple wind farms on bird species whose sensitivity maps overlapped with existing and proposed wind-farm developments. This is a good example of the use of thresholds and indicators in the study of spatially explicit cumulative impacts from a single sector (with multiple projects). This methodology can be extended by adding zones of influence and species' sensitivity ranges to maps.

KEYWORDS: *collisions, mapping, risk analysis, sensitivity classes, zones of influence.*

Coles, R.W. and J. Taylor. 1993. Wind power and planning: The environmental impact of windfarms in the UK. Land Use Policy 10(3):205–226. ***http://dx.doi.org/10.1016/0264-8377(93)90016-4***

The authors analyzed information and environmental impacts statements from six existing wind farms in the United Kingdom, examining to what extent this information may be used to develop a background policy framework for wind-farm development. The wildlife concerns section refers to collisions, habitat disturbance and displacement, and soil erosion from construction activities. The framework idea is vague, and has no biological relevance or reference to spatial or temporal scales of impacts. The authors did, however, create maps of locations where wind-speed potential would justify turbine placement, and where development would not overlap any "designated areas" (e.g., parks, protected areas). In British Columbia, similar maps of alternatives could be produced for sensitive habitat and parks where development of any natural resource sector could be limited unless deemed unavoidable.

KEYWORDS: *collisions, mapping, siting, turbine arrangement, zones of influence.*

National Wind Coordinating Collaborative. 2004. Wind turbine interactions with birds and bats: A summary of research results and remaining questions. Fact sheet: Second edition. National Wind Coordinating Committee, Washington, DC.
www.nationalwind.org/publications/wildlifewind.aspx? ***[An update to be posted soon on this website.]***

After 10 years of research and information gathering, the US National Wind Coordinating Committee published this information sheet summarizing knowledge on interactions between wind energy projects and avian species. The fact sheet does not address off-shore activities of turbines with a capacity of less than 40 kilowatts. The authors stated that the cumulative effects of wind developments on bird and bat species adds to many factors that have already led to declines in their populations. Direct impacts have been reported as mortality from collision with turbines or associated infrastructure. Indirect impacts include displacement and avoidance. Tables are given of statistics for fatalities by factors such as region and blade length. The authors suggested that navigation and turbine design may be factors in collision frequency. No information is provided on limits or thresholds of wind turbine development for avian populations, although this would be useful for cumulative impacts. This document is currently in the process of revision. An update should be posted soon on the National Wind Coordinating Collaborative website.

KEYWORDS: *avian decline, collision, national approach, turbine design.*

United States Geological Service. 2008. Use of innovative technologies to develop management tools for wildlife friendly wind power. US Department of the Interior, Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT. ***www.nrmsc.usgs.gov/files/norock/products/Wind_Wildlife_Info08.pdf***

This information sheet documents habitat destruction and fragmentation associated with wind-power development. Large wind facilities, such as those proposed for the northern US Rockies, often extend for thousands of acres, displacing natural habitat and ecosystem elements. The resultant disruption of migratory bird passage is of concern to the Northern Rocky Mountain Science Center, which is involved in two projects: (1) examining bird migration in relation to turbines, and (2) developing a decision-support system of "wildlife friendly" wind-power development. The objective is to develop a model predicting how birds interact with wind-power facilities to aid managers in site development that protects birds. Additional progress is being made to minimize impacts through turbine design and geometry as well as by developing tools to identify birds using Doppler radar. This is interesting research whose outcomes will be very useful in identifying cumulative wildlife effects from wind turbines.

KEYWORDS: *habitat fragmentation, migration, model development, project design.*

3.9 Urban and Rural Development

City of Vancouver, Planning Department, False Creek Planning Group. 1989. False Creek development impacts: A review of the effects that development around False Creek may have on surrounding areas and descriptions of studies needed to address these effects. A discussion paper.

Most effects reviewed in this paper pertain to social impacts from waterfront development, but the environmental impacts of development are also discussed. The potential for both positive and negative effects is highlighted. The major change recommended is a rezoning to high-density residential housing along the waterfront. The environmental effects covered are limited to developing "vacant areas," initiating recycling programs, cleaning up soil, losing views, and creating pollution. The paper emphasizes that through collaboration with the federal Department of Fisheries and Oceans, "no net loss of fish habitat" will occur and unacceptable water quality will be remediated. Although the paper looks at the cumulative effects of urban development on social, cultural, and environmental indicators, it is not clear how these impacts are to be mitigated or how relevant the "environmental impacts" are to most wildlife values.

KEYWORDS: *fish habitat, recycling, social impacts, soils, water quality.*

Conway, T. and R.G. Lathrop. 2005. Alternative land use regulations and environmental impacts: Assessing future land use in an urbanizing watershed. Landscape and Urban Planning 71(1):1–15. http://dx.doi.org/10.1016/j.landurbplan.2003.08.005

The authors used a model to predict urban growth under different management scenarios in New Jersey. Using four zoning regimes (current, down-zoning, protecting buffers, and protecting open spaces) and three indicators (water demand, pollution, and habitat fragmentation), they found little difference between cases. Under all scenarios, future water demand exceeded water supply, and increases in pollution and habitat fragmentation occurred. These trends suggest the need to adopt new policy frameworks to reduce impacts on water, pollution, and habitat indicators. The benefit of the methodology used here is that it is both temporally and spatially explicit; that is, the model predicts when and where new buildings will arise. This is necessary to frame impacts within a time and space that is both determined and relevant to the sector(s) processes assessed; however, spatially explicit models require spatial limits to development—such as urban zoning.

KEYWORDS: *indicators, pollutants, spatially explicit modelling, water, zoning scenarios.*

Theobald, D.M., J.R. Miller, and N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39(1):25–36. http://dx.doi.org/10.1016/S0169-2046(97)00041-8

The authors approached cumulative impacts using simple but elegant relationships between habitat responses and development distance in Summit County, Colorado. Within a circular zone of response, there is assumed to be disturbed habitat that varies in relation to different planning scenarios. Disturbance zone and various development layouts are illustrated using clear diagrams. The authors found that pattern in the clustering of houses influenced habitat fragmentation and disturbance more than building density. They suggested managers and planners consider geometry in their plans as a means of mitigating wildlife impacts. The "building-effect distances" used here range from 50 to 500 m per building. Although the method for deriving "effect distances" is unclear and buildings are not necessarily located in the centre of their zone of influence, the effects distance or zone of influence is not limited to urbanization and can be applied to any sector that overlaps in time or space.

KEYWORDS: *building density, disturbance zone, lot geometry, sub-developments.*

Wear, D.N., M.G. Turner, and R.J. Naiman. 1998. Land cover along an urban–rural gradient: Implications for water quality. Ecological Applications 8(3):619–630. ***http://dx.doi.org/10.1890/1051-0761(1998)008[0619:LCAAUR]2.0.CO;2***

The authors use information on land cover and distance from urban areas to formulate land use probabilities, which were then used to simulate future landscape conditions. The authors found that road distance to a metropolitan area significantly affected land cover changes in the part of North Carolina studied. These changes were confounded, however, by other factors (slope, zoning, etc.) included in the simulation, which was based on benefit analysis, likelihood ratios, and a quadratic varying parameters model. The study showed that water quality is most affected in landscapes at the edge of urban expansion and at the remote end of the urban–rural gradient. Comparable landscape simulation methods could be used to examine similar (or unique) influences caused by development gradients from urban (and other) development sectors. Models like these can estimate outcomes ("landscape signatures") of potential management decisions and therefore provide decision support for land use, zoning, hazard mapping, and other applications.

KEYWORDS: *elevated terrain, landscape simulation, landscape signatures, satellite imagery, water quality.*

Xue, X., H. Hong, and A.T. Charles. 2004. Cumulative environmental impacts and integrated coastal management: The case of Xiamen, China. Journal of Environmental Management 71(3):271–283. ***http://dx.doi.org/10.1016/j.jenvman.2004.03.006***

This article combines the concepts of cumulative impacts assessment with integrated coastal zone management and a marine zoning scheme. The research was carried out in response to a lack of assessments of cumulative effects and environmental impacts in Xiamen, China. The cumulative impacts stage involved identifying key impact pathways, selecting valued ecosystem components, and developing indicators for measurement. The coastal management stage involved the integration of sectors, government levels, spatial scales, science and management, and various nations. The zoning scheme was designed to accommodate multi-sector marine priorities. Valued ecosystem components identified were circulation and siltation, water quality, sediment transport, benthic communities, and mangrove forests. Measures used included concentration of pollutants and area changes in mangrove cover. The authors provided a clear and descriptive method for applying cumulative impacts in management regimes and through this case study developed indicators and measures that may prove beneficial in similar assessments of rapidly developing coastal communities.

KEYWORDS: *coastal zoning, indicators, integrated management, valued ecosystem components, waterfront development.*

Zandbergen, P.A. 1998. Urban watershed ecological risk assessment using GIS: A case study of the Brunette River watershed in British Columbia, Canada. Journal of Hazardous Materials 61(1–3):163–173. ***http://dx.doi.org/10.1016/S0304-3894(98)00120-4***

This article presents a framework for screening-level risk assessments of urbanized watersheds and then applies a conceptual model to the Brunette River, a small urban watershed in British Columbia. The model incorporates human activities, the stressors these create, and the consequences to watersheds. Impact indicators used include measures of riparian area, impervious surface, water and sediment quality, pollutant loads, fish health, and human health. These indicators were given dimensionless scores of zero to 100 based on level of risk, and were then overlapped on GIS maps to help managers and decision makers in incorporating "complex scientific information." Although good for this purpose, the indicators used are quite broad and require a more specific and perhaps numeric context, such as ratios of impervious-to-pervious surface or percentage of stream without riparian vegetation. One could easily apply measures or thresholds to these indicators and then manage to minimize negative impacts.

