Fisheries and Oceans Canada | Pêches et Océans Canada

5204-50th Avenue Suite 301
Yellowknife, NT
X1A 1E2

Your file *Votre référence*
EA1314-01

June 12, 2015

Our file *Notre référence*
15-HCAA-00266

Mackenzie Valley Environmental Impact Review Board
Attention: Mark Cliffe-Phillips, Executive Director
P.O. Box 938
Yellowknife, NT X1A 2N7

Dear Mr. Cliffe-Phillips:

Subject: Dominion Diamond Ekati Corporation – Jay Project, Second round of information requests

Fisheries and Oceans Canada – Fisheries Protection Program (DFO-FPP) has reviewed the intervention provided by the Mackenzie Valley Environmental Impact Review Board (MVEIRB) on June 5, 2015 during the second round of information requests (IR) for Dominion Diamond Ekati Corporation's (the Proponent) Jay project. The intervention addressed specifically to DFO contained the following questions:

1. MVEIRB IR#12: "Does the construction of a temporary diversion channel built exclusively for migration purposes meet the requirements of a DFO offsetting and/or compensation plan? If, at this stage, DFO is unable to make a determination on this question, what additional information would allow them to make their determination?"

   As mentioned at the technical meeting DFO-FPP can't confirm whether or not designing the diversion channel exclusively for fish migration meets the requirements of a DFO-FPP offsetting plan at this time. More information will be required during the regulatory phase in order to make this determination. For your information, the proponent received a DFO- licence to fish for scientific purposes on May 14, 2015 to carry out additional baseline studies in Streams Ac35, B0 and B1 from May 18, 2015 to September 30, 2015. These baseline studies should provide more information on the species of fish that utilize these waterbodies, and which stages of their life cycle are carried out in these waterbodies. Once we have reviewed this information DFO-FPP will be able to confirm whether or not the diversion channel as currently designed meets our requirements or if it will need to be redesigned.

2. MVEIRB IR #16: "What type of confidence in population estimates does DFO require in order to adequately develop an Offsetting Plan with Dominion? Additionally, with what level of conservatism will DFO approach this plan's development, given the high level of uncertainty involved?"

   It is acknowledged that there is uncertainty associated with fish population estimates provided during the Environmental Assessment Phase. The population estimates will be confirmed during the fish-out program. Generally, the proponent provides an estimate of the fish population in the offsetting plan; if based on the data from the fish-out program it is determined that the proponent underestimated the population, they have to offset for the actual loss of fish and not the estimated amount. During the Regulatory Phase, the *Fisheries Act* authorization will specify that the fish population is to be confirmed during the fish-out.

If you have any questions, please contact Véronique D'Amours-Gauthier at 867-669-4912, by fax at 867-669-4940, or by email at veronique.damours-gauthier@dfo-mpo.gc.ca. Please refer to the file number referenced above when corresponding with DFO-FPP.

Yours sincerely,

Georgina Williston

Georgina Williston
A/Senior Fisheries Protection Biologist
Fisheries Protection Program

cc:
Véronique D'Amours-Gauthier, DFO-FPP

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E-MAILED June 8/15

Chuck Hubert
Senior Environmental Assessment Officer
Mackenzie Valley Review Board
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5102-50th Avenue
Yellowknife, NT X1A 2N7
Email: chubert@reviewboard.ca

June 5, 2015

Re: EA1314-01 – Jay Project Information Request – Round 2

Dear Mr. Hubert,

The Deninu Kue First Nation (DKFN) is pleased to provide the following information requests regarding the Jay Project. The Jay Project is within the current and traditional socio-economic use areas as identified in the Deninu K'ue Ethno-history Report prepared by Vanden Berg and Associates. The area north of Great Slave Lake is home to an abundant amount of wildlife, fish and plants that are of meaningful use to the Akaitcho Dene. The project area has been used by the Akaitcho Dene since time immemorial for hunting, fishing, trapping and gathering. We look forward to being involved in the environmental assessment of this project and offer the *following information requests based on information presented in the* Developer's Assessment Report (DAR) and at the Technical Session in April of 2015.

DKFN IR#1 Reference: Section 12 Barren-Ground Caribou

Preamble: In its assessment, the Dominion Diamond Ekati Corporation (Dominion Diamond) has assumed, what it calls the maximum potential effect of the project, meaning that caribou were conservatively assumed to be deflected by the Jay Project (and the full Ekati project). Despite, this approach, Dominion Diamond does acknowledge that all caribou will not be deflected around the project since mitigation plans are being developed for the project roads.

Information Request: If caribou are in close proximity to the mine infrastructure it is expected that they would experience higher levels of stress and increased energy expenditures, exposure to poorer forage quality (as a result of dust deposition) compared to if they were deflected around the mine at the zone of influence distance. The overly conservative approach taken by Dominion Diamond may be unrealistic and not representative of the true condition and unknown effects may occur that are not accounted for in the DAR. Given the current population status and declines of the Bathurst Caribou Herd, additional stewardship activities from industry are warranted. Therefore we request the following:

a. Based on data from past monitoring programs at the Ekati Mine, what proportion of the Bathurst caribou herd can be expected to interact with the mine infrastructure?
b. What proportion of the current population, based on the most recent population estimates, of the Bathurst caribou herd does this represent?

DKFN IR#2 Reference: Section 12.4.2.3 Behavior, Energy Balance, and Calf Production – Energetic Costs from Development and Insect Harassment (page 12-114).

Preamble: In this assessment Dominion Diamond assumes that caribou are exposed to one major disturbance event per day when residing within a zone of influence (ZOI).

Information Request: Please provide a description of what "one major disturbance event" would be?

DKFN IR#3 Reference: Section 12.4.2.3 Behavior, Energy Balance, and Calf Production – Energetic Costs from Development and Insect Harassment (page 12-116).

Preamble: In the last paragraph of this section the proponent states:

> For those summers when insect harassment is low, female encounters with disturbance would be required to exceed 525 disturbance events so that there is an expenditure of 20% of 100 kg (i.e., 20 kg), and no calf production the following year. If considering the effects from severe insect harassment and disturbance encounters, then approximately 385 disturbance events per individual would be required to reduce parturition to zero, resulting in no calf production. Based on the expected number of disturbance encounters for current landscape conditions with the Project and future developments (approximately 28), female caribou would have to increase their encounter rate per day by approximately 14 to19 times to result in no calf production the following spring.

Information Request: Please clarify for the results of this analysis the reference to female encounters. Is this referring to all females within the Bathurst Caribou Herd or caribou on an individual level?

DKFN IR#4 Reference: Section 12.6.2 Results (page 12-131).

Preamble: In the last paragraph on this page the proponent states:

> Natural environmental factors that operate over large scales of space and time will likely have greater influences on seasonal distributions of caribou than the incremental and cumulative impacts from the Project and other developments. For example, studies of caribou have shown that the historical cumulative effect of overgrazing on calving, summer or winter ranges can result in periodic range shifts and large population fluctuations (Messier et al. 1988; Ferguson and Messier 2000; Tyler 2010). Climate change and weather can also influence the seasonal distribution of caribou by modifying insect levels, food abundance (primary productivity), timing of spring plant growth, snow depth and hardness, predator numbers (and alternative prey), and burns (Sharma et al. 2009; Vors and Boyce 2009; Festa-Bianchet et al. 2011; Kerby and Post 2013).

Information Request: We request that the proponent confirm:

a. Have periodic range shifts and large population fluctuations of the Bathurst Caribou Herd been attributed to overgrazing on calving, summer or winter ranges within the past five years?

b. How climate change and weather has influenced the seasonal distribution of the Bathurst Caribou Herd over the past five years?

DKFN IR#5 Reference: Section 15.4.1.2.1 Effects on Traditional Wildlife Harvesting – Residual Effects Summary on Traditional Wildlife Harvesting (page 15-45).

Preamble: In the last paragraph on this page the proponent states:

> As a result of the above factors, negative cumulative effects are predicted for effects on traditional wildlife harvesting that will impede the ability to harvest wildlife in some preferred areas. However, alternative preferred areas and resources are expected to continue to be available and unaffected. The incremental effects of the Project alone are expected to result in only minor effects on the continued opportunity to participate in traditional wildlife harvesting.

Information Request: We request that the proponent confirm:

a. Where the proponent believes the alternative preferred areas and resources that are expected to continue to be available and unaffected are for members of the Deninu Kue First Nation?

DKFN IR#6 Reference: Section 17.8 Barren-Ground Caribou (Cumulative Effects Assessment)

Preamble: On page 17-22 in the second paragraph, the proponent makes the following statements in regard to the cumulative effects assessment on caribou:

> Effects from sensory disturbance on habitat quality and calf production are anticipated to be reversible in the long term (***perhaps*** 5 to 10 years following the end of closure of a project), and ***should*** be within the resilience limits and adaptive capacity of the Bathurst herd. (emphasis added)

Information Request: The proponent has not instilled a high level of confidence in the cumulative effects assessment when subjective words are used. We request that the proponent:

a. Provide a cumulative effects assessment on the Bathurst Caribou Herd with a higher level of certainty in the assessment.

DKFN IR#7 Reference: Appendix 9A – Conceptual Offsetting Plan

Preamble: In its conceptual offsetting plan the proponent has identified several options that focus on local fisheries of concern and engage communities.

Information Request: Will the proponent agree to exploring offsetting options with the DKFN around the community of Fort Resolution?

DKFN IR#8 Reference: Conceptual Wildlife Effects Monitoring Plan, Jay Project

Preamble: Eight main objectives are identified in section 1.4 of the Wildlife Effects Monitoring Plan that fulfill requirements of the Environmental Agreement. A further four objectives are identified in section 3.2 as overall objectives of monitoring and then individual objectives for various components of the WEMP are identified in section 5.

Information Request: The objectives of the WEMP should focus on measureable parameters that will determine 1) if the predicted effects identified in the environmental assessment are realized; 2) if the proposed mitigation measures are effective and 3) if further actions are required to reduce effects. In addition, the monitoring of various components related to wildlife are only meaningful when results are related to the direct and/or indirect effects on wildlife species. For example, monitoring of direct habitat loss from the mine development should be placed in the context of the direct and/or indirect effects on wildlife species. We request:

a. Clear objectives for the WEMP be identified that can be monitored and tracked during the life of the project. This approach should be similar to that taken for the objectives identified in the Conceptual Aquatic Effects Monitoring Program Design Plan.

In closing, we look forward to further engagement in the review process of this project. Should you require any clarification on our information request please contact our technical advisor, Marc d'Entremont, at mdentremont@lgl.com or 250-656-0127.

Sincerely,

Chief Louis Balsillie

cc. Rosy Bjornson, DKFN Resource Management Coordinator
Marc d'Entremont, LGL Limited (DKFN Technical Advisor)

Environmental Protection Operations Directorate
Prairie & Northern Region
9250 – 49 Street NW
Edmonton, Alberta T6B 1K5

June 5, 2015

EC file: 5100 000 012/015
MVEIRB: EA1314-01

Chuck Hubert
Senior Environmental Assessment Officer
Mackenzie Valley Environmental Impact Review Board (MVEIRB)
Box 938, 5102-50th Ave
Yellowknife, NT X1A 2N7

Via Online Registry

RE: EA1314-01 - DDEC - Ekati Diamond Mine - Jay Project Developers Assessment Report – Second Round Information Requests

Environment Canada (EC) has reviewed the information provided in the first round of Information Requests (IRs) and undertakings resulting from the technical session regarding the above-mentioned Environmental Assessment and is submitting IRs via the online review system as requested by the Mackenzie Valley Environmental Impact Review Board (MVEIRB). EC's specialist advice is provided pursuant to the *Canadian Environmental Protection Act, 1999*, the pollution prevention provisions of the *Fisheries Act*, the *Migratory Birds Convention Act, 1994*, and the *Species at Risk Act*.

Should you require further information, please do not hesitate to contact Sarah-Lacey McMillan at (867) 669-4724 or sarah-lacey.mcmillan@ec.gc.ca.