KEYWORDS: *conceptual modelling, GIS, indicators, riparian habitat, risk analysis.*

3.10 Transportation and Utility Corridors

Botkin, D.B., R. Demarchi, D. Frost, A. Gunn, D. Marmorek, D. O'Gorman, and S. Riley. 2004. Environmental effects of a mining road through the traditional territory of the Taku River Tlingit First Nation: A critique of proposed management plans for a new mining road. Report to the Taku River Tlingit First Nation by the Independent Science Panel.
www.fw.msu.edu/~rileysh2/Final%20Redfern%20Report.pdf

This report presents a scientific review of a mining road proponent's "adaptive management plan" by a group of independent North American scientists, but is relevant to any resource sector that requires permanent access roads where no previous roads exist. Through a series of questions, the panel found that the proponent's adaptive management plan was: incapable of preventing unacceptable wildlife effects; deficient in implementation strategies; lacking monitoring and mitigation activities; statistically biased; too short in time scale; and unreliable for future population estimates. The plan did not account for the permanence or immensity of the road (60-m wide sections), or whether other natural resource sectors would have future access to this road. The proponent's plan did not provide measures for biological or physical impacts. From an adaptive management standpoint, it therefore failed to meet the objectives of iterative decision making through continuous monitoring. The panel provided examples of what the proponent missed and recommendations to improve the plan.

KEYWORDS: *adaptive management, First Nations, long-term monitoring, scientific review.*

CH2MHILL. 2005. SR 520 bridge replacement and HOV project draft EIS, Appendix J: Indirect and cumulative effects, Discipline report. Washington State Department of Transportation, Olympia, WA.
www.wsdot.wa.gov/NR/rdonlyres/22C631C4-FCD9-481A-9A95-7CC82A162ED7/0/SR520DEIS_AppendixJPart1.pdf

This discipline report is a component of Washington State's environmental review process. The report addresses indirect and cumulative effects from a proposed highway bridge replacement project. Both indirect and cumulative impact scenarios were projected using three possible development alternatives: (1) six lanes, (2) four lanes, or (3) no rebuilding. The report frames both the ecology and society from a historical perspective giving background to urban development and subsequent environmental changes. Future (2030) urban growth and changes to various townships were predicted using DRAM/EMPAL models to forecast the location and timing of urban development. With an emphasis on other transportation corridors (e.g., rail, tunnel), the cumulative impacts of these "reasonably foreseeable" developments were qualified. This report refers to a highly populated area, and makes little reference to wildlife; however, the acknowledged interaction between urbanization and roads is useful to test scenarios in any location that experiences both access and development pressures.

KEYWORDS: *bridge construction, development alternatives, historical data, population models.*

CH2MHILL. 2006. Environmental assessment, California Forest Highway 114, Hyampom Road, State Route 3 (Hayfork) to Hyampom Trinity County, California. Prepared for: Federal Highway Administration, Central Federal Lands Highway Division.

This environmental assessment examines all of the potential impacts (social, environmental, and economic) related to rebuilding most of a 35.4-km Forest Highway and discusses potential alternatives to the proposed actions. Under various "resource" headings, the authors defined the affected environment (current conditions and pathways of change), determined the regulatory framework governing the resource, specified potential environmental consequences of the highway on a particular resource, examined the cumulative impacts that may occur to the resource, and described several measures that may be used to mitigate negative impacts. Resource headings most relevant to wildlife and biodiversity include air quality, noise, water resources, floodplains, wetlands, and biology. The value of this report lays in its provision for alternatives to the proposed plan, showcasing that negative effects on valued wildlife (or here resources) can be minimized at the project-planning stage.

KEYWORDS: *development alternatives, environmental resources, mitigation, planning and appraisal.*

Coffin, A.W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography 15(5):396–406. ***http://dx.doi.org/10.1016/j.jtrangeo.2006.11.006***

This article explores existing literature to reveal the under-represented ecological impacts and developments in ecological scientific knowledge related to roads and other transportation corridors. Abiotic processes related to hydrologic and water impacts include barriers and crossings, erosion and sediment transport, the introduction of pollutants, and noise. Biotic processes examined include mortality and barriers, and corridor, conduit, and habitat creation. This is one of the few references to highlight some potential beneficial wildlife effects of development (e.g., native vegetation at roadsides or railsides). The author stressed both the scarcity and importance of research relating to cumulative landscape-level effects, especially those induced by entire road networks. Although the author presented no metrics, measures, methods, or zones of influence to analyze cumulative effects, this review may help to determine the pathways and indicators of relevance to wildlife in cumulative impacts assessments.

KEYWORDS: *biotic processes, indirect impacts, road ecology, socio-economic factors.*

Cundiff, B., R. Page, and L. Pitkanen. 2006. Roads: More than lines on a map. CPAWS Wildlands League, Toronto, ON. ***www.wildlandsleague.org/attachments/Roads.Report.pdf***

This Canadian Parks and Wilderness Society publication discusses numerous direct and indirect effects that roads (and other linear disturbances such as seismic lines) may have on the environment. The authors stated that many species (e.g., black bear [*Ursus americanus*] and wolverine [*Gulo gulo*]) are known to change their routes of movement because of roads and often use an avoidance approach when a new road comes through their range. The impacts of fragmentation and increased edge communities are noted, as are impacts from increased human presence and the absence of seismic line vegetative regeneration. Although the authors referred to studies and data, they included no reference citations, only providing a suggested reading list and air-photos taken from Schneider (2002; ***see below***). Without more solid scientific support, the authors' arguments are weakened.

KEYWORDS: *edge effects, indicator mammals, linear disturbances, suggested reading.*

Delgado, J.D., N.L. Arroyo, J.R. Arévalo, and J.M. Fernández-Palacios. 2007. Edge effects of roads on temperature, light, canopy cover, and canopy height in laurel and pine forests (Tenerife, Canary Islands). Landscape and Urban Planning 81(4):328–340. ***http://dx.doi.org/10.1016/j.landurbplan.2007.01.005***

The authors assessed "road edge effects" on temperature, light intensity, canopy cover, and forest height in oceanic island forests. Using ANOVA tests with Helmert difference contrasts to locate significant differences in parameters over spatial transects (perpendicular to the roads), they found high gradients of all measured parameters in laurel (*Laurus azorica*) forests. Pine (*Pinus canariensis*) forests showed strong soil temperature gradients for asphalt roads only and significant light gradients for all types of roads. The zone of influence was about 3 m for temperature, 6 m for light, and 10 m for tree height. Although zones of influence differ for forests depending on composition, this concept is useful to determine road impacts on ecosystems. Zones of influence could be measured (developed) for British Columbia using simple field experiments and statistical methods such as those outlined in this article. Edge effects extend the habitat impacts of roads far beyond their physical boundaries.

KEYWORDS: *canopy characteristics, edge effects, field measurements, island community, zone of influence.*

Söderman, T. 2006. Treatment of biodiversity issues in impact assessment of electricity power transmission lines: A Finnish case review. Environmental Impact Assessment Review 26(4):319–338. http://dx.doi.org/10.1016/j.eiar.2005.10.002

This article reviews the entire environmental assessment process for a power transmission line in Finland. The author found that neither cumulative effects nor biodiversity impacts were well addressed by the assessment process. Biodiversity was largely overshadowed by homeowner concerns during consultation and review, but the proponents did place a strong emphasis on the immediate impacts to flying squirrels (*Pteromys volans*). The flying squirrel represents a sensitive indicator or valued ecosystem component. The presence of squirrel habitat required power line rerouting through an alternative development scenario presented during the application phase. Cumulative effects of the power line itself were poorly addressed (only fragmentation was discussed), and the impacts of other power lines in the area were excluded. Despite excluding cumulative impacts, the original assessment illustrates the importance of presenting mitigation strategies for both indicators and development alternatives at the planning stage.

KEYWORDS: *development alternatives, indicator species, power lines, review process.*

Stoffle, R., G. Rogers, F. Grayman, G. Bullets Benson, K. Van Vlack, and J. Medwied-Savage. 2008. Timescapes in conflict: Cumulative impacts on a solar calendar. Impact Assessment and Project Appraisal 26(3):209–218. www.ingentaconnect.com/content/beech/iapa/2008/00000026/00000003/art00005

This article does not address the impacts of utility corridors on wildlife, but instead provides an example of how cumulative impacts may be missed by typical single-project impact assessments. The indicator of choice is a cultural artefact—an Aboriginal solar calendar in southern Utah. An initial study suggested that increased access could threaten the location, which was kept secret as a result. Over the next 25 years, five utility projects were constructed in the corridor. Aboriginal communities had been consulted during each project's planning stage. Nevertheless, the combined impacts from the access provided by all of the projects resulted in damage to the sacred site that might have been avoidable if a co-ordinated effort had been employed. A co-ordinated approach to range access is necessary to prevent similar effects to biological, chemical, or wildlife indicators.

KEYWORDS: *access, archaeology, long-term impacts, traditional knowledge.*

3.11 Outdoor Tourism and Recreation

Bedrossian, T.L. and S.D. Reynolds. 2007. Development of a soil conservation standard and guidelines for OHV recreation management in California. Environmental & Engineering Geoscience XIII(3):241–253. http://eeg.geoscienceworld.org/cgi/reprint/13/3/241

This article discusses the revision of a guideline for soil conservation in off-highway vehicle recreation management. The benefit of the new guideline is its flexible application throughout the state of California. Old guidelines were subjective and difficult to monitor. Developed through multi-stakeholder consultation, mapping, and site-specific surveys, the guideline update includes coloured markers to indicate trail condition, and new protocols for hazard and repair evaluation, minimizing erosion, and generally ensuring that effects do not reach beyond the bounds of the facility. It is unclear, however, how the mitigation measures are to be accomplished.