Sincerely,

Susanne Forbrich
Regional Director

cc: Loretta Ransom, A/Head Environmental Assessment North (NT & NU), EPOD

Attachment: Excel Sheet with EC's IRs

Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2012/112 | **Document de recherche 2012/112**

National Capital Region | **Région de la capitale nationale**

A science-based interpretation of ongoing productivity of commercial, recreational or Aboriginal fisheries

Une interprétation scientifique de la productivité continue des pêches commerciales, récréatives ou autochtones

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TABLE OF CONTENTS

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ABSTRACT

Canada's *Fisheries Act*, amended in 2012, refers to 'sustainability and ongoing productivity of commercial, recreational or Aboriginal fisheries'. A conceptual framework for a science-based interpretation of ongoing productivity of fisheries is described. The productivity of a fish population is determined by vital rates (reproduction, growth and survival) and by life history traits (fecundity, age at maturity). The vital rates regulate population abundance, biomass and fish production. Fish production rate is the rate that biomass is accumulated per unit area per unit of time. Fisheries yield (landings) is a function of total fish production. Fisheries are often comprised of more than one population or species. Fisheries productivity, in the context of the Fisheries Protection Provisions (FPP), is interpreted as the sustained yield of all component populations and species, and their habitat, which support and contribute to a fishery in a specified area. Sustainability, biodiversity, and measurement uncertainty are key dimensions of ongoing productivity that need to be kept in mind within the conceptual framework. Population abundance is dynamic over time, but to be sustainable, the management of habitat-related physical impacts and other threats must be done such that populations can rebuild within a reasonable period of time if they become temporarily depleted. The new Provisions focus on a larger, functional spatial scale (landscape, population or fishery) than the localized project scale that was the case historically. Three categories of projects that vary in spatial scale and complexity were identified: small scale projects involving loss of habitat area, diffuse projects that impact vital rates through changes in habitat quality, and large projects that result in ecosystem transformation. To be operational and to measure impacts at a landscape scale, the appropriate surrogates of productivity will vary depending on the project category, ranging from habitat-based approaches, where ongoing fish productivity is inferred from the quantity and quality of habitat, to more direct measures of fisheries productivity (such as yield) for larger scale projects. Two pressing needs for implementation are a clear description of the operational tools available to measure productivity at the landscape scale, and a new precautionary framework to guide fishery protection to maintain productivity and ecosystem function.

RÉSUMÉ

La *Loi sur les pêches* fédérale, modifiée en 2012, fait référence « à la durabilité et à la productivité continue des pêches commerciales, récréatives et autochtones ». On décrit un cadre conceptuel pour une interprétation scientifique de la productivité continue des pêches. La productivité d'une population de poissons est déterminée par des indices vitaux (reproduction, croissance et survie) et des paramètres du cycle biologique (fécondité, âge à la maturité). Les indices vitaux régissent l'abondance de la population, la biomasse ainsi que la production de piscicole. Le taux de production du poisson est le taux correspondant à la biomasse accumulée par unité de surface par unité de temps. Le rendement de la pêche (débarquements) est fonction de la production piscicole totale. Les pêches ciblent souvent plus d'une population ou espèce. La productivité des pêches, dans le contexte des dispositions sur la protection des pêches, est interprétée comme étant le rendement soutenu de toutes les composantes des populations et des espèces, ainsi que de leur habitat, qui soutiennent la pêche dans une zone définie et qui y contribuent. La durabilité, la biodiversité et l'incertitude relative aux mesures sont les principaux éléments de la productivité continue qui doivent être pris en compte en ce qui a trait au cadre conceptuel. L'abondance de la population est dynamique à long terme, mais pour qu'elle soit durable, il faut gérer les impacts physiques sur l'habitat et les autres menaces de manière à ce que les populations puissent se restaurer dans un délai raisonnable en cas d'épuisement temporaire. Le nouveau programme de protection des pêches met l'accent sur une échelle spatiale plus générale et fonctionnelle (paysage, population ou pêche) que celle généralement utilisée par le passé. On a défini trois catégories de projets dont la complexité et l'échelle spatiale varient : des projets à petite échelle associés à une perte de la superficie d'habitat, des projets diffus qui ont une incidence sur les indices vitaux à cause de changements dans la qualité de l'habitat, et des projets à grande échelle qui entraînent une transformation de l'écosystème. Afin de pouvoir être opérationnels et mesurer les impacts à l'échelle du paysage, les substituts appropriés de la productivité varieront selon la catégorie du projet, allant d'approches fondées sur l'habitat, pour lesquelles la productivité continue du poisson est déduite à partir de la superficie et de la qualité de l'habitat, à des mesures plus directes sur la productivité des pêches (comme le rendement) pour des projets à plus grande échelle. Deux besoins urgents de mise en œuvre sont une description claire des outils opérationnels disponibles pour mesurer la productivité à l'échelle du paysage, et un nouveau cadre de précaution pour orienter la protection du poisson afin de maintenir la productivité et la fonction de l'écosystème.

1. ONGOING PRODUCTIVITY

The purpose statement of the Fisheries Protection Provisions in the 2012 revisions to the *Fisheries Act* (s 6.1) is 'to provide for the sustainability and ongoing productivity of commercial, recreational or Aboriginal fisheries'. The term 'ongoing productivity' is stated again in section 6 as the first of four factors that must be taken into account in making fisheries protection decisions. Section 6.1(a) is 'the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries'.

The objective of this paper is to provide an operational interpretation of 'ongoing productivity'. Many of the threats to fisheries that will be regulated by DFO are physical impacts, often habitat-related, that occur at the scale of individual works, activities or undertakings. The challenge is how to connect these physical impacts to the ongoing productivity of commercial, recreational and Aboriginal (CRA) fisheries. To make this connection, the first step is to move toward a functional interpretation of productivity, which not only has a sound science base, but also can be applied in a consistent manner under a range of operational circumstances in marine, coastal, estuarine, riverine or lacustrine areas.

CONCEPTUAL INTERPRETATION

Ecological productivity is defined by Oxford Dictionaries Online as 'the rate of production of new biomass by an individual, population, or community' or 'the fertility or capacity of a given habitat or area' (e.g., 'nutrient-rich waters with high primary productivity'). To elaborate on an interpretation of ongoing productivity with respect to CRA fisheries, we start from a species and population context, and then move to a fisheries and ecosystem perspective. The ultimate goal is to provide an operational interpretation consistent with an ecosystem framework for fisheries protection. Much of the discussion below provides a conceptual framework for productivity that can be used in the real-world decision making, and helps to clarify the properties that indices and units must have to inform the operational application and measurement of ongoing productivity. We encourage the use of common terminology (Randall 2003) for Fisheries Protection and Ecosystem and Fisheries Management.

Productivity

Productivity of a fish population is determined by the vital rates of reproduction, growth and survival, and life history characteristics of the population such as fecundity and age at maturity. Key vital rates are used as measures of productivity, and they are the factors that result in population abundance or biomass The United Nations Food and Agriculture Association (FAO), Fisheries Department, describes the factors that affect productivity of a stock: 'relates to the birth, growth and death rates of a stock. A highly productive stock is characterized by high birth, growth and mortality rates, and as a consequence, a high turn-over and production to biomass ratios (P/B)' (www.fao.org/fi/glossary/default.asp); alphabetical list of terms). Productivity of a population is inherently reflective of a species' life history strategy, which often involves suites of co-evolved traits (e.g., age at maturity, longevity, fecundity, etc.) that ultimately dictate their productivity (Charnov 1993; Musick 1999). The three basic vital rates of reproduction, growth and survival are also affected by threats (stress), including declines in habitat suitability or fishing. Expected changes to these rates can be used to measure the potential effects of threats on productivity (Power 2007).

From a population-level perspective sustained exploitation by a fishery is predicated on the productivity of the population being sufficient to allow harvest. The intrinsic rate of population growth ($\lambda = N_{t+1}/N_t$) is a summary metric that is used to describe population productivity. When the population is increasing either as changes in abundance or biomass over time, $\lambda > 1$. In standard fish population theory, populations have their highest rate of intrinsic growth when spawners are adequately numerous to saturate suitable habitat for eggs and early larvae, but overall abundance of each life history stage is low enough that competition for limiting resources (food, space) is low. When a population is near its carrying capacity, density-dependent processes strongly constrain further increases in abundance and no population increase is expected ($\lambda \approx 1$). Populations with a higher productivity can be sustainably exploited at higher rates. Productivity varies within populations over time (Bradford and Irvine 2000; Peterman and Dorner 2012), or spatially among populations of the same species (MacKenzie et al. 2003; Mantzouni et al. 2010), because of changes differences in environmental factors (e.g., temperature, ocean currents) or interactions with other populations or species (competition, predation).

Recruitment (the production of new individuals for the adult population) often can serve as a measure of productivity. A key aspect of recruitment rate is the slope at the origin of stock recruitment (SR) relation. This is the maximum possible rate of production of new recruits per unit of adult spawner abundance or biomass, when density-dependent processes are at their weakest. Beverton-Holt and Ricker SR models with biological reference points are shown in Fig. 1. However, there are often statistical challenges with this approach, as many years of stock and recruit data are required for robust fits to S-R data. The SR relationships are not linear because density-dependent constraints increase with increasing abundance. The maximum rate of recruitment potential is measured as the expected number of recruits per spawner when the numbers of spawners is small (slope at the origin; e.g., Myers et al. 1997).

The ubiquity of density-dependent feedback processes in the juvenile stages is central to sustainable harvest levels, and consequently to decision-making about sustainable exploitation rates and patterns. Because direct measures of density-dependent feedback processes are hard to make, surrogates must incorporate this concept when the necessary data do not exist to parameterize an S-R functional relationship for a stock. In general, threats to the population that occur prior to the density-dependent stage will have less impact on population productivity than those that take place after density-dependent mortality occurs (Power 2007), because of the inherent compensation properties of density-depending population regulation processes. A reduction in abundance in an early life stage will be compensated to some extent by lower mortality at the density-dependent stage. Only very strong density-dependent mortality can completely offset losses in the early life stages, particularly when such losses are anomalously high. Such situations are reported in some stream-dwelling salmonids that have very strong density dependence and can withstand large losses of spawners or eggs without significant effect on smolt production (Bradford et al. 2000). However, the density-dependent processes cannot compensate fully for impacts that reduce a habitat carrying capacity (whether the impacts are human or not) when that habitat is used by life history stages after the main density-dependent filter has been applied.

Fish Production

The population vital rates, identified in the previous section, determine the fish production rate which in turn determines the potential yield to fisheries. Fish production rate is the 'total elaboration of new body substance in a stock in a unit of time, irrespective of whether or not it survives to the end of that time' (Ricker 1975). Fish production has a spatial and temporal context, and the production of a fish population depends on the amount and quality of habitat required for each life stage. The unit of time for measurement of production is often one year, and the units of production are total numbers of fish or kilograms (produced) for a specific species and fishing area (number yr^{-1} or kg yr^{-1}), or as relative units of kilograms (or number) per hectare per year (kg ha^{-1} yr^{-1}).

There are many methods and models for estimating fish production. The instantaneous growth method (Chapman 1978), where P is calculated as the product of growth ($G_{\Delta t}$) and average biomass (B) for a defined time period (Δt), helps conceptualize production as the dynamics involving growth and survival of all cohorts up to and during the interval of interest, with recruitment rate determining the initial year-class size. Mertz and Myers (1998) provide simplified but more detailed formulae for production, where growth is offset by losses from natural morality (plus fishing mortality if the population is being harvested).

Production as a rate is rarely measured directly, but recognition of the concept of production is central to any operational framework that has a sound scientific basis. Our interpretation of practical and attainable measures of surrogates of production and their limitations are discussed in the Operational Implications section.

The ratio of mean annual production to mean annual biomass (P/B) is a measure of the turnover rate of a population, and is linked to production and productivity for both fishes and aquatic invertebrates (Dolbeth et al. 2012). The instantaneous growth rate equations (above) can be restructured to show that the P/B ratio is equal to biomass-average somatic growth ($P/B = G_{\Delta t}$). P/B has been shown empirically to be inversely related to body size and life span (Dickie 1972; Banse and Mosher 1980; Peters 1983). Randall and Minns (2000) used allometry with fish size to estimate P/B and, subsequently to parameterize a production index based on the product of P/B and seasonal average fish biomass. Average fish biomass and fish production rate, by calculation, are highly correlated. For the purpose of an operational interpretation of productivity, P/B can be a shortcut method of estimating production rate, noting that ratio estimators have additional statistical problems.

Yield

Yield is the fisheries catch; units are often kg or number per area per unit time. Fishing catch and yield are often used interchangeably; exceptions are if catch includes catch and release data, or if discarding of dead fish is common, in which cases catch statistics and yield (landings) would be different. Potential yield is a component of production, and for marine fisheries, production is frequently estimated from yield using suitable adjustment factors (Mertz and Myers 1998; Power 2007). Mertz and Myers (1998) indicated that yield could be used as a proxy for production if yield to production ratios were know. Recent research has shown there are many problems with using landings as an exact surrogate of stock biomass (Branch et al. 2011; Daan et al. 2011). For the data used by Mertz and Myers (1998), Y/P ratios were found to vary from 0.3 to 0.8, depending on the species and trophic level.

The sustainable yield to a fishery is also proportional to the size of the population, which is often determined by a life stage that is limited by the amount of suitable habitat for it. Such limitations might be apparent by the size of the lake or stream, or more subtly, being defined by areas of suitable temperature, ocean currents, biological productivity or other factors. Bradford et al. (2000) describe examples of habitat limitation for Coho Salmon and Mantzouni et al. (2010) show relations between cod population size and habitat area.

Sustainable yield is often impacted by recruitment, the process that results in new individuals being added to the adult populations. Productive populations have higher rates of juvenile production per spawner, usually because the environmental conditions and habitats available for spawning and rearing result in relatively good survival and growth and produce healthy recruits that can contribute to the adult population. Many populations are constrained by habitat limitation in the egg-to-juvenile stages (causing density-dependent mortality; Myers and Cadigan 1993; Bradford et al. 2000), and in these cases yield will be maximized by a combination of the amount and quality of habitat available at the pre-recruit or recruitment stages of a species' life history.

Sustainability is discussed further below in the context of ongoing productivity.

Fisheries Productivity

Fisheries in a particular area are sometimes comprised of multiple populations or species. Ongoing productivity of CRA fisheries is interpreted here as the sustained yield of one or all CRA fish species that comprise a fishery in a specified fishing area. Ongoing is interpreted as being sustained productivity, as experienced by participants in the fishery at and just before the time of interest.

This text best describes our interpretation of 'sustainable and ongoing productivity of CRA fisheries' as stated in the new FPP. Supporting species (Kenchington et al. 2013) and the species and habitats that contribute to ongoing productivity (Koops et al. 2013) are implicitly included in this interpretation.

Ecosystem Productivity

Ecosystem productivity is dependent on ecosystem structure and function (Worm and Duffy 2003; Naeem et al. 2012), and can be measured indirectly as multispecies cumulative biomass (for marine environments, see Bundy et al. 2012) or primary or secondary production (Dolbeth et al. 2012). The theory associated with ecosystem productivity is complex. Although it is conceptually important to include the concept of ecosystem productivity because of bottom-up influences on fisheries productivity, it is challenging to use this concept practically. Indices of factors influencing multi-species productivity at multiple trophic levels (e.g., total phosphorus, TP) are sometimes used as predictors in empirical whole-system models to estimate fish biomass or fisheries yield (Table 1). Ultimately, the fishable biomass cannot exceed a cap set by primary production (Pauly and Christensen 1995), but this upper bound is rarely reached because of other limiting factors. The effect of physical habitat modifications on ecosystem productivity will likely be manifested by its effect on the productivities of component species.

PRODUCTIVITY AND SUSTAINABILITY

Sustainability is explicitly mentioned in s 6.1 of the *Fisheries Act* in the phrase "sustainability and ongoing productivity of commercial, recreational or Aboriginal fisheries".

The Webster's dictionary definition of sustainable is: 'of, related to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged'.

A commonly used definition of sustainable development is: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." which is from the World Commission on Environment and Development's (the Brundtland Commission) report Our Common Future (World Commission on Environment and Development, 1987). The UNCED definition is the basis for Canada's government-wide Sustainable Development Policy.

The *Federal Sustainability Development Act* indicates that sustainability "means the capacity of a thing, action, activity, or process to be maintained indefinitely" (laws-lois.justice.gc.ca). Sustainability is usually defined as achieving a balance between the carrying out of current-day activities while allowing for future generations to achieve their needs. Most definitions of sustainability recognize present day and future human needs for natural resources, and the limits of the natural environment to sustain growth. For fisheries, sustainability has been described at different scales by Hilborn (2005). The narrowest perspective concerns single populations or stocks and is often framed in the traditional fisheries management context of maintaining yield and historical allocations, both preferably within the relatively narrow bounds of an "optimal" value. Control systems attempt to regulate human activities (particularly fishing) in a manner to keep abundance and yield within acceptable levels (Rice 2009). Implicit in this approach is the notion of fundamental stability and resilience of the ecosystem (sometimes incorrectly characterized as 'the balance of nature') and that fish stocks can be sustained by adjusting harvest rates.

A slightly broader definition is based on the concept of intergenerational equity and aligns with the Bruntland Commission definition of sustainable development. This view recognizes that populations will fluctuate, and some may decline significantly with exploitation or changing environmental conditions, but the basis of fisheries (the target species and their ecosystem) should be managed such that future human needs can be satisfied. There is less focus, in this perspective, for maintaining current conditions, relative to the notion of maintaining conditions that will permit a fishery in uncertain, and likely different, future conditions. For example, Hilborn (2005) proposes that if a stock becomes depleted but can be rebuilt within a generation, then that could be considered a sustainable practice. Hilborn's broadest perspective considers a combined biological and human ecosystem and recognizes that a human system of exploitation can be sustainable despite large changes that can include changes to human societies and the ecosystems they use. This perspective is most consistent with modern day definition of sustainable development that is based on three axes: environmental protection, economic growth and social equity.

Sustainability of fish populations

The sustainability and ongoing productivity of fish populations depends on the amount and quality of the habitats (Fig. 2) required for each life stage, interactions with other species, and the appropriate management of fisheries and anthropogenic threats. For long-term sustainability, it is important to acknowledge that known activities (e.g., fishing, physical impacts) can be managed, but unknown factors affecting productivity can only be reacted to, once detected.

Fish populations vary significantly at annual and longer time scales, and predictions of future states are highly uncertain. While the fluctuations of small pelagic fishes such as herring and sardines are well known, as population data accumulates for other species, it is apparent that large changes in abundance can occur, often independent of human factors such as habitat change or exploitation (Hilborn et al. 2003; Peterman and Dorner 2012). Thus sustainable fish populations are not constant ones, but rather are populations that have the inherent capacity to be productive when their habitats and environmental conditions permit.

Sustainability and ongoing productivity of fisheries

Sustainable development is based on the premise that opportunities of future generations should not be compromised by present-day decisions or actions. For fisheries, this definition of sustainability allows for changes in individual populations or species, recognizing that individual components of a fishery (or an ecosystem that supports a fishery) will fluctuate over time. The benchmark condition is not an unfished stock, rather it is a stock that is exploited but not to the point where future recruitment is diminished. Sustainability ensures that important or key species (Kenchington et al. 2012) are not driven by anthropogenic threats to levels of abundance that changes their role in the ecosystem, nor results in the impairment of the productivity or genetic potential of the species. Similarly, the structure and function of the supporting ecosystem are maintained to allow some combination of species or populations to be sufficiently productive to sustain a fishery. This view is supported by recent work on the notion of "biocomplexity" which argues that the productivity of individual populations constantly changes with environmental factors and we cannot predict which species or populations will flourish (or decline) in the future (Hilborn et al. 2003). Fisheries are most likely to be sustainable when both species diversity, and the genetic and population diversity within species is maintained (Hauser and Carvalho 2008). Analogies have been drawn between investment portfolio diversity and biocomplexity (Schindler et al. 2010) - in the financial world investors have poor success in picking stocks, and this has led to a strategy of managing risk and sustaining returns using a portfolio of diversified investments. Similarly, biologists have little success in anticipating changes in productivity in fish populations. Hilborn et al. (2003) proposed that the best strategy for sustainable fisheries is to ensure management decisions do not compromise the potential for any constituent population or species to contribute to future fisheries. A management strategy under this paradigm would include ensuring the potential productivity of the necessary habitats of all life stages for key populations and species within the portfolio. Other anthropogenic threats (pollution, non-endemic disease, invasive species, domestication/cultivation impacts) should be managed to allow for present day and future productivity. Lastly, the maintenance of intra-specific diversity should be achieved by protecting a sufficient number of population segments from extirpation through exploitation or other threats.

<u>Time and the sustainability and ongoing productivity of fisheries</u>

The notion of allowing for present-day needs without compromising future conditions within the concept of sustainable development does not preclude short-term or transitory impacts on the environment. For example, rotational harvest strategies could cause local impacts but could be sustainable if the prospects for rebuilding were high under a reasonable time frame. Similarly, impacts to habitat caused by construction activities could also be managed in a manner that would not cause a long-term impact on productivity, although there could be short-term impacts to some cohorts until habitats recover.

There is no explicit guidance on the duration of impacts to fisheries productivity that would be consistent with the definitions for sustainability. The FAO's guidelines for deep-sea fisheries (FAO 2009) provide the following advice:

"Temporary impacts are those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. Such time frames should be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems. In determining whether an impact is temporary, both the duration and the frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary. In circumstances of limited information, States and RFMO/As (regional fisheries management organizations and arrangements) should apply the precautionary approach in their determinations regarding the nature and duration of impacts."

An important point from the FAO definition is that reoccurring transitory threats could be considered permanent impacts if the habitats or stocks cannot recover between events. Examples could include rapid changes in flow in a regulated river, or repeated impacts to river or ocean floors such as dredging or bottom trawling.

For Pacific salmonids the concept of recovery in one generation (typically 4-6 years) after the cessation of the threat (in this case fishing; Johnston et al. 2000) was used to define abundance-based target reference points (Holt and Bradford 2011). This definition is roughly consistent with the FAO guidelines for recovery.

An example of a temporary threat that is limited in scope and duration is provided by studies on the impacts of pipeline crossings of streams (summarized by Lésveque and Dubé 2007). Typically, those activities result in the release of sediment and disturb the stream bed, which can cause short-term stress on fish and their food supply. However, recovery generally occurs within a year (or few years in some cases) after the scouring effects of the freshet. From a sustainable productivity perspective, the impact is shorter than the life cycle of stream-dwelling fish, and any impacts to productivity are expected to be short lived.

PRODUCTIVITY AND BIODIVERSITY

The ecological concepts of ecosystem productivity, biodiversity and resilience are linked (Worm and Duffy 2003; Worm et al. 2006) and these linkages have received a great deal of attention in the scientific literature over the past 20 years (Naeem et al. 2012). The original purpose of this research was to investigate how biodiversity affected productivity via the simple question “does the production of biomass vary predictably with the change in species richness” (Naeen et al. 2012). While scientific debate continues on this subject, as richness is only one component of biodiversity (see Allen et al. 2002; Soininen et al. 2012; Naeen et al. 2012), a few generalities that are relevant to fisheries productivity have emerged.

A more diverse ecosystem tends to have higher overall productivity and is generally more resilient to perturbation, both natural and anthropogenic (Cardinale et al. 2006; Naeem et al. 2012; Worm et al. 2006), possibly because of the portfolio effect which was introduced earlier. Biological diversity is thought to stabilize ecosystem processes and the services they provide (Schindler et al. 2010). Biodiversity has several dimensions: taxonomic, phylogenetic, genetic, functional, spatial and landscape (Naeem et al. 2012). In fisheries, for example, landscape diversity and/or habitat complexity have been shown to positively correlate with both production (Carey et al. 2010) and yield (Bracken et al. 2007). Similarly, diversity in life history traits (a type of functional diversity) has been shown to increase productivity and resilience in relatively species poor salmonid communities (Hilborn et al. 2003; Gibson et al.1993).

A second trend that emerges from recent biodiversity research is that there are gradients of biodiversity that exist in nature within all the major ecosystem types (Allen et al. 2002; Oberdorff et al. 1995). Globally, biodiversity is highest in the tropics and reduces on a latitudinal gradient (Allen et al. 2002). This observation has been linked to both the availability of resources and temperature (Allen et al. 2002) although there is still debate on this topic (Soinien et al. 2012). On a regional or geographic scale physical factors such as ecosystem size (Oberdorff et al. 1995; Dodson et al. 2000; Dembkowski and Miranda 2012) and climate interact with historical factors such as dispersal patterns to determine species richness. Dispersal patterns have been shown to be particularly important for determining species composition and richness in Canada’s freshwater fishes (e.g., Mandrak and Crossman 1992; Scott and Crossman 1964). Local biological, (i.e., predation and competition) and physical factors (i.e., habitat complexity) which are nested in the two larger scales are then the final determinates of ecosystem biodiversity (Oberdorff et al. 1995).

Direct threats to biodiversity include over exploitation, pollution, habitat destruction/alteration and introduced species (Worm et al. 2006; Smith et al. 2012). Climate change may also indirectly affect biodiversity by changing habitat conditions (e.g., temperature regimes, flow patterns, ocean biogeochemistry etc.) and/or biological conditions especially with relation to introduced species (Smith et al. 2012). Management of the threats to biodiversity should strive to ensure healthy and productive aquatic ecosystems which in turn will produce healthy commercial, recreational and aboriginal fisheries. The fisheries protection provisions will focus on the threats to habitat and those posed by invasive species while other threats will be managed by different instruments and measures.

Projects that either remove a portion of habitat or reduce a habitat that appears to be plentiful are challenging to deal with from a biodiversity/productivity point of view. Habitat quality can have a large effect on population productivity (see elsewhere) as can single physical stressors (e.g. water temperature, sedimentation; Koops et al. 2013) but the question of how much habitat is required to protect biodiversity and ecosystem services such as fishery yield is a topic of much debate (Rolf 2009). Much of this debate is occurring in the conservation literature both for freshwater (Williams et al. 2011) and marine (Rolf 2009; Rondinini and Chiozza 2010) systems but the concepts and methods are relevant to habitat management practices. Rondinini and Chiozza (2010) recently reviewed quantitative methods for setting percentage area targets to protect habitat types for marine conservation and found that at present no one ideal method existed and the overall conservation goal and data availability really decided which method could be used. This means that these projects will still require management on a case by case basis using some form of risk assessment.