KEYWORDS: *guidelines, soil loss, stakeholder consultation, trail markers.*

Foltz, R.B. and D.L. Meadows. 2007. Impacts of ATV traffic on undesignated trails. US Department of Agriculture Forest Service, Rocky Mountain Research Station, Stream Systems Technology Center, Fort Collins, CO. Stream Notes, April 2007, pp. 5–7.
www.stream.fs.fed.us/news/streamnt/pdf/SN_04_07.pdf

This study reviews the impacts from all-terrain vehicle (ATV) traffic on natural resources and experimentally examines the vehicle characteristics that created the most impact. Using specific vehicular and tire types, prescribed tracks were run as controlled trials in ATV-driven areas of five different states. Low, medium, and high disturbance classes, based on the indicators of ground cover, track width, and wheel rut depth, were used to assess trail condition. The authors found that loamy sand was the most sensitive soil to runoff, and that ATV use increased runoff and sediment loss at these locations. Disturbance levels were similar regardless of tire or vehicle type (size); however, straight (rather than curved) sections of trail had less disturbance and soil loss. This research is useful in the planning of ATV trails. Although impacts from ATVs cannot be completely avoided (or quantified), trail design and location can minimize cumulative impacts on soil and vegetation.

KEYWORDS: *erosion, experiment, trail geometry, vehicle type.*

McCarthy J.E. 2004. Snowmobiles: Environmental standard and access to national parks. Library of Congress, Congressional Research Service, Washington, DC.
http://digital.library.unt.edu/govdocs/crs/permalink/meta-crs-10032:1

This report focuses on the impacts of noise and atmospheric emissions from snowmobiles in national parks in the United States. Currently, no emission or noise regulations exist for snowmobiles in either the United States or Canada. The authors noted that 1 hour of snowmobile operation emits the equivalent amount of volatile organic compounds as an entire year of driving a 2001 car (approx. 39 100 km). To understand the extent of these impacts, one must determine the number of snowmobile visits per area (particular park) per unit time (usually a season or year). The report gives suggested Environmental Protection Agency limits for emissions and access allowances, which were developed to minimize wildlife disturbance. These limits may be consulted when planning park management activities and cumulative impacts mitigation. Public opinion, however, may prove stronger than wildlife conservation principles when it comes to recreational vehicle use, as was found in the United States.

KEYWORDS: *air pollution, exposure metrics, national parks, noise, policy.*

Nelleman, C., O-G. StØen, J. Kindberg, J.E. Swenson, I. Vistnes, G. Ericsson, J. Katajisto, B.P. Kaltenborn, J. Martin, and A. Ordiz. 2007. Terrain use by an expanding brown bear population in relation to age, recreational resorts, and human settlements. Biological Conservation 138(1–2):157–165.
http://dx.doi.org/10.1016/j.biocon.2007.04.011

This article examines impacts from human settlements on brown bears (*Ursus arctos*) in Sweden. The authors recorded habitat use through radio-collaring and DNA scat analysis. They found a high preference for habitat more than 10 km from human settlements; the area within a 10-km radius was more frequently used by the youngest bears. This raises concern regarding the expanding bear population in relation to expanding resort settlements, particularly near national parks. Although this article looks at settlements beyond the recreational and resort areas, these were the focus, especially considering off-road or forest trail human presence. British Columbia is experiencing similar development pressures in rural areas and near parks or wildlands, and increases in its black bear (*Ursus americanus*) population. Direct destruction of habitat, together with the zone of influence from development, means that the growing bear population is confined to a smaller area of preferred habitat, and faces human confrontation or conflict.

KEYWORDS: *age classes, bears, habitat preference, monitoring, zones of influence.*

Wisdom, M.J, A.A. Ager, H.K. Preisler, N.J. Cimon, and B.K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. **In** ***Transactions of the 69th North American Wildlife and Natural Resources Conference, Spokane, WA, March 16–20, 2004, pp. 531–550.***
www.fs.fed.us/pnw/pubs/journals/pnw_2004_wisdom001.pdf

This paper reports on the assessment of cumulative impacts on mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) from multiple, off-road recreation activities in northeastern Oregon. In addition to identifying impacts and management issues associated with these off-road uses, the authors measured effects using "response variables," which can be translated into energy costs for the animal in question. These measures were established using experimentally applied, off-road activities on typically used routes in an area with contained and radio-collared "wild" ungulates. Off-road activities, especially ATV riding, were found to increase movement rates and flight response. These responses are shown to be distance-dependent, particularly for elk. Unfortunately, movement rate and flight response are not converted into energy units relating to food or habitat requirements, although this is a future goal of the work. This research shows that wild ungulates are affected by nearby, off-road recreation; however, controlled methods of radio-collaring are impractical for most cumulative impact studies.

KEYWORDS: *animal monitoring, energy responses, experimentation, impact measures, wild ungulates.*

4 MULTI-SECTOR CUMULATIVE IMPACT STUDIES

Unlike the previous annotations, the following section outlines research and approaches relating to the cumulative impacts of more than one resource sector. Although some of the examples examine one particular impact pathway, the focus is interactions, additivity, and synergism between sectors (and sometimes activities).

4.1 Wildlife Receptor Approaches

Dyer S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65(3):531–542. ***www.jstor.org/pss/3803106***

In this study, woodland caribou (*Rangifer tarandus caribou*) were fitted with global positioning system (GPS) collars to measure their movement and distribution in relation to landscape disturbances (multi-sector resource extraction) in the 6000 km^2 study location over 1 year. Measurement results from this location were extrapolated to an area of over 600 000 ha to interpret the impacts of disturbances such as seismic lines, well pads, and peat excavation on caribou distribution. The physical footprint of the development was found to drastically underestimate the true spatial scale of avoided habitat by the affected caribou. This article (like that of James and Stuart-Smith [2000]; ***see below***) supports inclusion of avoidance effects in habitat modelling (or other estimates) for cumulative effects management. The results should not be extrapolated to areas far from the site studied (northeastern Alberta); however, depending on the level and type of assessment conducted, this research provides qualitative guidance for estimating woodland caribou impacts.

KEYWORDS: *avoidance, development buffers, spatial extrapolation, telemetry.*

Finch, D.M., J.L. Ganey, W. Yong, R.T. Kimball, and R. Sallabanks. 1997. Effects and interactions of fire, logging, and grazing. **In** ***Songbird ecology in southwestern ponderosa pine forests: A literature review. US Department of Agriculture Forest Service, Fort Collins, CO. Gen. Tech. Rep. RM-GTR-292, pp. 103–136.*** ***www.fs.fed.us/rm/pubs_rm/rm_gtr292.pdf***

This chapter examines the cumulative impacts of fire, logging, and grazing on songbird habitat. Fire is not necessarily an impact of natural resource development, but is sometimes the result of our mismanagement of other resources. The potential impacts to songbirds from fire, logging, and grazing are very similar to those of recreation and urbanization discussed below (***see Marzluff*** [1997]). Specifically, songbirds are most affected through changes in habitat, food supply, and predator–prey relationships. The use of multiple species as biological indicators may be addressed using similar tools, and the pathways and measures of effects from various forms of resource development can be approached through similar means. This is only a review paper, but it does cover many aspects and pathways of potential (unmeasured) effects on various songbird species.

KEYWORDS: *effect pathways, food supply, habitat disturbance, predation.*

James A.R.C. and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64(1):154–159. ***www.jstor.org/stable/pdfplus/3802985.pdf***

This article examines the spatial patterns of both caribou (*Rangifer tarandus caribou*) and wolves (*Canis lupus*) in relation to linear disturbance corridors in Alberta. Using radio-telemetry (for both species), corridor distances, and random point distances, the authors tested the hypothesis that corridors increase the risk of caribou predation. A general linear model was employed to analyze nearest corridor distances from mortality and predation events, and statistics to formulate likelihoods. They found caribou predation was greater near corridors, but that caribou tended to avoid corridors, likely because of predator presence. This avoidance ends up reducing usable caribou habitat and stresses the notion that the most obvious impact pathway (increased predation) is not always the most severe (habitat reduction). The article examines roads, pipelines, seismic lines, and trails illustrating the grouping of various resource sectors by a common disturbance type, which is useful in regional multi-sector impact assessments that qualify caribou impact parameters.

KEYWORDS: *general linear model, GIS, hunting, predation, telemetry.*

Jeffries, K.M., E.R. Nelson, L.J. Jackson, and H.R. Habibi. 2008. Basin-wide impacts of compounds with estrogen-like activity on longnose dace **(Rhinichthys cataractae)** ***in two prairie rivers of Alberta, Canada. Environmental Toxicology and Chemistry 27(10):2042–2052.*** ***www3.interscience.wiley.com/journal/122677057/abstract***

This article examines the spatial relationship between municipal and agricultural wastewater and endocrine disruption in the longnose dase (*Rhinichthys cataractae*), a minnow found in the Oldman and Bow rivers of southern Alberta. The authors illustrated how levels of a genetic biomarker in a species can be a measure of estrogen-mimicking compounds from various activities. In this case, the sources were agriculture (primarily cattle farms) and municipal wastewater. Effects from the 28 compounds found in the rivers were primarily reproductive and developmental. This work shows how levels of vitellogenin mRNA can be measured in *R. cataractae* samples, and how this species can be used as an indicator of wildlife and human health impacts resulting from municipal and agricultural waste within a river basin. Sex-ratios in this species also proved a good indicator, and the authors stressed the need for large-scale measurements. The same is likely true of other sentinel species, biomarkers, and impact pathway relationships.