Introduced species or aquatic invasive species are another threat to biodiversity that will be managed by the fisheries protection provisions. Invasive species directly change species richness and through biological interactions can affect ecosystem functioning (Smith et al. 2012). Probably the best known example of this is the introduction of the zebra mussel to the Great Lakes which drastically changed water clarity in these systems (Strayer 2009). While the southern areas of Canada have had the most invasive species in the past and remain at risk to new invasions (Smith et al. 2012; Chu et al. 2003) range expansion related to climate change is also expected to affect the north (Prowse et al. 2009).

Ecosystems are complex and the changes induced by a habitat alteration/destruction or introduced species may not always be immediately evident, which makes predictions difficult. Couple this difficulty with fact that the results of diversity changes may take time to fully equilibrate (e.g., reservoir creation, see Milbrink et al. 2011) and the case for strong monitoring programs linked to an adaptive management framework can be made for projects that are expected to reduce ecosystem diversity, either through reduced habitat complexity or species richness. Finally it is important to point out that ecosystem changes that result in changes to local biodiversity can sometimes benefit preferred fisheries species. These situations, however, should be viewed as the exceptions rather than the expectations of biodiversity change.

Specifics of biodiversity components to support ongoing productivity of CRA fisheries are described in detail by Kenchington et al. (2013).

2. OPERATIONAL IMPLICATIONS

SPATIAL SCALE

Consideration of spatial scale will play an important role in the assessment of a project-based impact on fish or their habitat, and in the application of s.6 in departmental decision making. The scale of a project's direct impacts are usually well defined, however, the spatial context in which those impacts are considered will affect the tools and metrics to be used and criteria (particularly the factors of section 6) to be used for decision making.

The 1986 Policy operated at the smallest spatial scale by attempting to mitigate or offset each habitat-based impact with the goal of maintaining or replacing the function of the impacted habitat. It was implicitly assumed this approach would minimize or negate the effects of the project at all broader spatial scales.

As indicated in Section 1 of this paper the revised *Act* seeks to "provide for the sustainability and ongoing productivity of CRA fisheries" suggesting that broader spatial scales than the project's immediate footprint are the most relevant scales for evaluation. Decisions about spatial scale are ultimately policy choices but there are some science-based issues that we consider here. We note that the discussion is focused on development projects, but could also apply to other non-project based threats to productivity (particularly Aquatic Invasive Species, AIS).

Scales larger than the project could be considered in at least three ways: landscapes, biological populations, or fisheries.

From a landscape-level perspective, the most likely scale that would be considered is matched to physical features that roughly support ecosystems. In freshwater these could be watersheds (likely mid-order), small and medium sized lakes, and basins or arms of larger lakes. In the coastal area individual estuaries or bays and physically defined areas of the ocean may be an appropriate scale for assessing projects. A landscape-based assessment might consider the amount and value of habitat of various types within the unit, the severity of existing impacts to the unit, and the project impact relative to these factors. Habitat-based assessment tools would predominate in this context, but habitat-based biological indicators (such as lower trophic levels) could also be used in cases where projects alter food or energy webs. The landscape-level approach is probably the scale that will be most appropriate for cumulative effects assessment, and is expected to be important for the definition of Ecologically Significant Areas, so there will be some commonalities if this scale is given prominence in evaluations.

A higher level of scale is biologically-based and considers the impacts of projects on CRA fishery species. A demographic or genetic definition of population could be used here. For restricted populations (those that occupy a lake or stream), the geographic scale of this approach may not differ from the landscape level one, but in other cases where populations are broadly distributed, the population scale could be much larger. A biologically-based definition of scale will likely entail a population-dynamics based approach to the assessment of project impacts, in order to evaluate the change to population abundance or productivity.

Finally, a potentially broad spatial scale is that of the fishery, depending on defining what constitutes a fishery. In some cases, the fishery is well-defined and the associated populations can be easily identified. In other cases the fishery has no clear boundaries and a decision about scoping will need to be made. These could include existing fishery management units, but could also include other factors based on local use, for example. An assessment at this scale will ultimately attempt to estimate the changes to key fishery indicators (yield, catch rates, species composition, and others).

THE PRECAUTIONARY APPROACH AND PRODUCTIVITY

Even in the most information-rich settings there will be uncertainty about the productivity of a population contributing to CRA fisheries, as well as the physical impact of an activity on the productivity, regardless of the spatial scale of the project. At the same time, the consequences of some impacts to a population's productivity could be serious and difficult to reverse. Under those circumstances, it is appropriate to apply precaution in decision-making (PCO 2003).

In fisheries harvest management, the application of precaution in decision-making is aided by a structured approach, using three categories of stock status (Healthy, Cautious, and Critical) and a rate of allowable impact (fishing mortality) that varies systematically with the category in which the stock falls, based on its assessment (Rice 2009). The framework is anchored by a limit reference point for stock biomass (the critical – cautious boundary), where fishing mortality is at the lowest level possible to achieve through management. This Limit Reference Point is in turn determined by a stock-recruit relationship or other appropriate method to estimate how stock productivity varies with stock size. The objective is to prevent the stock reaching a state (the Critical zone) where productivity is impaired such that stock rebuilding would not be rapid and secure if fishing mortality were minimized. The other key position on the stock status axis is the cautious / healthy boundary, whose position is determined by the overall uncertainty in the estimation of the Limit Reference Point, the estimation of annual stock size relative to that reference point, and the uncertainty about the effectiveness of management. That is, the higher the total uncertainty, the wider the Cautious zone. Thus when uncertainty is high management actions to reduce exploitation rate begin at larger relative stock sizes than when uncertainty is lower.

This framework is well grounded in theory and has proven to be operational over wide ranges of types of stocks and fisheries, and of quantities and qualities of data. Its performance is robust (guides management in the right direction and in the proper general magnitude of response) even if much more data and time-demanding approaches to supporting harvest decisions under uncertainty can be shown to be more precise for our most information-rich stocks.

The situation with implementing the new provisions of the *Fisheries Act* has some important similarities to harvest management as framed above. There will be uncertainty about how productivity of a population that is part of a CRA fishery varies with the state of the habitat, uncertainty about how an activity/undertaking will alter key characteristics of the habitat, and uncertainty about how effective any mitigation or compensation measures could be. In the major activities/undertakings to which the new provisions are intended to apply, there will be at least sometimes risk of harm that would be serious and difficult to reverse, especially since the alterations of habitat could be permanent. Therefore precaution will need to be applied in decision-making about these activities/undertakings, and a similar framework for guiding the advice on application of precaution will be needed.

Work has been done to generalize the fisheries precautionary framework to a much wider range of environmental issues, including habitat impacts (Rice 2009). The concepts all transfer fully to these broader contexts, but few operational applications have been attempted. However, any approach to implementing the new fishery protection provisions in specific cases is going to require at least general identifications of how productivity is expected to vary with habitat status, the point at which productivity has been impaired such that improvement is no longer expected to be rapid and secure, and the uncertainty in these factors. Those are all the properties needed to adapt and apply the same three-category framework to fisheries protection as is done in fisheries management. There would be benefits to science, to management and policy, and for communications, if we are able to apply a known and tested framework in supporting the application of precaution implementing the fishery protection provisions of the *Fisheries Act*. These ideas will be fully developed by Koops et al. (2012), and are implicit in our discussion of operational implications above, and in the "applications" section below.

Uncertainty with respect to impacts to the affected habitat and species, and subsequently to the ongoing productivity of fisheries, would be directly related to the type of habitat and to the spatial scale of the project.

APPLICATION

The application of the preceding ideas can be aided with a more explicit description of the types of projects that may be considered in decision-making. To simplify the discussion, we focus on development projects that would be handled by the referral process and define three categories of projects by their type of impact and scale as:

1. Smaller scale infills/alterations or exclusions (barriers) that render habitat unusable to fish populations ("destruction"). From a population/fisheries dynamics perspective these are less likely to affect the productivity of individuals of the impacted population; rather they may change the carrying capacity of the ecosystem. This will impact the size of the fish population and the sustainable yield (moving left along the horizontal axis of Figure 2) by removing habitat from the system. The magnitude of change to fisheries productivity will depend on the size of the project and the significance of the habitat being removed from the system.
2. "Diffuse" projects that affect productivity. These projects affect the quality of fish habitat and at least some could be considered a "permanent alteration". Vital rates of fish populations are impacted by the activity and this can cause productivity of individuals in the population to decrease. This is equivalent to moving downward along the vertical axis of Figure 2. Examples include flow alterations, non-lethal sediment discharges, nutrient inputs, temperature changes and riparian clearing that might be associated with a number of land-use activities. Projects involving noise, changes to ice regimes and large-scale substrate alterations from dredging, trawling, and those that cause mortality (entrainment in turbines, intakes) fit within this category as well. Aquatic invasive species can have similar impacts. The spatial scale of these projects can be highly variable but could be much larger than those of category 1.
3. Major projects that result in significant ecosystem transformation (e.g., hydropower resulting in river to reservoir transformation), or removal of the ecosystem from use (e.g., lake infills, other, large infills). These are dealt with by undertaking or requiring detailed case-specific studies and a variety of approaches can and are used to determine the existing productivity, and to make predictions about future conditions. Since these are whole ecosystem changes, incremental approaches would be of limited value. These assessments are usually managed by CEAA and the information requirements may differ from those required by the *Fisheries Act*.

These project categories are listed in order of increasing complexity of assessment, and likely in spatial scale. The categories, and the spatial scales identified in this section form a template that we use to provide some initial thoughts on ways to operationalize the concepts of “ongoing productivity of CRA fisheries” described in Section 1 of this report.

For smaller projects (mainly in the first category) it is unlikely that sufficiently sensitive metrics exist to measure the effects of the projects on fish production or fisheries productivity, particularly at the scales at which “fisheries” are typically defined, Habitat-population models could be used to link project impacts to productivity, but these would require data, assumptions, and making some difficult judgments about the spatial scale for the assessment (Minns et al. 2011).

For these projects, the objective of s.6.1 of the Act (provide for the sustainability and ongoing productivity of CRA fisheries) may be met by establishing that the habitats that are impacted are those of CRA species (or support species) and that the changes to the habitats will lead to negative impacts on fisheries productivity. As noted above and illustrated in Figure 2, destruction of habitat or other activities that reduce the habitat supply will ultimately impact fishery yield. Thus these projects can be adequately managed using habitat-based approaches (Table 1).

The second category of projects is likely to directly impact fish production and productivity. These can be assessed using the Pathways of Effects (PoE) approach (Jones et al. 1996; Clarke et al. 2008) which links changes in habitats to fish population vital rates and productivity. The PoE approach is qualitative, but likely can identify the direction of change in productivity, and determine if the change is meaningful in the context of the habitats affected. The scale of assessment is that of the project (but including downstream or vicinity effects).

A more detailed approach attempts to more directly measure impacts to productivity. However, production rate is not often directly measured because of the large data sets needed on seasonal growth and mortality (but see Rago 1984 for a production-based method of estimating the consequences (lost production) of fish entrainment at power plants). Rather, biological indices (e.g., fish biomass, salmonid smolt yield, fisheries landings, P/B, vital rates) or habitat surrogates such as habitat suitability indices or estimates of primary or secondary production can be used to indirectly evaluate project-related impact to fish production and productivity (Table 1 and Minns et al. 2011). This approach will require some consideration of the spatial scale of the assessment, either at the landscape or population scale.

Fish biomass or standing stock, averaged seasonally, is a common denominator for many of the above indices, as a proxy for production. Direct and indirect estimates of fish productivity as related to specific habitats, using biological indices (biomass, vital rates and others) or physical habitat surrogate methods, are summarized by Minns et al. (2011), along with a discussion of limitations and assumptions of the methods. Despite the need for further work, habitat surrogates can be used now as a practical option for measuring ongoing productivity (Bérubé et al. 2005; Minns et al. 2011). Nevertheless, it would be informative to review the efficacy of the various surrogates for application within the context of the new FPP.

Large projects are likely best evaluated by assessing changes in fish production and fisheries productivity. In some cases whole ecosystems will be lost and that impact can be expressed in terms of fish production or fishery-based statistics such as yield or use. In other cases the ecosystems can undergo large-scale transformations and the change to fisheries can be estimated using productivity or production measures. Bérubé et al. (2005)

and McCarthy et al. (2008) provide examples of habitat-based production models for evaluating large hydroelectric projects. Other approaches include habitat-related biomass, population structure and P/B to estimating production or yield (Randall and Minns 2000).