KEYWORDS: *agriculture, biological measures, endocrine disruption, urbanization, water quality.*

Jeffries, K.M., L.J. Jackson, L.E. Peters, and K.R. Munkittrick. 2008. Changes in population, growth, and physiological indices of longnose dace* (Rhinichthys cataractae) *associated with land use in the Red Deer River, Alberta, Canada. Archives of Environmental Contamination and Toxicology 55(4):639–651.
www.springerlink.com/content/d02k574241657338/?p=79496002520f4507b7431b31dddbd4d1&pi=10

Similar to the *article above*, this study uses longnose dace (*Rhinichthys cataractae*) as an indicator species of impacts from municipal wastewater and agriculture (cattle). This study looks at body and liver size as measures of river productivity (enrichment), testosterone levels as a measure of endocrine disruption, and ethoxyresorufin-O-deethylase as a measure of aromatic hydrocarbon levels. The authors found that age class distribution was related to cumulative and multiple effects of various contaminant pathways. Biological expression of these traits and compounds was related to distance from multiple point (municipal) and non-point (agricultural) sources of waste. This article not only illustrates the use of biological indicators in effects research, but also demonstrates the importance of using multiple measures to examine impacts.

KEYWORDS: *biological measures, effects-based approach, endocrine disruption, halogenated aromatic hydrocarbons, water contamination.*

Johnson, C.J., M.S. Boyce, R.L. Case, H.D. Cluff, R.J. Gau, A. Gunn, and R. Mulders. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monographs 160:1–36.
www.jstor.org/pss/3830812

The authors examined the cumulative impacts from diamond mining and associated infrastructure (roads, exploration, and outfitting) on four native arctic animal species: (1) barren-ground caribou (*Rangifer tarandus groenlandicus*), (2) grey wolves (*Canis lupus*), (3) grizzly bears (*Ursus arctos*), and (4) wolverines (*Gulo gulo*). Eleven seasonal resource selection (habitat) models were developed for each species (nine of which were good predictors) using vegetation, animal interaction, and disturbance variables derived from telemetry, satellite imagery, and land use maps. The resultant seasonal species maps can be used to aid in management decisions, but the authors stressed the limitations of such regional assessments (approximations) and the importance of specific monitoring and data analysis to fully describe true cumulative impacts occurrence and strength. Although the focus here was on diamond extraction in the Northwest Territories and Nunavut, similar preliminary approaches could be used in other regions to examine cumulative wildlife impacts from multi-sector or project-specific activities.

KEYWORDS: *animal behaviour, ecological seasons, GIS, keystone species, resource selection functions.*

Manville, A.M., II. 2005. Bird strikes and electrocutions at power lines, communication towers, and wind turbines: State of the art and state of the science—next steps toward mitigation.* In *Bird conservation implementation and integration in the Americas: Proceedings of the Third International Partners in Flight Conference, March 20–24 2002. C.J. Ralph and T.D. Rich (editors). US Department of Agriculture Forest Service, Pacific Southwest Research Station, Albany, CA. Gen. Tech. Rep. PSW-GTR-191, pp. 1051–1064.
www.fs.fed.us/psw/publications/documents/psw_gtr191/Asilomar/pdfs/1051-1064.pdf

Although the primary effect of towers and turbines on migratory birds is mortality through either collision or electrocution, this report provides background information on other impacts and interactions such as evidence for impacts from non-thermal radiation in the embryonic stage of nesting birds. The author addressed issues of placement, acoustics, size, lighting, and habitat modifications in relation to the development of power lines, communication towers, and wind turbines. The author did not review a cumulative impacts project, but instead made recommendations to avoid or minimize impacts and suggested the assessment of cumulative impacts of multiple towers/projects (including pre-existing ones). Also provided are recommendations for assessment at the multi-sector level and a means of minimizing tower impacts that could be applied anywhere.

KEYWORDS: *collision, corridors, electrocution, site geometry.*

***Marzluff, J.M. 1997. Effects of urbanization and recreation on songbirds.* In *Songbird ecology in southwestern ponderosa pine forests. US Department of Agriculture Forest Service, Fort Collins, CO. Gen. Tech. Rep. RM-GTR-292, pp. 89–102.* www.fs.fed.us/rm/pubs_rm/rm_gtr292.pdf**

This entire report (***see Finch et al. above***) looks at factors affecting songbird populations in the southwestern United States. This particular chapter gives particularly good examples of the potential combined effects from recreation and urbanization. Continuous human presence is a factor distinguishing these from other "natural resource" sector effects. The author discussed potential changes in ecosystem processes, habitat, and forage availability that can result from human presence in ecosystems, and how these changes may subsequently effect songbird populations of the southwestern ponderosa pine forests. Ecosystem processes are influenced by fire suppression and water usage, and habitat changes are induced through fragmentation and the replacement, removal, or damage of native vegetation. Songbird food resources are affected by the same pathways and by human feeding. Birds' response to human interactions is species specific; however, species that show tolerance towards human activity often become pests and face their own survival difficulties.

KEYWORDS: *ecosystem processes, habitat disturbance, human presence, species tolerance.*

Nitschke, C.R. 2008. The cumulative effects of resource development on biodiversity and ecological integrity in the Peace–Moberly Region of northeast British Columbia, Canada. Biodiversity and Conservation 17:1715–1740.
www.springerlink.com/content/r24428l47153671j/?p=391a51c740bb4c099cd2fc2f2826aaea&pi=10

The author examined cumulative impacts from multiple resource sectors over a large area (410 000 ha) in northeastern British Columbia. Threatened and culturally important species were identified, and changes in landscape/habitat structure (patch size, etc.) were mapped over time using GIS raster coverages and defined habitat variables for pre-1970 and "current" scenarios. Individual models were developed for 82 different species based on range and habitat effectiveness. Although habitat variables and richness calculations are clearly defined, it is less clear how certain activities, particularly seismic lines or pipelines, are represented. Despite these and other undefined assumptions and some conclusions drawn from tropical literature, the article provides a good example of land use and habitat receptor modelling and identifies both positive and negative effects of habitat fragmentation using indicator species.

KEYWORDS: *ecosystem modelling, GIS, habitat suitability, parasitism, species richness.*

Stenhouse, G., J. Dugas, J. Boulanger, D. Hobson, and H. Purves. 2003. Grizzly bear cumulative effects assessment model review for the Regional Carnivore Management Group. Foothills Model Forest, Hinton, AB.
http://foothillsresearchinstitute.ca/Content_Files/Files/GB/GB_report5.pdf

This report assesses the predictive capabilities of a grizzly bear cumulative effects assessment model using telemetry and DNA data for bears in Jasper National Park. The model is based on habitat maps and assumptions about impacts from human presence. The output values are "habitat effectiveness" (the ability to support grizzly bears given human use and habitat values), and "security areas" (areas able to support foraging female adults). The model simulates linear features and human-use intensities related to forestry, mining, and recreation. The authors found a lack of strong relationships between modelled parameters and bear distribution mapped using DNA or radio-telemetry, but did not reject the model based on these findings. They suggested instead that ongoing research and model improvements be made before inclusion in cumulative effects management. This illustrates modelling uncertainties; however, models can predict information at spatial and temporal scales that would not be feasible with monitoring and measurement alone, especially in the prediction of future effects.

KEYWORDS: *animal monitoring, grizzly bears, linear features, measures, modelling.*

Weller, M.W. 1988. Issues and approaches in assessing cumulative impacts on waterbird habitat in wetlands. Environmental Management 12(5):695–701.
www.springerlink.com/content/w8345438x653m802

This review article discusses methods and systems of estimating wildlife habitat losses, particularly in wetlands, with a focus on birds as indicators of change. The author explored, at various scales, how physical, chemical, and biological processes caused by human activity may be assessed cumulatively, and derived habitat losses from population curves with both natural and experimental fluctuations. Examples of operational habitat measures are given. Birds are responsive to change and are good for monitoring impacts at a local level, but are too responsive for larger-scale or comparative studies. In addition, the author stressed the methodological problems in assessing cumulative impacts on any vertebrate habitat owing to the dynamic and complex nature of natural systems. Accurate and effective measures or limits of change are difficult to set without long-term monitoring, which may need to be developed on a site-, project-, or watershed-specific level.

KEYWORDS: *habitat change, indicator response, measures, monitoring, wetlands.*

4.2 Ecosystem-based Approaches

Abbruzzese, B. and S.G. Leibowitz. 1997. Environmental auditing: A synoptic approach for assessing cumulative impacts to wetlands. Environmental Management 21(3):457–475.
www.springerlink.com/content/tx2eyqkjbwu0xbpn

This article makes a case for using qualitative information in cumulative impacts assessments for wetlands. A "synoptic" framework is developed that conceptually links landscape subunits so that cumulative impacts may be included in management practices. Maps and available data are used to create categorical indices of land use. The authors argued that time and cost constraints, data shortages, knowledge gaps, low risks related to assumed uncertainty levels, and multiple decisions warranted this sort of qualitative approach in decision-making processes. Ideally, limits and thresholds of change are quantitative and scientifically based, and research programs are developed where knowledge is lacking. Although possibly not practical on a project-by-project basis, these analyses may be facilitated through data sharing, multi-sector co-operation, and regional management. The synoptic and qualitative approach prescribed here for wetland management can, however, constitute an important initial stage in any cumulative impacts assessment process, such as those required on an individual project basis.

KEYWORDS: *land use indices, mapping, qualitative analysis, research constraints, wetlands.*

Dubé, M., B. Johnson, G. Dunn, J. Culp, K.Cash, K. Munkittrick, I. Wong, K. Hedley, W. Booty, D. Lam, O. Resler, and A. Storey. 2006. Development of a new approach to cumulative effects assessment: A northern river ecosystem example. Environmental Monitoring and Assessment 113(1–3):87–115.
www.springerlink.com/content/153357u5r6862517/?p=046991989de84a12a6afa6854663e3f0&pi=6

This article describes a cumulative-effects approach developed under the Northern River Ecosystems Initiative (Peace, Slave, and Athabasca rivers of Alberta). The approach hinges on integrating existing data and information related to monitoring and thresholds for aquatic ecosystems. A GIS is developed to determine water-quality indices based on selected testing parameters, water guidelines, and area of interest. Measurements used by the tool include dissolved oxygen, organic carbon and oxides of nitrogen, total phosphorous and ammonia, major ions, and trace metals. Although the spatial resolution of monitoring data was found to limit spatial analysis, relationships were drawn between biological fish characteristics (size, age, condition, etc.) and water chemistry measurements. This article builds on existing data and initiatives and is an example of a good use of resources.

KEYWORDS: *baseline conditions, federal initiatives, integrated effects monitoring, thresholds, Water Quality Index.*

Halpern, B.S., K.L. McLeod, A.A. Rosenberg, and L.B. Crowder. 2008. Managing for cumulative impacts in ecosystem-based management through ocean zoning. Ocean and Coastal Management 51(3):203–211. ***http://dx.doi.org/10.1016/j.ocecoaman.2007.08.002***

In this article, comprehensive zoning plans are used to illustrate cumulative impacts concepts, such as impact pathways, scales of analysis, and the incorporation cumulative impacts management into marine planning. The authors elegantly described the theory and concepts of cumulative impacts, including differences in the dominant, additive, multiplicative, and mitigative relationships between impacts, and mathematical concepts of thresholds. The authors suggested several factors that determine impacts of any activity (e.g., spatial scale, taxonomic scale, activity frequency and duration, and the recovery time and resistance of an ecological system to an activity). Zoning is recommended to limit the combined effects of, and conflict between, various users of the marine system. An ecosystem-based approach to management utilizes changes in ecosystems services (function or value) to quantify impacts, consequences, and trade-offs imposed by various industries. The zoning approach described here may facilitate ecosystem management and activity forecasts on land as well.

KEYWORDS: *ecological recovery, marine environments, scale, thresholds, zoning.*

Scrimgeour, G.J., P.J. Hvenegaard, and J. Tchir. 2008. Cumulative industrial activity alters lotic fish assemblages in two boreal forest watersheds of Alberta, Canada. Environmental Management 42(6):957–970. ***www.springerlink.com/content/n42r6784058q7252***

The authors compared measures of fish density at impacted and non-impacted sites in two northwest Alberta watersheds to examine the cumulative effects of resource activity on fish assemblages. The dominant activities are forest harvesting and oil and gas extraction. Using historical and electro-sampled fish assemblage data, GIS land use databases, and statistical regression, the authors found that the occurrence of dominant species was directly related to development-based indices of road density and percent disturbance. To predict the occurrence of fish species, multidimensional scaling and disturbance indices were used in the creation of logistic multivariate models. Most species were negatively related to the development metrics, though some increased with disturbance. The study site was located on the provincial border and has similar ecology and natural resource activity to nearby areas in British Columbia. These models are useful for predicting how freshwater ecosystems will be affected by future development under various landscape and development scenarios.

KEYWORDS: *development indices, fish abundance, GIS, multivariate statistical modelling, watershed.*

4.3 General Multi-sector Approaches

Braat, T. 2001. Regional cumulative effects management framework for Cold Lake, Alberta. Canadian Environmental Protection Agency's Research and Development Program. Research and Development Monograph Series. ***www.ceaa.gc.ca/015/001/017/print-version_e.htm***

Primarily qualitative, this report summarizes current land uses, the potential effects of these and future land uses, and stakeholder interview results for the area of Cold Lake, Alberta. This information is used to develop a tool to assess cumulative effects of multiple sectors in the region. Land uses addressed include the oil sands, conventional oil and gas, agriculture, forestry, defence, and tourism sectors. The framework consists of a multi-stakeholder steering committee, project-specific and regional assessment processes, a research body, and regional monitoring and data management. Monitoring is imperative in establishing baseline conditions and following indicator status. This report is a good example of applying what is known about cumulative effects to develop a real-world, multi-sector, regional-level cumulative impacts assessment framework. Because multiple user groups are the origin of the impacts, basing the effects framework on inputs from multiple interests is key.

KEYWORDS: *baseline conditions, effects framework, monitoring, stakeholders, thresholds.*

Callahan, M.A. and K. Sexton. 2007. If cumulative risk assessment is the answer, what is the question? Environmental Health Perspectives 115(5):799–806. ***http://ehp03.niehs.nih.gov/article/fetchArticle.action;jsessionid=E6785C7638543C2725839508E6262AC6?articleURI=info%3Adoi%2F10.1289%2Fehp.9330***

This is a review of a US Environmental Protection Agency (EPA) program that involves the development of guidelines for "cumulative risk assessment." Here the risk is either to human health or the environment. The authors discussed the scientific background and basis for this type of risk assessment in combination with the EPA's 2003 framework. The framework is composed of three steps: (1) project scoping and conceptualization, (2) analysis, and (3) subsequent interpretation or classification of the risk. The authors used examples of risks associated with cumulative exposure to toxic chemicals to illustrate the process of cumulative risk assessment. In the analysis phase, the combined risks of exposure from multiple stressors are estimated, which is difficult because these risks are not necessarily additive; however, the dose relationships used here are additive. Although similar indices could be developed for other impact pathways (e.g., habitat disturbance), the resulting measures would not be relevant to the complex nature of ecosystem responses to accumulated, incremental effects.

KEYWORDS: *conceptualization, human and environmental health, interpretation, risk management, toxic mixtures.*

Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, National Research Council. 2000. Ecological indicators for the nation. National Academy Press, Washington, DC. ***http://books.nap.edu/openbook.php?isbn=0309068452***

This document was designed to aid policy-makers in the United States in the development of management practices to measure the indirect effects of human activities on ecological "services." It includes chapters on the foundations and concepts of indicator development; a framework for developing indicators; and the use of indicators at the national, regional, or local level. To be of relevance, indicators must be linked directly to ecological processes of the system and must be measurable. This includes possessing the available skills and data to develop conceptual models, identify indicators, and subsequently apply indicators at the desired scale. This may require multidisciplinary teams for indicator development, research, and application, allowing the same indicator to be used for the measurement of multiple effects on the same ecological system. This document not only looks at indicators and their development, but also measures thresholds of change, giving examples of indicators and systems of application.

KEYWORDS: *conceptual modelling, database management, ecosystem services, indicator development, thresholds of change.*

Culp, J., K. Cash, and F. Wrona. 2000. Cumulative effects assessment for the Northern River Basins Study. Journal of Aquatic Ecosystem Stress and Recovery 8(1):87–94. ***www.springerlink.com/content/x3w112x8u912x236/?p=03fdf3f5072b414d9e806723e875bf5f&pi=8***

The article explores a "weight of evidence" qualitative approach to cumulative effects assessment in three northern Alberta river basins (Slave, Peace, and Athabasca). This approach involves the assembly of data, development of criteria to weigh these data, and collaboration with various stakeholder groups, but ignores the additivity and synergism that may occur between individual effects. The authors examined numerous threats including chemical contaminants, land use, river flow control, and climate variability. Major management issues included dissolved oxygen, nutrient enrichment, hydrologic regime, human health, and contaminants—each ranked by level of concern at various locations along stream reaches. Of greatest concern was nutrient nitrogen enrichment downstream of pulp mills. The authors did not include all results from the Northern Basins River Study, but instead offered an overall summary of the methods and theory used in approaching cumulative effects. This report is a good example of incorporating science- and community-based objectives.

KEYWORDS: *causal criteria, monitoring, river basins, stakeholder collaboration.*

Davies, K. 1992. An advisory guide on addressing cumulative environmental effects under the Canadian Environmental Assessment Act: A discussion paper. The Federal Environmental Assessment Review Office, Hull, QC.

This guide suggests a framework for approaching project-level cumulative effects in federal impact assessments. Projects should be related to past, present, and future developments in the same area. A single project's ability to stimulate further development also needs to be evaluated along with any immediate or indirect effects this may have on ecological systems. Examples of cumulative effects parameters are given for land, air, water, ecology, and resource factors, as well as for social, cultural, economic, and health factors. Parameters relevant to wildlife are substance accumulation, habitat loss/fragmentation, biotic health effects, nutrient budgets, and changes in productivity or species composition. The framework includes steps for creating historical and future development profiles, assessing effects from these developments, collecting ecological data, predicting future outcomes, analyzing mitigation measures, and developing continuous monitoring programs. Although not a step-by-step guide for executing project-specific cumulative effects assessments, it provides a template for developing techniques, measures, and scales for such studies.

KEYWORDS: *effects framework, effects parameters, land use planning, monitoring, scoping.*

Dixon, J. and B.E. Montz. 1995. From concept to practice: Implementing cumulative impact assessment in New Zealand. Environmental Management 19(3):445–456. http://commerce.metapress.com/content/p32714h78214740u/?p=9c63d9e120a54f49b5821712a4ae5146&pi=11

This review article responds to a 1991 law requiring the consideration of cumulative impacts as part of traditional impact assessment in New Zealand. Although practical methodologies to do so did exist, the authors described ways by which traditional assessments could be modified to include cumulative impacts at a management level. Rather than offer a scientific or predictive basis for assessment, they provided a means to evaluate outcomes that arise cumulatively from management decisions. One of the methods presented is the layered matrix, which evaluates impacts through a hierarchy of direct, secondary, and tertiary impacts. The second method involves a network of flow diagrams feeding from various activities, along routes of synergistic, additive, or individual impacts into regional components (receptors). Of these conceptual planning approaches, the matrix design is tidier, and likely useful at the initial planning stage of any project requiring cumulative effects management.