Changes to biodiversity resulting from larger-scale projects or impacts should also be considered but there is a paucity of scientifically established approaches currently available. As an example, the amount of impervious surface (IS; i.e., surfaces that prevent rainwater infiltration to soil such as pavement, buildings) within a watershed has been shown to be a good indicator of the effects of human development on stream biota (Uphoff et al. 2011, Wheeler et al. 2005). In general, ecosystems with IS values between 10 and 20% have been shown to be biologically impaired (Uphoff et al. 2011; Wheeler et al. 2005) and this can lead to reductions in biodiversity and biomass (Stanfield and Kilgour 2006). In areas where species are at the limit of their geographic range a lower level of human disturbance corresponding to IS values in the 5% range can create changes in biodiversity (Stranko et al. 2008). While it is important to note that most of this work has been conducted in freshwater systems a similar trend has been observed in estuaries (Uphoff et al. 2011). Further work of this type on linkages between biodiversity change, fisheries productivity and human activities is needed before more precise management advice can be provided.

Major projects need to consider the changes in biodiversity as there is potential for impacts that are not easily captured in fish production assessment and modelling. It is important to be mindful of the bidirectional nature of the biodiversity-productivity relationship (Worm and Duffy 2003). This means that any project that can be expected to reduce local species composition can be expected to reduce overall productivity and vice versa, any project that reduces overall productivity can be expected to reduce local biodiversity. At the same time, many types of changes to habitat features can reduce the quality of the habitat for one set of species but improve it for another set. Under the new FPP the relative importance of species as part of CRA fisheries may help to inform which of such “trade-offs” are of concern and which are acceptable. However, this is an area where there is little experience and little directed research, and there is a need for a focused effort at understanding the nature of the trade-offs that may be encountered as the FPP is implemented.

Projects that affect local biodiversity tend to change ecosystem structure and function either through major habitat alterations, fragmenting the ecosystem or cumulative impacts. A good example of such a large habitat change is the damming of rivers, either to produce electricity or provide water for irrigation (Clarke et al. 2008; Poff et al. 2007). These major projects can degrade the ecosystem by a number of pathways at once. Dams, for example, alter flows and create reservoirs which results in a change in community structure, productivity (Milbrink et al. 2011) and can potentially fragment the ecosystem (Nilsson et al. 2005). Currently there is a great deal of scientific interest in measuring connectivity in both freshwater (Cote et al. 2009, Bourne et al. 2011) and marine systems (Botsford et al. 2009) and some specific thresholds have been proposed (Perkin and Gido 2011). A more detailed review of this subject might provide guidance to managers.

In summary, we suggest that the implementation of the new measures of the *Fisheries Act* can be achieved with a pragmatic approach that takes advantage of existing habitat-based approaches for smaller projects, and the use of direct measures, proxies and surrogates for productivity for larger ones. For major projects productivity-based approaches that evaluate impacts to fisheries will be more meaningful than habitat measures when impacts to aquatic environments are evaluated in the environmental assessment process along with social, economic and other environmental effects.

3. IMPLEMENTATION IMPLICATIONS

The amendments to the *Fisheries Act* provide a focus to protect ongoing productivity to ensure sustainability of fisheries for commercial, recreational and Aboriginal use. This protection will be provided by managing threats such as the alteration or destruction of fish habitat and/or the introduction of alien species. These threats can have lasting effects on fish populations, ecosystem resilience and the sustainability of resource utilization. Therefore, knowledge of the linkages between habitat and population productivity will remain the overarching theme of science contributions in support of the implementation of the fisheries protection provisions.

Operationally, moving from a site level management approach to one that considers the ongoing productivity of populations and fisheries will require new operational tools. Scientific information will be important in the development of these tools and below is an initial list of tools that could be developed in the near to medium term (1-5 years). This list is not meant to be exhaustive; it can be added to and modified as consultation continues on the fisheries protection provisions.

- Guidance on the surrogate measures of productivity (i.e., Table 1). While this paper introduces some metrics, how and when to use each and their relationship to productivity could be the subject of a guidance document or training program for program staff.
- Improve and develop ecological spatial analysis tools. Link mapping of physical habitat (e.g., acoustic seabed mapping) to biological productivity both with respect to habitat utilization and quality.
- Provide guidance on the development of regional productivity benchmarks (e.g., Bradford et al. 1997; Cote et al. 2011).
- Continue to develop standards and thresholds for common project types that affect habitat (e.g., ecologically significant flows).
- Provide guidance on the extrapolation of data in data poor situations (Kenchington et al. 2013).
- Develop and validate methods and metrics for cumulative impact assessment.
- Provide criteria and frameworks for designating Ecologically Significant Areas (ESAs).

4. CLIENT SUMMARY

The concept of ‘ongoing productivity’ of commercial, recreational or aboriginal fisheries’ refers to a biological process, the product of which is catch in numbers or weight of fish in a particular habitat area on a sustained basis. Habitat-related physical impacts that affect productivity will impact the vital rates that determine production; specifically reproduction, growth and survival. The field measurement and tracking of ongoing productivity at different habitat spatial scales will often involve, directly or by inference, impacts on vital rates. Feasible field surrogates of productivity can be biology-based (fish abundance, catch, indices of production) or habitat-based, depending on the habitat and scale.

Sustainability and biodiversity are important dimensions to include in a conceptual definition of ongoing productivity. Sustainability, in a broad sense, means that current actions designed to manage threats to fisheries should ensure that future human needs can be satisfied. The ecological concept of sustainability recognizes that populations fluctuate over time, but threats should be managed such that if depleted, there is a reasonable expectation of recovery in a short period of time. Fisheries are often based on more than one population or species, and therefore biodiversity comes into play. Natural gradients in biodiversity exist both globally and within Canada, and provide a background context for managing threats. Some thresholds that relate habitat disruption to biodiversity and productivity are discernible (e.g., imperviousness of watersheds, minimum flow, and sedimentation). A framework for evaluating thresholds in the context of contributions to CRA fisheries is being developed (Koops et al. 2013).

With the new focus in Fisheries Protection on the ongoing productivity of fisheries, the precautionary approach to management will apply. A framework relevant to Fisheries Protection is being developed. Uncertainty of impacts to populations and fisheries is related to the spatial scale of the impact. Because of potential impacts to productivity, the numerous small scale projects will continue to be relevant, as well as the larger scale projects. Area-based management tools (integrated fisheries management plans, Ecologically Significant Areas, and cumulative effects assessment) will be useful in future and provide support for an ecosystem-based framework for Fisheries Protection.

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6. TABLES

Table 1. Example surrogate measures of productivity.

Measure	Scale	Predictors	References
Production	Small	habitat quality	Clarke and Scruton 1999
Yield	Large (lake)	lake area, morphometry, light, thermal habitat	Marshall 1996; Lester et al. 2004
Biomass	Large (lake)	TP, area, location	Downing and Plante 1993; Cote et al. 2011
Smolts& parr	Large & small(rivers)	landscape, latitude	Bradford et al. 1997; Gibson 2006
Abundance (density, CPUE)	Small/large	Habitat quality	McCarthy et al. 2008
Population structure (P/B, body size)	Multiple scales	Habitat quality, community structure	Randall and Minns 2000; Bérubé et al. 2005
Vital Rates (growth, survival, recruitment)	Multiple scales	Habitat quality	*see* Minns et al. 2011 for examples
Habitat (HSI, PHABSIM)	Multiple scales	Habitat quality	*see* Minns et al. 2011 for examples

Table 2. Descriptive summary of operational implications.

Measures of productivity

- Maintaining fish production, the core biological process leading to fisheries yield, is the foundation of ongoing productivity. Production rate *per se* is rarely measured but surrogate measures of productivity are available for populations, fisheries and ecosystems.
- Fish catch, abundance, biomass, vital rates, habitat metrics or empirical relationships can be used to measure productivity, depending on the spatial scale and complexity of the project (examples in Table 1).
- A pragmatic approach would be to use existing habitat-based approaches for smaller projects, and to use proxies of productivity such as biomass or yield for larger projects.
- Ecosystem drivers of productivity, such as total phosphorus, thermal properties or secondary production, are sometimes used as predictors in empirical models of fish biomass or yield.
- Physical habitat modifications affecting ecosystem productivity will likely be manifested in the productivity of component species.
- Constraints, limitations and uncertainty associated with using each type of measure of productivity need to be taken into account, to inform implementation of the FPP.
- Guidelines for developing regional benchmarks of productivity can be developed.

Sustainability and productivity

- Although sustainability has three dimensions, ecological, social, and economic, only the ecological context is considered in this report.
- Populations are dynamic. One criterion for sustainability is that if populations are depleted, they must be able to rebuild within a generation.
- Ensure that management decisions do not compromise the potential for any constituent species or population to contribute to future fisheries productivity.
- This must include the protection of necessary habitats of all key species and populations.
- Definitions of sustainability can be used to inform “permanent”.

Biodiversity and productivity

- Productivity, biodiversity and resilience are positively related.
- Biodiversity has several dimensions: taxonomic, phylogenetic, genetic, functional, spatial and landscape. Biodiversity and habitat/landscape diversity are related.
- Quantification of some thresholds relating habitat disruption to biodiversity and productivity is available (e.g., imperviousness, flow, sedimentation).

Spatial considerations

- Spatial scale and complexity of projects will vary from small (e.g., localized infills) to large (ecosystem transformation), and methods for measuring productivity will vary accordingly.
- For FPP, relevant spatial scales for measuring impacts to productivity are landscape, population and fishery, with landscape scale being the likely focus as ecosystem function often operates at this scale.
- Ecological Significant Areas are a potentially important tool for protecting ongoing productivity, but guidance is needed on criteria and frameworks for identifying ESAs.
- Integrated fisheries management plans, already available or planned for many areas, will be valuable for identifying regional conservation objectives relevant to ongoing productivity.
- Ecological Significant Areas and regional fisheries management plans could provide the spatial framework for cumulative effects assessment of diffuse projects.
- For data-poor areas, extrapolation of data from other areas with similar biota and habitat attributes will be necessary.

7. FIGURES

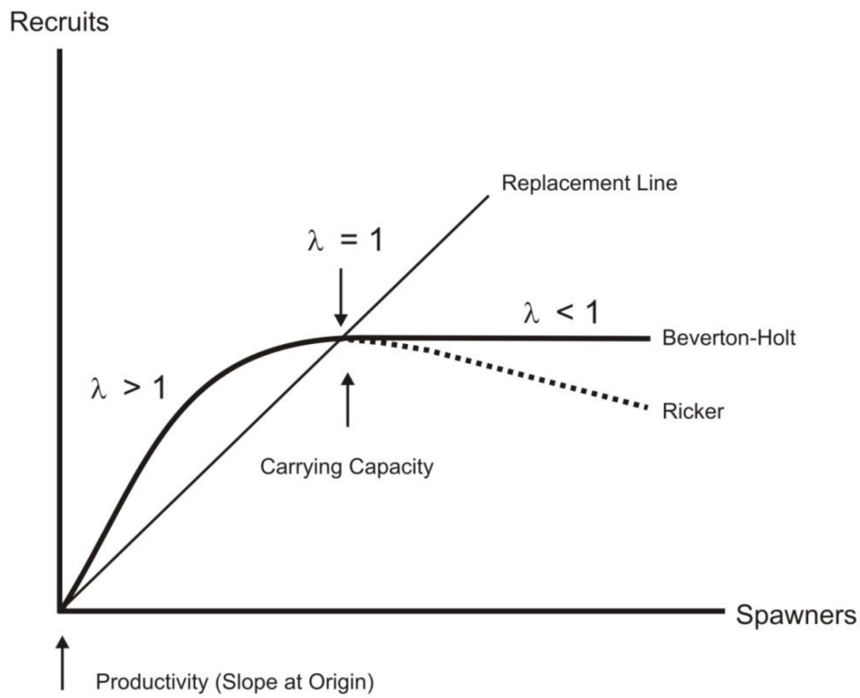

Figure 1. Conceptual diagram of salmonid stock-recruitment relationships (Beverton-Holt and Ricker) showing how the intrinsic rate of growth, λ, varies with abundance relative to the carrying capacity.