KEYWORDS: *conceptual diagrams, hierarchal approach, policy, project-based assessments, regional planning.*

Givertz, E.H., J.H. Thorne, A.M. Berry, and J.A.G. Jaeger. 2008. Integration of landscape fragmentation analysis into regional planning: A statewide multi-scale case study from California, USA. Landscape and Urban Planning 86(3–4):205–218. http://dx.doi.org/10.1016/j.landurbplan.2008.02.007

The authors used "effective mesh size" to quantify habitat fragmentation in California. Ecologically and spatially relevant, this measure is based on the probability of two random points in the same region existing within the same non-fragmented habitat patch (i.e., the distance a wild animal can travel before encountering an obstacle). They calculated effective mesh size at various scales using GIS overlays of roads, highways, agriculture, urban areas, and natural disturbances. Roads were found to cause the most fragmentation and agriculture the least. Jurisdictional boundaries, having no geophysical basis, created bias in the landscape metric at boundary edges. Effective mesh size is a useful measure of habitat fragmentation that can be applied to any natural resource sector causing direct habitat disturbance; however, this metric should be used in combination with other measures in cumulative impacts assessments to ensure the inclusion of other impact pathways.

KEYWORDS: *ecological measures, habitat fragmentation, GIS, landscape metrics.*

Great Sand Hills Scientific Advisory Committee. 2007. Great Sand Hills regional environmental study: Final report. Government of Saskatchewan, Regina, SK.
www.environment.gov.sk.ca/2007-104GreatSandHillsEnvironmentalStudy

This study integrates biodiversity and strategic environmental assessment in a sparsely populated area of Saskatchewan primarily subject to grazing as well as oil and gas development and recreational activities. A result of 2 years of intensive research, the webpage provides links to the final report's summary, chapters, and appendices. This project is the closest we found to a "true" cumulative effects/ impacts assessment. It sets clear levels of scale (regional- and landscape-level), includes monitoring to set baseline conditions, uses a model (MARXAN) to assess areas for conservation, and assesses surface disturbance under three alternative scenarios. Resulting map layers are used to develop planning principles and policy recommendations to protect economic and wildlife values. The recommendations for land use decisions rooted in principles of biodiversity and conservation are bound to reduce some impacts on wildlife elements.

KEYWORDS: *baseline monitoring, GIS, scenario forecasts, trend projections, valued ecosystem components.*

Hegmann, G., C. Cocklin, R. Creasey, S. Dupuis, A. Kennedy, L. Kingsley, W. Ross, H. Spaling, and D. Stalker. 1999. Cumulative effects assessment practitioners guide. Prepared by AXYS Environmental Consulting Ltd. and the CEA Working Group for the Canadian Environmental Assessment Agency, Hull, QC.
http://dsp-psd.pwgsc.gc.ca/Collection/En106-44-1999E.pdf

This federal guide outlines methods for addressing cumulative (biophysical) effects under the *Canadian Environmental Assessment Act*. The guide provides rough "best practices" for determining cumulative effects and a step-by-step approach to completing assessments. Valued ecosystem components are used as indicators of unacceptable impacts. Through the guide's background, case studies, and "lessons learned," the importance of setting the scope and scale of project-based cumulative effects assessment is illustrated. The guide stresses meeting the needs of the project in question, as well as addressing any combined impacts with existing and future land uses. Intended for government personnel, consultants, and proponents, the guide does not describe legislative requirements of cumulative effects assessments, but rather provides a starting point for such assessments. The assessment of "cumulative" or future effects requires an element of prediction. According to the guide, this prediction cannot be "hypothetical"; however, hypothetical land use scenarios may prove essential in regional effects mitigation and planning processes.

KEYWORDS: *case studies, guidelines, project-based assessments, thresholds, valued ecosystem components.*

Kennett, S. 2006. From science-based thresholds to regulatory limits: Implementation issues for cumulative effects management. Environment Canada Northern Division.
www.ngps.nt.ca/Upload/Interveners/Environment%20Canada/071121%20EC%20Report%20-%20 From%20Science-Based%20Thresholds%20to%20Regulatory%20Limits.pdf

This report clarifies issues and concepts associated with the implementation of thresholds in cumulative effects assessment. Thresholds provide an indication of a particular value, whereas limits are specific values that stem from threshold-based management—an important distinction. This report emphasizes the acceptance, establishment, and implementation of limits through planning and accounting for necessary trade-offs. The author cited the Muskwa-Kechika pre-tenure plans of northeastern British Columbia as the first example of indicator use in northern Canada, but stressed that the regional implementation was hindered by extensive promotion of resource development and a lack of First Nations involvement. As one recommendation, the author suggested the use of thresholds to manage adverse effects rather than to hinder resource development. This is a helpful clarifying and guidance document to both develop and implement the use of thresholds and limits in cumulative effects management (such as through a cap-and-trade system).

KEYWORDS: *implementation, planning, regulatory limits, thresholds, trade-offs.*

Forest Practices Board. 2008. Terms of reference for a special investigation: A cumulative effects assessment of the Kiskatinaw Planning Unit, Dawson Creek, British Columbia. Victoria, BC.
www.fpb.gov.bc.ca/assets/0/114/178/186/358/0f742d38-97c6-4f0d-990f-4821df74f40b.pdf

These terms of reference are part of a Forest Practices Board audit of natural resource sectors with tenures in British Columbia's Kiskatinaw River watershed. The team is assessing the cumulative impacts of multiple industries on water quality, soil conservation, and caribou (*Rangifer tarandus*) habitat values. Indicators used include road length, density and sediment hazard, stream condition, length of stream affected, and forest cover lost. Indicators are mapped over time, from 1940 to the present, in an attempt to divide the various long-term effects among different land uses. This project is simple and elegant, and is a particularly clear example of a way to measure cumulative impacts across industries using indicators and wildlife-relevant thresholds. It fails, however, to look at impacts on water and soil quality other than those of sediment and erosion; the sectors in question may also be affecting ecosystems through atmospheric, water, or land-based emission pathways.

KEYWORDS: *caribou habitat, historical data, indicators, soil conservation, thresholds.*

Kilgour, B., M. Dubé, K. Hedley, C. Portt, and K. Munkittrick. 2007. Aquatic environmental effects monitoring guidance for environmental assessment practitioners. Environmental Monitoring and Assessment 130(1–3):423–436.
www.springerlink.com/content/g4674271362611w8/?p=dc5bda82aa2b4d63bf6e019922e5dcdf&pi=37

This article attempts to bridge gaps between pre-approval environmental assessment and post-operational environmental effects monitoring in Canada. The result is essentially a design for cumulative effects assessment that includes environmental thresholds and biological indicators. The example used here is for aquatic ecosystems receiving effluent from mines and pulp mills. Various sampling, monitoring, and assessment designs are graphically illustrated along stream reaches. Although the authors stressed that biological-effects monitoring (rather than physical or chemical) is necessary to understand biological response, this approach does not include the possibility of time lags and dynamics between ecosystem change and a measured response in the indicator species. This problem can be minimized by monitoring lower trophic levels (e.g., benthos). The choice of indicator or threshold depends largely on the project and its assessment budget, but this article clearly illustrates methodology that can be extended to various sectors and management programs.

KEYWORDS: *effects monitoring, fish, indicators, thresholds, wastewater effluent.*

Laurance, W.F., T.E. Lovejoy, H.J. Vasconcelos, E.M. Bruna, R.K. Didham, P.C. Stouffer, C. Gascon, R.O. Bierregaard, S.G. Laurance, and E. Sampaio. 2002. Ecosystem decay of Amazonian forest fragments: A 22-year investigation. Conservation Biology 16(3):605–618.
www3.interscience.wiley.com/journal/118954154/abstract?CRETRY=1&SRETRY=0

This research is part of an experimental study examining the effects of habitat fragmentation on various wildlife species. Species' abundance data are recorded both before and after fragmentation for grazing purposes and compared over 22 years. Results show information that relate edge effects and patch sizes to wildlife presence, trophic structure, and dynamics. Species abundance is strongly affected by fragment size, both positively and negatively, depending on the species. The authors also found synergistic interactions between fragmentation and other stressors, such as fires and hunting. Although the fragmentation was a result of grazing-land clearance (and not truly "experimental"), fragmentation is a common element of most resource sectors. This article reveals some possible effects pathways from the tropics (which should be extrapolated to other environments with caution). It also illustrates the importance of field data and monitoring in identifying impact pathways and end points.

KEYWORDS: *Amazon, edge effects, fragmentation, species abundance.*

MacDonald, L.H. 2000. Evaluating and managing cumulative effects: Processes and constraints. Environmental Management 26(3):299–315.
www.springerlink.com/content/r57xymdf8npn9kh7/?p=6c8084424949410db452ba9978725581&pi=4

This article proposes a process to alleviate the major problems associated with cumulative effects evaluation and management. The problems include setting the scale and determining interactions, and the process involves a tiered approach and minimizing local impacts. The article elucidates differences between additive and synergistic effects, and the legal background for cumulative effects policy development in the United States, using clear explanations and examples. The emphasis is on watershed effects, which constitutes the largest body of knowledge. The author defined phases in the process for scoping, analysis, and management including specific stages within each phase, feedback loops, and examples. The process presented is comprehensive and logical, highlighting the inclusion of natural processes, variability, and recovery. The author stressed limitations associated with any cumulative effects methodology and offered both impact minimization and adaptive management as alternative, or parallel, approaches to managing cumulative effects.