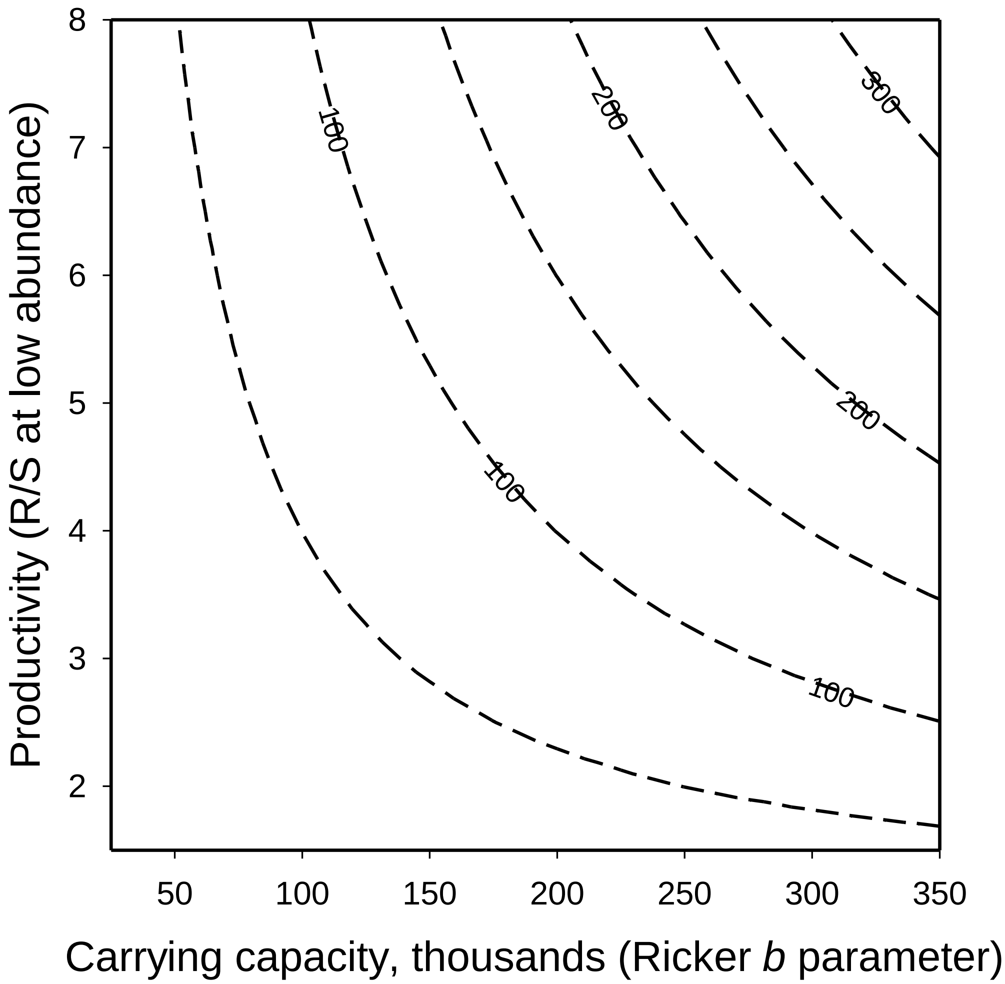

Figure 2. Relation between maximum sustainable yield (MSY) and population parameters for a hypothetical salmon population using the Ricker stock-recruit function, $R = Se^{a(1-S/b)}$. Productivity is indexed by the ratio of returning recruits (R) to the parent spawners (S) at low abundance ($R/S = e^{a}$). Habitat capacity or size is the Ricker b parameter, the unfished equilibrium. Contours of annual yield (thousands of fish) illustrate how a sustainable fishery depends on both the quantity (via b) and quality (productivity, a) of the population and its habitats.

REVISED TECHNICAL GUIDANCE ON HOW TO CONDUCT EFFLUENT PLUME DELINEATION STUDIES

National Environmental Effects Monitoring Office
National Water Research Institute
Environment Canada

MARCH 2003

FINAL REPORT TO

ENVIRONMENT CANADA

ON

REVISED TECHNICAL GUIDANCE ON HOW TO CONDUCT EFFLUENT PLUME DELINEATION STUDIES (CONTRACT NO. K1130-2-2033)

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TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

At the request of Environment Canada (Contract No. K1130-2-2033), Jacques Whitford Environment Limited (JWEL) and NATECH Environmental Services Inc. (NATECH) have prepared revised technical guidance for pulp and paper effluent plume delineation for the aquatic environmental effects monitoring (EEM) required under the *Pulp and Paper Effluent Regulations* (*PPER*). This revised guidance replaces the existing guidance for effluent plume delineation in Section 2.2 ("Description of the Study Area") of the April 1998 release of the Pulp and Paper Technical Guidance Document for Aquatic Environmental Effects Monitoring (Environment Canada 1998).

1.1 Purpose of Plume Delineation

Effluent plume delineation is required in the design phase of the EEM program for each pulp and paper mill. The objective of plume delineation is to understand how the mill effluent behaves in the receiving environment and to identify effluent boundaries describing exposure areas and reference areas within which to establish sampling locations.

The exposure area(s) for EEM studies is the area where the effluent concentration is 1% or greater, reflecting a dilution of no more than 1:100. It is important to understand the spatial distribution of effluent in the water column to determine areas for fish collection, as well as to understand where the effluent comes in contact with the bottom substrate to determine areas for sampling the benthic invertebrate community. This is particularly important for effluent that may not exhibit complete vertical or horizontal mixing throughout the receiving environment.

Selection of sampling locations within the reference area(s) for EEM studies requires an understanding of the extended dilution of effluent beyond the 0.1% (1:1000 dilution) effluent concentration limit. This understanding is particularly important for mills discharging into water bodies where flow is not unidirectional.

Delineation of effluent plumes will typically involve field work to track plume movement during a single time period, coupled with the use of numerical modeling to determine target dilution zones over a broader range of environmental conditions. It is recommended that the effluent exposure zone be predicted for the:

- maximum extent, reflecting the zone within which effluent is periodically detectable at a concentration of 1% or greater; and
- long-term average conditions, reflecting the zones within which effluent concentrations of 1% or greater, and 0.1% or greater would be regularly detectable.

Areas beyond the maximum extent delineation under worst case conditions would be expected to be minimally affected by the discharge and may be suitable as “far field” or “reference” areas, depending on the sampling design (*e.g.,* control/impact design or gradient design). The long-term average conditions define what would be considered the “normal” envelop of plume extent and can be use to design an EEM sampling program that will assess the long-term effect of the effluent discharge. It may also be useful to determine the long-term average conditions of 10% or greater effluent concentration to identify areas that may be most impacted by exposure to effluent. It is important to evaluate what are the “normal” environmental conditions to which the effluent will be subjected and what are the extremes that may, on occasion, override the “normal”.

For discharge environments with high receiving water flow, in which the effluent is expected to be rapidly mixed, it is important to determine whether the effluent is diluted to less than 1% within 250 m of the discharge, which would remove the EEM requirement to conduct a fish survey.

The EEM program requires that effluent plume delineation be conducted only once, provided there are no substantive changes in effluent characteristics, discharge quantity, discharge method or location, or in the hydraulic or hydrographic features of the receiving environment. Plume delineation must be reviewed in the design phase of each subsequent cycle of EEM to evaluate the need for a new delineation. The onus is on the mill to ensure that they have an understanding of the hydrographic nature of the receiving waters, sufficient data and numerical modeling to meet the objectives of plume delineation for EEM.

2.0 EFFLUENT DISPERSION

Plume delineation requires information on effluent characteristics, discharge conditions and the nature of the receiving environment.

2.1 Initial Concept of Effluent Dispersion

An initial concept of effluent dispersal should be developed to help plan the field studies. This "first cut" at understanding effluent behaviour in the receiving water requires some basic information, including:

- effluent characteristics, such as density and velocity;
- number of discharges, location, orientation, depth, type (*e.g.,* diffuser, ditch);
- receiving water characteristics including density, flow characteristics, seasonal or lunar factors (*e.g.,* water level, tidal cycle); and
- estimation of the initial effluent dilution when the plume surfaces; this can be estimated using a simple numerical model such as the U.S. EPA's Visual Plumes or the Cormix model.

A sketch of the expected plume behaviour should be made, showing expected initial dilution and subsequent dilution in relation to site features near the discharge location and farther away. It is important at this stage to determine the type of numerical modeling (*i.e.*, one-dimensional, two-dimensional, three-dimensional) that will be needed to analyze the field data and extrapolate these data to describe maximum extent and long-term average concentrations in the receiving waters. The type of numerical modeling required may dictate what data will have to be collected for the field study.

Effluent dispersion in the receiving environment is a two-stage process comprising initial dilution near the point of effluent introduction, followed by subsequent dilution farther from the discharge. Initial dilution of the effluent is determined by the method and dynamics of introduction of effluent and by differences in density between effluent and receiving waters. The introduction of effluent is usually visualized as a rising jet (not necessarily vertical) to the water surface where it encounters an upflow boundary and forms a streaming plume moving down stream, carrying the effluent away. Illustrations of initial dilution of effluent are shown in Figure 2.1; depictions such as these are useful in developing an initial concept of effluent dispersion.

Initial dilution near the discharge can be approximated using numerical models (*e.g.*, Cormix) or nomographs (*i.e.*, graphical representations of equations with multiple variables, such as may be found in Wood *et al.*, 1993). Further dilution of the plume occurs by horizontal and vertical mixing. In most cases, horizontal dispersion of the effluent occurs at least an order of magnitude more rapidly than vertical mixing, such that the plume may disperse horizontally for some distance without being fully mixed in the water column. It is therefore important to consider the depth component of dispersion during the field studies and to incorporate this into numerical modeling to determine the plume location within the water column and where it comes into contact with the bottom substrate.

Discharged effluent usually has higher velocity than the receiving water, which results in shear stress with the receiving water. This shear stress results in turbulent mixing. Initial dilution continues until the energy in the discharge dissipates and the velocity of the plume matches that of the receiving water. Once this occurs, the "natural" turbulence in the receiving water causes further dilution or mixing of the effluent with the receiving water.

In addition to velocity differences, most receiving water and effluents differ in density. The effluent is typically less dense than the receiving water (often due to being warmer, or freshwater effluent discharging to marine waters) and therefore tends to rise in the water column. This results in another shear stress, similar to that resulting from the velocity difference.

In most cases, the combination of velocity and density shearing provides sufficient upward momentum to cause the effluent plume to break the water surface. If the density of the plume mixture is still lighter than the receiving water, then the plume will stay at the surface. If the plume mixture is slightly heavier than the receiving water, it will plunge down to the level at which there is a water mass of equal density and then be transported by and mix with that body of water.

After initial dilution, the effluent plume typically moves horizontally with the receiving waters. Subsequent dilution and dispersion depends on the receiving environment and climatic conditions (see Section 2.4).

Additional resources for guidance on effluent dispersion conceptualization include: Bishop (1984), Day (1975), Jirka *et al.* (1996), Neshyba (1987), Roberts (1989), Roberts and Ferrier (1996), Sorensen (1978), Thomann and Mueller (1987), Tsanis and Valeo (1994), Williams (1985), and Wood (1993).

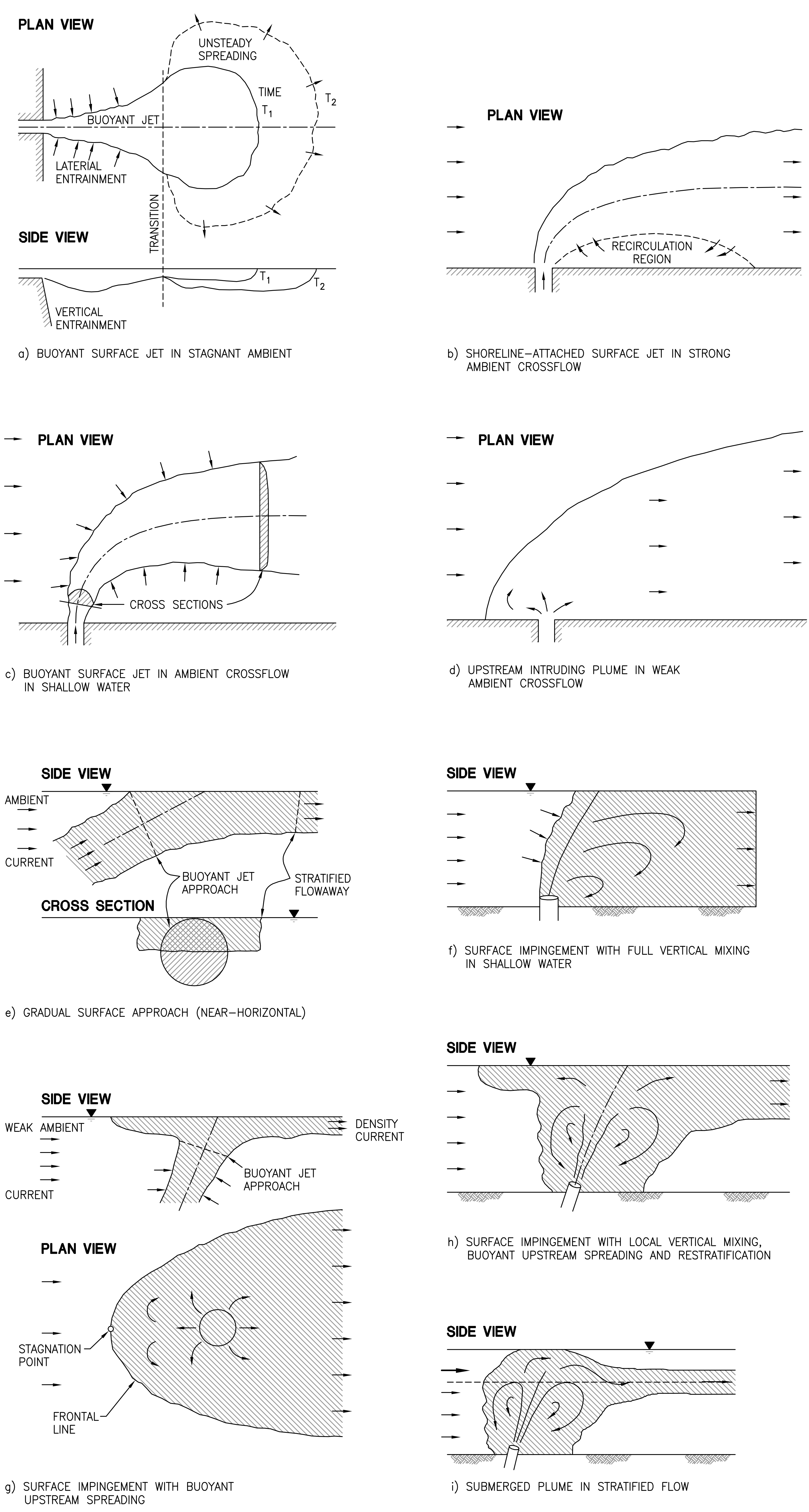

Figure 2.1 Examples of plume behaviour in receiving environments (modified from Jirka et al. 1996)

2.2 Effluent Characteristics

The most important effluent characteristics that influence initial dispersion are density and velocity differences compared to receiving water (see Section 2.1). Velocity will influence the degree of shear and therefore mixing that occurs when effluent is discharged. Effluent density will influence the rate of rise and position of the plume in the water column. Velocity may be measured as effluent flow rate (as a daily average), including whether the discharge is continuous or discontinuous (*e.g.*, batch release). The velocity of flow through each discharge pipe port should be considered, in comparison to the receiving water. Density of the effluent should be determined. Additional information on the effluent for plume delineation may include the presence of tracers, which are substances occurring naturally in the effluent, such as resin acids, sodium, and magnesium. These tracers may be used to track dispersion. Effluent values for the two most recent years should be considered.

2.3 Effluent Discharge Design

The discharge configuration and performance should be described. Using existing data, such as the most recent underwater inspection reports of the discharge, the performance should be compared to the design or the "as built" drawings. The location, length and orientation of the discharge should be known when determining the width of the plume. It is also important to consider the depth of the discharge within the water column in relation to flows and density gradients that may exist.

2.4 Receiving Environment Factors Affecting Plume Dispersion

The receiving environment should be described in terms of flow and currents, physical and chemical water quality and the spatial and temporal variations of these factors. This information is necessary to develop an initial concept of effluent dispersion, as well as to plan the field study. Climatic conditions should be summarized, with a view to their possible influence on plume behaviour.

Field parameters and their general importance in delineating plumes are described below. More detailed guidance for specific receiving environments is provided in Section 5.

2.4.1 Freshwater Flows

Minimum, maximum and average freshwater flows should be described in the receiving environment. This is important for all receiving environments, except those that are strictly marine with no local freshwater inputs. Freshwater flows will influence the initial dilution of the plume as well as subsequent horizontal and vertical mixing. The direction of flow, which may vary with depth and location, will influence the orientation of the plume. Typically, field studies are conducted at near minimum annual flow when effluent dilution will be low and the plume large relative to other times of the year. Field results can be extrapolated to reflect average and maximum flow scenarios for effluent dispersion.

2.4.2 Water Levels

Minimum, maximum and average water levels should be described for all receiving environments. The water level will influence initial dilution and the volume of water available for subsequent dispersion. Fluctuations in water level may occur daily (*i.e.*, tidal areas) or seasonally.

2.4.3 Water Quality

Water quality measures for receiving water that may be useful for plume delineation studies include temperature, density or specific gravity, salinity (for estuarine and marine studies), colour, suspended solids, and substances that may be used as effluent tracers. All of these measures can be used to track the movement of effluent within the receiving environment, as described in Sections 3 and 5.

2.4.4 Variation in Temperature and Salinity

Temperature and salinity both affect the density of the receiving water, and therefore their structure and variation within the water mass over space and time is important in all aspects of conducting a plume delineation study. Plumes that are warmer or less saline than the receiving water will be thermally buoyant when discharged and will rise towards the surface, creating shear that will generate initial mixing and dilution. Subsequent dilution and dispersion will also be influenced by temperature and salinity in the receiving water. Temperature and salinity may vary horizontally and vertically over short (*e.g.*, tidal areas) or long (*e.g.*, seasonal) time frames.

2.4.5 Tides and Seiches

The timing of tides and magnitudes is important to understand when planning the field study for estuarine and marine waters. In addition to marine and estuarine receiving waters, large lakes may also display a tidal cycle, albeit minor by comparison. Large bodies of water, such as lakes, estuaries and fjords, may also display the effects of storm surges and seiches, both in the surface elevation and in internal waves. All of these will influence the direction and pattern of effluent mixing.

2.4.6 Climatic Conditions

Wind and ice may significantly affect effluent dispersion, air temperature, ice conditions and wave action can all influence plume behaviour. Wind acting on large bodies of water may induce currents and waves. Ice may affect dispersion in two ways: by reducing wind-driven currents, and by increasing turbulence by providing a solid rough boundary to flow. Climatic conditions are discussed in more detail in Section 5.

2.4.7 Confounding Conditions

Although plume delineation is intended to capture normal discharge and receiving environment conditions, there are some potentially confounding conditions that may influence interpretation of field study results. Confounding conditions arise from events that are outside of the operational or environmental norms or are transitory events, and may result in a temporary change in the more "normal" location of plume boundaries. These conditions may affect effluent dispersion and therefore, their possibility should be considered when conducting a plume delineation study. Examples of such conditions include the following:

- pulp mill system upsets in the effluent treatment and discharge process that result in a temporary change in effluent quality or quantity;
- adverse weather, in particular wind conditions, that generates currents that are not typical for the receiving environment;
- seasonal events, such as ice conditions or thermal stratification, which can lead to a misleading representation of the plume behaviour; and
- flow regulation for hydro-electric power production..

3.0 FIELD TRACER STUDY

Field work involves tracking the dispersion of effluent using a tracer that is either naturally present in the effluent or is added. The purpose of this study is to obtain sufficient field data on a "snap shot" of effluent dispersion such that numerical modeling can then be used to estimate the maximum extent of the ≥1% effluent plume, and the long term average extent of the ≥1% and the ≥0.1% effluent plumes.

3.1 Study Team Personnel

Table 3.1 outlines the roles and responsibilities of study team personnel for conducting a plume delineation study, including a field tracer study.

Table 3.1 Study Team Roles and Responsibilities

Role	Responsibility
Team Leader	Scientist or engineer who directs and represents the study team and is the liaison with local authorities and the pulp and paper mill.
Field Supervisor	Scientist, engineer or technician with substantial practical field experience who directs and conducts the field work.
Tracer Injection Supervisor	Scientist, engineer or technician who supervises injection of the tracer in to the effluent stream. This person may be accompanied by a technical assistant.
Boat Crews (one or two)	At least one boat crew is required to conduct the field work. A second boat is useful to assist with drogue tracking, if conducted at the same time as the tracer study, and as a support to the main boat during the tracer study. The field supervisor may be a crew member.
Numerical modeler	Scientist or engineer with experience in numerical modeling of plume behaviour.

3.2 Communication

It is important to contact local authorities to notify them of the planned activities and the possible visible presence of dye in the water. Authorities to contact will depend upon the location, but may include one or several of the following: local port authority or harbour master, nearest offices of Environment Canada and Fisheries and Oceans, nearest office for the provincial departments of environment and/or natural resources, local municipal town hall or city hall, local fishing groups, non-governmental environmental groups, and possibly the local radio station. During the course of the field work, continuous communication between the team leader, the dye injection crew and the boat crew(s) is important.

3.3 Boats

The boat hull design and the propulsion unit should minimize disturbance/mixing to the plume as the vessel moves through it. While speed is generally very desirable, it will require judgement as to how much it may compromise some of the other requirements. A hull mounted recording depth sonar, combined with a GPS unit, is very desirable. Radar is also useful in coastal and marine areas.

If a dye tracer is to be used, the boat should include a firmly braced outrigger off the bow (with a restraining wire to the bow) to position the sampling intake or head of the fluorometer at a predetermined depth in the receiving water. The intake or head should be positioned such that it is clear of bow waves and is easy to detach and bring on board, or to reposition to a different water depth. Use a depressor if the intake is towed at depths greater than 2 m. In general, a system towed astern is not recommended because sampling is disturbed by the wake of the vessel; in addition, its positioning depth is very sensitive to the boat speed and length of the tow rope.

If high capacity 12/24V batteries are required for operating equipment, it is recommended to use batteries that are independent of vessel batteries, although the same charger may be used. It may be useful to have a second boat for handling drogues and for collecting bottled grab samples (if required).

3.4 Positioning (GPS)

Positioning of the sample stations, drogues and the boat track in relation to the discharge is important. Use of a Global Positioning System (GPS) unit may be the most convenient and accurate method to obtain and record positioning information. The accuracy of the GPS unit should be better than ± 2.5m, but this accuracy is dependent on a number of factors, including the availability of navigational satellites (maintained by the U.S. Department of Defense), environmental conditions that may result in “shading” of satellite signals, and the differential correction of signals. Differential correction on the GPS (DGPS) is provided by fixed receiver stations located at known positions, maintained by the Canadian Coast Guard for Canadian Atlantic and Pacific coastal waters, as well as the St. Lawrence Seaway. On the Great Lakes, DGPS is provided by Canadian and American receiver stations. Additional accuracy can be obtained using averaging of two or more receiver results. At some sites, more traditional survey methods, such as triangulation, may be equally effective, as long as the target accuracy is obtained.

3.5 Tracer Selection

Ideal plume tracers have the following characteristics:

- not harmful to the environment (dye tracer);
- near-zero background level;

- very slow decay rate (conservative substance) during field work;
- mixes freely into the effluent and receiving water;
- readily measured in the field at low concentrations; and
- released at a rate proportional to the effluent discharge rate.

Two types of tracers may be used: 1) tracers that occur normally in the effluent at known and relatively constant concentrations; and 2) tracers that are added to the effluent for the duration of the test.

The currently preferred added tracer is Rhodamine WT, a fluorescent dye that is most often used for EEM studies. It fulfils the characteristics of an ideal tracer. This dye has been shown to be non-carcinogenic and has low potential for toxicity and adverse effects in the aquatic environment (Parker 1973). It is safe when handled with care, generally available and can be readily measured in the field at concentrations less than 1 μg/L. For practical reasons, it should be obtained in liquid form. Rhodamine WT is considered conservative in most cases and typically has a near zero background level. Fluorescent tracers such as Rhodamine WT can be affected by some types of solids and chemical agents (*e.g.,* bleaches, sulphides, sunlight, and microorganisms). Chlorine in its elemental form rapidly destroys the fluorescence of Rhodamine WT. This effect is particularly noticeable in sea water due to the supporting effects of bromine. Fortunately, elemental chlorine exists only transiently in solution. Chlorine found as NaCl in sea water does not affect the fluorescence. Preliminary tests are recommended of dye-effluent interaction to describe the stability of the tracer and to determine any loss coefficient that should be used with the tracer.

An advantage of using tracers already present in the effluent is that they have an established equilibrium in the receiving environment. Effluents from most mills contain a variety of constituents that could potentially be used as tracers for delineating the zone of effluent mixing, such as effluent colour, sodium, chloride, magnesuim, tannin-lignins, conductivity and chloroform. An evaluation of effluent constituents as tracers should consider the following: detectability, ability to measure in real time, decay rate, variability in concentration in the effluent, and variability in background concentrations in the receiving water.

Additional resources for guidance on tracer selection and use include: Feunstein (1963), Ferrier *et al.* (1993), Kilpatrick and Cobb (1985), and Wright and Collings (1964).

3.6 Tracer Injection (Added Tracer)

The effluent system should be inspected and the dye injection point selected. Key factors for the selection of the injection point should include the following:

- an adequate mixing length (at least 40 times the diameter of the discharge pipe) before the final discharge point;
- no additional discharges after the injection point; and
- a sample access valve from which the fully mixed tracer can be sampled prior to final discharge.

The dye injection pump should be set up in the laboratory to confirm that the desired volumetric dosage rate is obtained. It is also important to determine the total time from introducing the tracer to the suction tube of the pump until it reaches the discharge. This includes the time to prime the injection system and the time for the dye to reach the final discharge point from the dosage point.

A continuous flow-rate injection system is preferred to simulate the operation of a discharge with flow proportional, continuous discharge loading. This type of injection system makes field measurements more reliable. The discharge rate of the pump versus battery charge should be monitored as well as the effect of cold temperature on battery voltage (if relevant).