KEYWORDS: *adaptive management, landscape indices, nesting, recovery, watersheds.*

Monterey County 21st Century Program. 2004. Cumulative impacts. **In** ***21st century Monterey County general plan: Environmental impact report. Salinas, CA. Chapter 6.***

Like other Californian studies, this report classifies cumulative impacts by the "resources" that are affected. The report considers the impacts of multiple future development sectors (e.g., housing, agriculture, and wineries) on various "resources" (e.g., geologic, historic, biologic, and air quality). Although the report looks at multiple sector impacts, the driving force of all impacts is projected population growth. The report uses future population growth scenarios to determine the extent and intensity of the impacts discussed. While interesting in its structure, this report offers little new information or methodology, and is unfortunately not quantitative. It provides no measures or limits, but does do a good job of discussing potential impacts qualitatively—for instance, how improper water treatment could lead to freshwater nitrification/eutrophication.

KEYWORDS: *growth scenarios, qualitative analysis, transportation, urbanization, valued resources.*

Noble, B.F. 2008. Promise and dismay: The state of strategic environmental assessment systems and practices in Canada. Environmental Impact Assessment Review 29(1):66–75.
http://dx.doi.org/10.1016/j.eiar.2008.05.004

This review article examines the theory and practice of "strategic environmental assessment" (SEA) in Canada. The author gives a history of SEA, including its federal beginnings as a Cabinet Directive for assessing the impacts of a policy, plan, or program. The evaluation criteria for SEA are grouped by system, process, and result components. Cumulative effects criteria fit within the process component. The criteria are not equal, but vary by policy or by program. Similarly, cumulative effects criteria vary based on the aim and scope of the assessment. Ten case studies are provided and include a description, criteria review, and follow-up with the SEA practitioner. Examples related to the natural resource sector include energy, land use, urban, trade, forestry, waste, and trade-based initiatives. SEA is most useful if carried out before implementing a strategic decision. It can complement cumulative effects assessments by identifying preferred options and decision-making processes.

KEYWORDS: *criteria, decision making, legislation, policy, tiered approaches.*

Schneider, R. 2002. Cumulative impacts.* In *Alternative futures: Alberta's boreal forest at the crossroads. The Federation of Alberta Naturalists and Alberta Centre for Boreal Research. pp. 63–81. www.borealcentre.ca/reports/book/5%20Future.pdf

In this paper, the ALCES® model is used to facilitate land use analysis over a 69 000 km^2 study area in northern Alberta. The author tracked past and potential development of seismic lines, wells, agriculture, forest harvesting, towns, transmission lines, and peat mining. This model does not have a spatial modelling component. To facilitate spatial analysis, users must stratify the landscape into subunits that are tracked independently. Although ALCES cannot predict effects on wildlife, the author cited and described various studies (some discussed in this report) that have linked wildlife populations to industrial footprints in Alberta. In general, this intensive land use has been found to directly reduce bird numbers and available mammal habitat. The model may be helpful in predicting future landscapes, as long as approached from a specialized and technical view of the sector(s) in question, so that spatial stratification is realistic.

KEYWORDS: *integrated resource management, mapping, model assumptions, modelling.*

Schneider, R.R., J.B. Stelfox, S. Boutin, and S. Wasel. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: A modeling approach. Conservation Ecology 7(1):8. www.consecol.org/vol7/iss1/art8

The authors used the ALCES model to predict the cumulative landscape impacts of multiple development practices in a region of Alberta over the next 100 years. The research compares impacts between current "piecemeal" regulatory frameworks and an alternative "best-practices" management scenario. Disturbance types included in the model are limited to forest harvesting, petroleum exploration and development, road construction, and fire. The authors found human-origin edge to be the dominant measure of impact. Current practices occur at both a high economic cost and at the cost of the forest land base, thereby reducing harvestable timber and available wildlife habitat. The development scenarios were projected based on current activity and economic trends. The ALCES model simulates multiple activities and appears to have significant potential for evaluating and minimizing the cumulative landscape effects of natural resource industries throughout British Columbia, but it requires a spatially explicit component to be relevant to wildlife.

KEYWORDS: *cost analysis, impact measures, modelling, regulatory frameworks.*

South Coast Air Quality Management District. Cumulative Impacts Working Group. Diamond Bar, CA. www.aqmd.gov/rules/ciwg/index.html

This webpage for a multi-stakeholder working group includes industry, government (the district), and environmental/citizen organizations in southern California. The outputs from this working group (formed in 2003) are cancer-risk maps and a "White Paper" report available on the webpage. The paper looks at the cumulative impacts of multiple pollutants from multiple sources (transportation corridors, industry) on sensitive receptors (schools, residences, low-income communities) using a grid- and map-based prediction approach. Although the project examines cumulative sources of air pollution, the effects are limited to issues of human health and nuisance. Effects relevant to British Columbia may include forest health effects, ecosystem acidification, and direct damage to plant or animal health. Cumulative effects of air pollution on wildlife may be approached in a similar way as human health effects, using different exposure thresholds for wildlife receptors.

KEYWORDS: *air quality, human health, mapping, risk analysis, thresholds.*

Spaling, H. and B. Smit. 1993. Cumulative environmental change: Conceptual frameworks, evaluation approaches, and institutional perspectives. Environmental Management 17(5):587–600. http://dx.doi.org/10.1007/BF02393721

This review article describes both scientific- and planning-oriented conceptual frameworks for cumulative effects assessment, and examines the relationship between theory and practice. Topics of discussion include the shortcomings of traditional environmental impacts assessments in approaching cumulative effects, how to overcome these inadequacies (e.g., by regional-scale assessments), and various frameworks and classifications of what the authors termed "cumulative environmental change." This article gives a balance of concepts and methods used in assessing cumulative environmental change up to the time it was written. It is approached from a Canadian perspective including a regulatory analysis and comparisons with the United States. The authors stressed the need for a plural approach to effects assessment that incorporates scientific, planning, analytical, and institutional methods to cumulative effects assessment.

KEYWORDS: *causal models, frameworks, history of cumulative effects, legislation.*

Wilson, B. and B. Stelfox. 2008. Indicator synthesis: Selection rationale, modelling results, and monitoring considerations for key indicators of the Terrestrial Ecosystem Management Framework. Silvatech Group, Salmon Arm, BC. www.cemaonline.ca/index.php/component/docman/doc_download/1454-sewg-temf-indicator-synthesis-final-june-5-2008

This report defines land use indicators for use in cumulative impacts research and assessments and devises a terrestrial ecosystems management framework. This includes base case and future scenario predictions, forecasts of indicator performance, indicator sensitivity, regional objectives, and natural ranges of variability. Wildlife indicators include habitat of black bears (*Ursus americanus*), moose (*Alces alces*), fisher (*Martes pennanti*), birds of old-growth forests, woodland caribou (*Rangifera terandus caribou*), and an index of native fish integrity. Future scenarios and performance were predicted using the ALCES model. As the model is not spatially explicit, "Map Now" software has been designed to give it a spatial (mapping) component. Furthermore, ALCES is stochastic, using random numbers to predict development patterns that are not random. Although the derivation and scientific significance of the measures used (habitat effectiveness index) are unclear, these measures may provide a useful basis for indicator selection.

KEYWORDS: *land use indicators, management framework, modelling, wildlife indicators.*

5 DISCUSSION

The annotated references above represent a wealth of information. Some are obviously more relevant than others, but all provide some insight into the assessment of cumulative effects from natural resource development on ecosystems and wildlife. Individual sector components reveal numerous impact pathways, wildlife responses, and potential measures, providing many of the necessary tools for impact evaluation and management. Multi-sector studies take this one step further and examine potential interactions between impact pathways or resource sectors. Some of the methodologies are purely conceptual and qualitative; others involve complex numerical simulations of future states or ecosystem responses. In sum, this bibliography illustrates the diversity of cumulative effects approaches, the breath of potential impacts, and the complexity of interactions that occur within a shared land base.

Whether single-pathway effects studies or regional cumulative effects frameworks, some common themes emerged, including:

- the use of GIS for mapping, analyzing, and modelling land uses and their impacts;
- the use of ecosystem monitoring for various signs or measures of impacts;
- the use of thresholds or limits to determine, through monitoring (or modelling), whether or not undesirable impacts are occurring;
- the importance of choosing an appropriate scale in achieving realistic results for any level of approach;
- the use of modelling as a surrogate for monitoring or to predict future land use or ecosystem responses; and
- the occurrence of fragmentation as a common impact pathway of all sectors affecting all forms of wildlife.

Multi-sector studies appear better suited to the exploration of multiple (rather than individual) impact sources and pathways. Few single-sector examples or approaches of cumulative impacts assessment or management were found. This is not to say that none exist, but only that they were not readily available or selected as per the methods discussed at the outset of this report. The assessment of cumulative effects involves beginning at the source level and measuring or predicting outcomes from past, present, or future actions. Cumulative effects management, however, can begin at the desired state or outcome and then devise plans of action to ensure that these desired outcomes are met.

Strategic environmental assessment employs this type of management approach and focuses its efforts on the decision-making outcomes. Noble (2008, *discussed above*), reviewed the use of these assessments thus far in Canada. The Canadian Council of Ministers of the Environment (CCME) has a new initiative that employs what it calls "regional strategic environmental assessment" (R-SEA). This assessment method is designed to combine cumulative effects assessment with strategic effects assessment to arrive at desirable, rather than inevitable, outcomes. The MARXAN model uses end-point conservation goals to employ appropriate land use decisions, and the Great Sand Hills Project is given as an example of R-SEA in the CCME consultation document. For the full CCME document on R-SEA and suggestions for One Project–One Assessment-based approaches, go to: *www.ccme.ca/ourwork/environment.html?category_id=135*. Sector-specific reviews of impacts, indicators, pathways, and measures can be conceptually useful in combining elements to perform multi-sector assessments. At the same time, regional approaches such as R-SEA can be used to help steer project-specific cumulative effects assessments that may be required by legislation.

In British Columbia, strategic (formerly "sustainable") resource management plans (SRMPs) exist for some regions, and define directions and priorities based on end-use goals such as the resolution of land claims and resource conflicts or the provision of investment certainty. In contrast, land and resource management plans (LRMPs) are more detailed and based on the principles of integrated resource management. Both plan types examine social and economic factors in addition to environmental ones. Conceptual similarities also exist between each of the planning processes and cumulative impacts evaluation. Both planning processes make use of indicators and thresholds to determine the viability and targets of management plans; however, neither deals directly with cumulative effects. The LRMPs are comparable to the scoping stage of a regional cumulative effects assessment. It is possible that the two processes could evolve to complement one another.

Some particular impact pathways (e.g., fragmentation) are common to all natural resource sectors. This facilitates multi-sectoral co-operation and the development of regionally specific wildlife indicators and thresholds. Other pathways, such as water usage and contamination, often have sector-specific, if not site-specific, measures and indicators associated with them. Physical impacts may be more unifying of natural resource sectors, but biological and chemical pathways are often unique. The interactions between these impacts mean they require unique measures and limits. One example of a biologically relevant chemical limit that can be applied to multi-sector activities is "critical load." Estimates of critical load are used to set limits on atmospheric acidic and/or nutrient deposition (from all sources) to fresh water, soil, or forests. Limits are based on the total input that the system can absorb (usually per year) before unacceptable change occurs to an organism or soil quality (indicator). Although not included in this publication, examples of critical loads application in policy and management exist for parts of Canada, the United States, and throughout Europe.

6 RESEARCH/KNOWLEDGE GAPS

Gaps exist in the literature pertaining to both cumulative impacts and single-sector environmental impacts. Specific sectors lacking in effects research are fisheries and aquaculture, agriculture and wineries, tourism and recreation (other than motorized trail use), and wind power (other than avian impacts). These sectors likely lack this information owing to their exclusion from traditional environmental impact assessment requirements (unless issues exist regarding waste disposal, protected species, or the clearance of substantial tracts of public land). The impacts to wildlife and ecosystems posed by waste from any sector (other than agricultural runoff) are also under-represented in the literature, despite provincial and federal mandates to assess these impacts from a regulatory perspective. In addition, although research from all over the world exists regarding particular effects from individual mines (most of which was not included in this document), mining is a sector not generally looked at from a cumulative impacts perspective; long-term impacts, or those that occur in combination with impacts from other sectors or mines sharing the land base, are rarely included.

No established communities of practice within the policy, research, or natural resource management realms address cumulative impacts, despite the wealth and diversity of literature suggesting how these should be developed and implemented. Also lacking are well-defined measures and thresholds to determine, regulate, and manage cumulative impacts. Thresholds require limits of a spatial and/or temporal significance to wildlife. In British Columbia, these measures should be relevant to provincial wildlife and ecosystems. Some indicators do exist for forest management in the province and are applicable to multi-sector physical impacts, but these indicators and measures are lacking for other sectors and impact pathways. For instance, little documentation exists for landscape-level chemical and biological effects, or how these can be measured or monitored within the province. These effects are especially dynamic and synergistic between sectors as they occur beyond the physical space of the natural resource activity or licence area. If impacts are to be avoided, the evaluation of these impacts requires collaboration across sectors. For instance, a knowledge of how much effluent ends up in the same river from sources at various locations along its length depends on working together, as is illustrated by the Northern River Basins Study (*Culp et al. 2000*) and Ecosystem Initiative (*Dubé et al. 2006*). One limitation to co-operation or the development of standards across sectors is the lack of information and data flow between industries and agencies and the issues of confidentially which may exist with these types of data sources.

No truly spatially explicit method or model exists to simulate the ecological and resource processes responsible for impacts or their expression. Models such as ALCES or MARXAN simulate landscape changes, but do so by dividing or stratifying the landscape into units or strata, across which all things are considered equal. Spatial stratification of the landscape into units means that the space is treated as discrete (rather than continuous) and location is implicitly (rather than explicitly) defined. Although this sort of approach is relevant for any perspective already dictated by spatial units of division (zoning, planning, etc.), such strata may not be as relevant to wildlife unless the strata are developed specifically to represent particular ranges or habitats. These methods also do not account for natural heterogeneity or patchiness within landscape units. To account for this spatial variability, data may need to be collected on a general, or assessment, basis.

Despite the number of articles and projects reviewed here, none represent a complete or ideal multi-sector, long-term cumulative impacts assessment. This "ideal" would also include management options and potential mitigation measures. Even though this ideal may not be necessary or even desirable for some levels of assessment, the elements of such an approach are described below.

7 RECOMMENDATIONS AND CONCLUSIONS

From an analysis of the above literature, the following recommendations are made to aid the development of cumulative impacts assessment guidelines for British Columbia's natural resource sector. Depending on whether the assessment is regional, project-based, strategic, or specific to a single wildlife element, some or all of these suggestions may be necessary. We suggest that the analysis of cumulative impacts should (in no particular order):

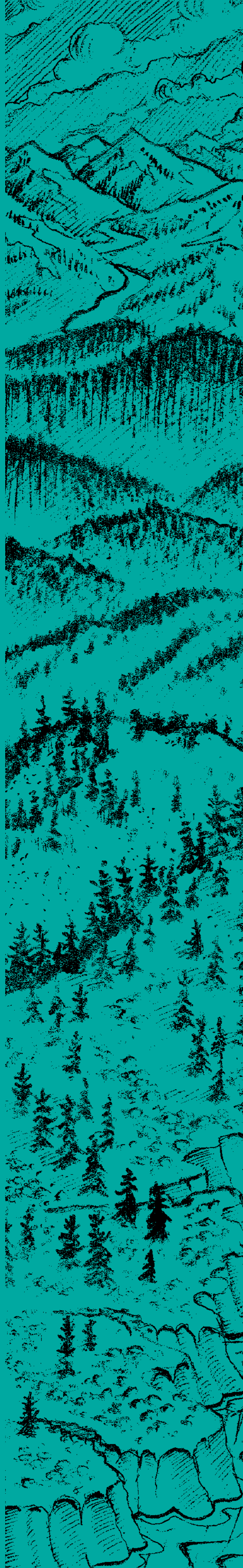
- be based on sound scientific principles of experiment, measurement, and monitoring
- be spatially and temporally explicit (unless from a zoning/parcel perspective)
- make use of all available tools and data (GIS, databases, etc.)
- include ecosystem monitoring, preferably continuous
- simulate the dynamic physical, biological, and chemical processes that drive future landscape or ecosystem change
- include the development of criteria, measures, and limits of undesirable change that are relevant to local wildlife receptors
- approach impacts from a multi-sectoral, regional scale
- adapt to new knowledge and research
- provide an analysis of development scenarios and alternatives
- incorporate First Nations knowledge into continuous environmental monitoring efforts and the development of indicators, thresholds, and limits

Not all of the above suggestions may be needed as our knowledge improves. For instance, once we have data from long-term monitoring programs (and some may already exist), we can develop thresholds and models that can be standardized and used to substitute monitoring for regulatory purposes (e.g., permits). A similar approach is taken to air pollution permitting in British Columbia that, despite its weaknesses, is very efficient.

Of the suggestions listed, the most difficult to carry out is the simulation of future processes. Although predictive techniques have been used in the meteorological sciences for decades, cumulative impacts prediction includes an element of behaviour and choice from which the atmosphere is luckily exempt. It is this human behavioural element that makes the future of development, and its associated impacts, so difficult to predict. Some have overcome this obstacle through the use of zoning to legislate potential land use outcomes. Recently, some have retreated from attempts to accurately predict the future in cumulative impacts work, moving instead towards an exploration of possible outcomes made through various assumptions (such as with SEA). The analysis of alternative actions is essential to understand the outcomes of planning decisions, or to reach a desired state. Outcomes from particular scenarios can be used to optimize the planning process. This has been seen in the CCME's plan for R-SEA and in the MARXAN model, which optimizes conservation units based on societal, economic, and ecological values.

The more sectors or resource activities that can be included in a cumulative impacts assessment, the better and, in theory, the more realistic its results. Increasing complexity, however, may amplify the error associated with these evaluations. Regional assessments are suggested because impacts are far-reaching. Institutionally, this can also aid in data flow because individual project proponents may not be equipped with the necessary data or expertise to consider multi-sector cumulative impacts. Unless some sort of policy is developed to promote the sharing of information and data in a way that balances confidentiality and privacy issues, some of this data may not be available on a regional basis. To increase ecological relevance, the regional (assessment) boundaries should have some geophysical basis (e.g., a watershed); however, this may at times cause undesirable overlap between jurisdictions.

The preceding bibliography and discussion aims to provide natural resource practitioners and managers with increased knowledge and understanding in relation to impacts on ecosystems and biodiversity posed by their, and other, natural resource sectors. The multi-sector section provides information on frameworks and methodologies already in practice that can be used, modified, and built upon for various cumulative impacts applications. Key concepts can be utilized by any sector to expand or design its own framework for a particular application. Through the process of evaluating the cumulative effects from natural resource activities on wildlife in British Columbia, we will inevitably gain a better understanding of the measures and indicators required for various applications. This will likely require intensive monitoring and data collection (in some parts of the province more than others), but the information obtained could reach across sectors and disciplines, beyond cumulative effects evaluation, and have far-reaching benefits for the future of this province. Any method we use must be adaptive to new knowledge, new data, and new developments. In that sense, it doesn't really matter where we begin, only that we do.



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