For pulp mills discharging effluent in batches, mix the dye into the batch prior to release and allow for sufficient time for complete mixing. Sample the discharge pipe at regular intervals during the discharge period.

For an added tracer with zero background levels, the required tracer quantity can be calculated as follows:

$$M = C_x \times q_{eff} \times T \times \%_{eff} \times 3{,}600 \text{ seconds/hour}$$

where: M = amount of tracer required for the test (kg)
C_x = tracer detection limit concentration (*e.g.*, 1×10^{-9} kg/L or 1 ppb)
q_{eff} = effluent flow rate (*e.g.*, 1,000 L/sec)
T = duration of the test (*e.g.*, 12 hours)
$\%_{eff}$ = dilution limit of the plume in % effluent concentration (*e.g.,* for 1:100, use 100)

The injection rate (kg/hr) is obtained by dividing the amount of tracer required by the duration of the test. The concentration of the tracer in the injection mixture (typically 20% by weight) does not have to be considered in the calculation, since the detection limit is based on the diluted initial mixture. Dilution standards are typically prepared based on weight. Should the standards be prepared by volume, the correct specific gravity of the tracer should be applied. The specific gravity of Rhodamine WT is in the range of 1.15 to 1.2, and typically 1.19.

3.6.1 Duration of Dye Injection

Dye must be injected over a sufficient time period to establish an equilibrium concentration in the receiving water and to give sufficient time for the field team to complete the sampling. The duration of dye injection is site-specific. As a minimum in unidirectional flow, dye injection should continue until the plume has been delineated in the field. The more dynamic receiving environments require longer injection times, particularly if the plume is found to be unstable. In lakes and rivers, injection may need to continue for several hours. In estuaries, injection should continue through at least one tidal cycle from low water, to high water, and back to low water (normally 13 hours). In coastal marine environments and fjords where already polluted water may be re-circulated back into the plume, dye may have to be injected over several tidal cycles. A judgement will need to be made on whether the time and effort is best spent continuing dye injection, or using the predictive strength of numerical modeling.

The term "slug release" is used when a known and generally small volume of dye, possibly diluted with receiving water, is introduced into the water column at the level of the anticipated plume with as little disturbance as possible. Great care must be taken to ensure that the dye release liquid has the same density as the receiving water into which it is being released. The movement and subsequent dispersion of this dye patch is monitored in a similar manner as a plume and dispersion coefficients can be computed. In this case, a secondary objective is to determine the extent of, and dye concentrations within, the dye patch at regular timed intervals. As a check on the quality of delineation of the dye patch, the quantity of dye calculated to be present at each time interval should approximate the quantity released. Slug tests will not provide an adequate description of effluent dispersion. However, they may provide useful information on localized dispersion characteristics that can then be used for numerical modeling of effluent behaviour.

3.7 Water Quality Meters

Water quality parameters and tracer concentrations should be measured *in situ* with the probe immersed in the water. Water quality parameters to be measured include fluorescence (dye tracers), temperature, and salinity (estuarine and marine waters). Sample location, time and immersed depth of the sampling probe must be recorded, along with visual observations, if applicable. It is recommended that as many of the desired parameters as possible be measured simultaneously.

3.7.1 Fluorometer

The fluorometer measures fluorescence of injected dyes, and must be in clean and reliable condition. Since the fluorometer readings must be converted to effluent concentrations, a site-specific calibration curve is required, and this will be generated in the laboratory. A typical calibration curve is illustrated in Figure 3.1.

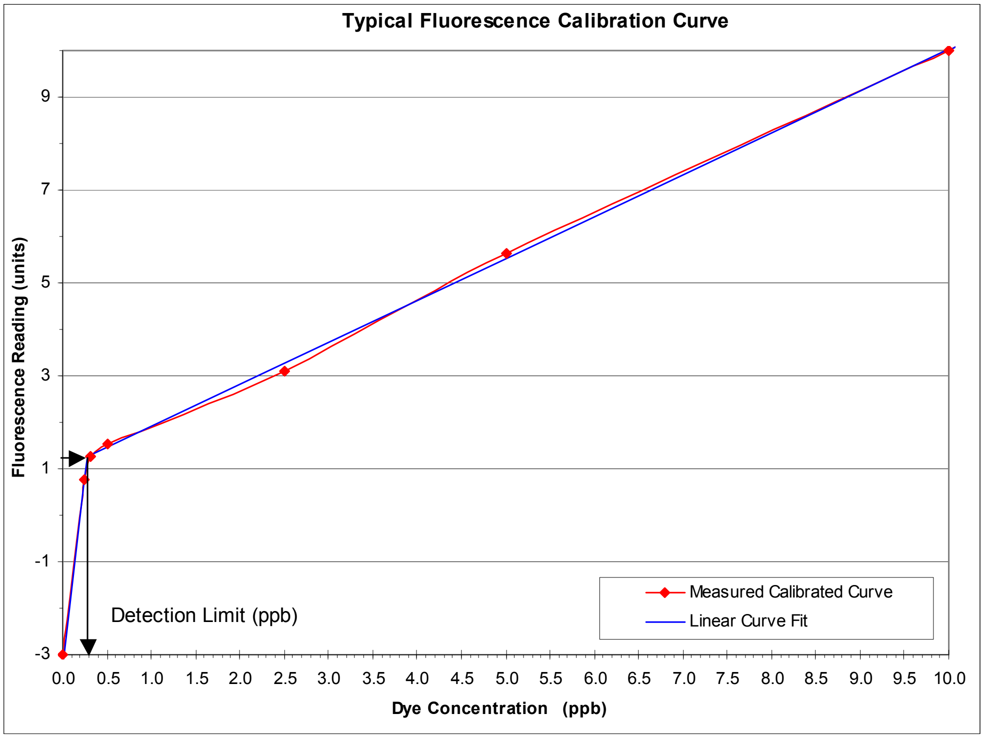

Figure 3.1 Typical calibration curve relating fluorescence to tracer dye concentration

The relationship between dye concentration and corresponding effluent concentration must be established prior to initiating field measurement, in order to be able to determine, in the field, at what fluorescence readings the target effluent concentrations have been found. In addition, the dye detection limit of the fluorometer in the receiving water will be determined. This concentration is required for the computation of the dye injection rate (see equation in Section 3.6).

To prepare the calibration curve, a dilution series for the dye should be established for the expected ranges of concentrations. Separate dilution series must be established for dye mixtures in the receiving water, pulp mill effluent and clean water. For saline receiving waters, at least a maximum and minimum salinity should be used. Any variations between the types of water used should be recorded and considered in the interpretation of field results.

Dilutions typically range from 0.1 x 10^{-9} kg/L (0.1 ppb) to 10^{-6} kg/L (1 ppm). The fluorescence measurements should show a linear correlation with dye concentration over the range of interest. A regression analysis will provide the mathematical expression required for converting fluorescence readings to effluent concentrations.

3.8 Equipment Used to Track Currents and Effluent Movement

Drogues and current meters are the basic types of equipment that may be used to track the movement of currents and thereby also the movement of an effluent. A description of each type is provided below.

3.8.1 Drogues

Drogues are used to determine movement of water in the effluent plume and also other current speeds and directions in the field. Drogues may also be used to assist in determining where to sample for tracers, particularly for sub-surface plumes. Drogues released near the discharge will drift with the current, indicating where the plume is being transported, provided it stays within the same water mass. Should the plume lie beneath the surface water mass, the drogue must be designed (weighted) to allow it to stay within the appropriate water mass. Examples of drogues are shown in Figure 3.2.

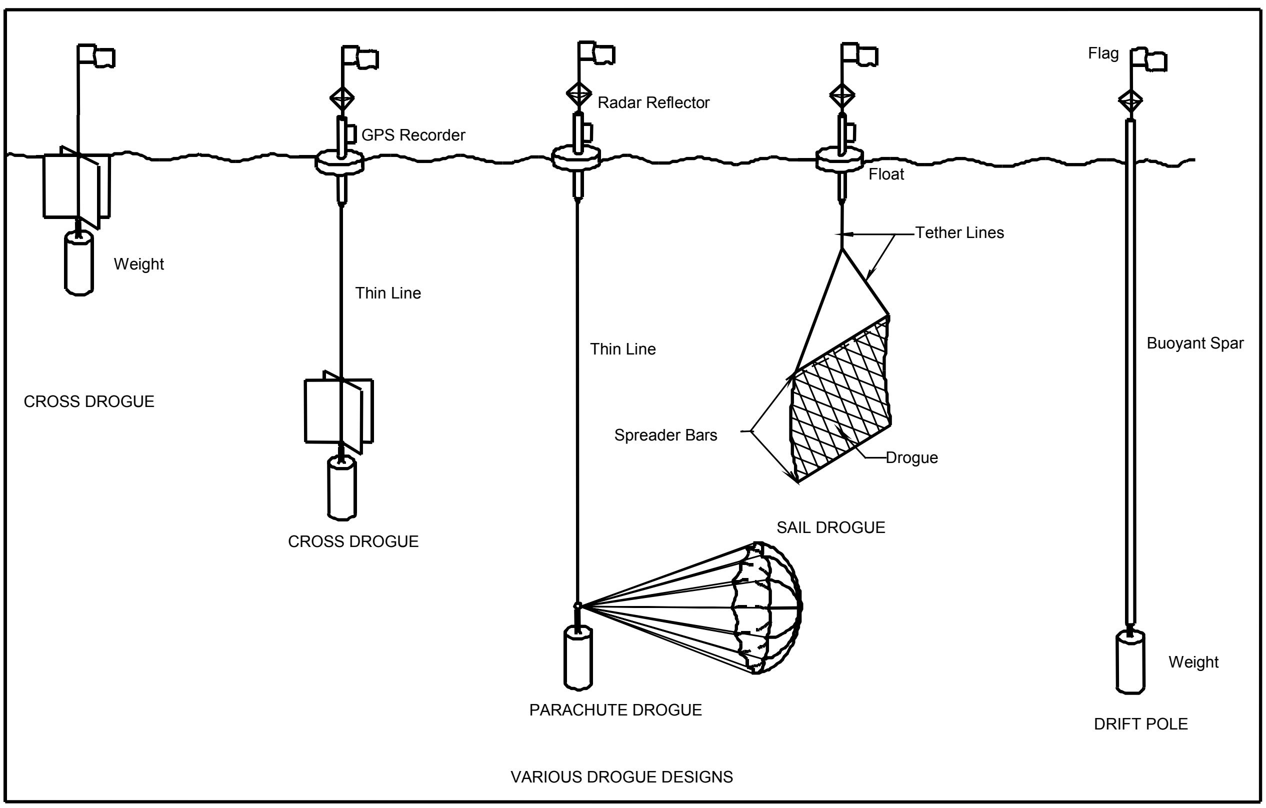

Figure 3.2 A variety of drogue types used for plume delineation (adapted from the Canadian Tidal Manual)

Drogues that are used to follow surface waters should be a relatively simple design, such as the "cross drogue" (Figure 3.2) made of two sheets of plywood weighted to keep the upper edge of plywood just below the water surface (50 cm or less). The dimensions of each vane should be not less than about 30 cm but otherwise can be constructed to a scale appropriate to conditions. Visual location of the drogue is typically marked by a flagged rod sticking out of the water and/or by a surface float, although acoustic markers may also be used (see below). The use of a surface float with some reserve buoyancy makes sure the drogue always remains at the correct depth in the water column. It is important that the wind resistance of any marker or the drag of the surface float will be minimal compared to that of the drogue itself. If there is considerable wave action or turbulence, then the distance between the surface float and drogue should be increased (see "cross drogue" with longer shaft in Figure 3.2) to ensure that the upper edge of the drogue does not flip out of the water and become influenced by wind forces. To check that the drogue is remaining within the same water mass as the plume, measurement of a simple parameter (*e.g.,* temperature, salinity) alongside the drogue may be used.

Some drogues should be placed in the water to determine surface water movement and a few should be placed at greater depth, particularly if the plume may plunge or be entrapped at a lower layer. The drogue tracks will give visual confirmation of the likely plume track. In estuarine and marine conditions, the drogues need to be dropped in the discharge area at high water, low water and both mid tides. Since it is desirable that some of the earlier drogues are allowed to run the full course, a significant number of drogues may be required. On board plots on charts can be used to track drogue movement, which should greatly assist in recovery of the drogues.

There may be situations in which the plume may remain below the surface or may plunge later. In both cases, the plume will be moving below a less dense water mass at the surface. Some guidance can still be obtained in these cases using the same basic drogue design but taking care to weight the drogue so that it represents the same density as the displaced water of the plume. A long, slack line to the surface buoy of the drogue will enable the drogue location to be approximated. Alternatively, an acoustic locator can be attached to the drogue. These "acoustic drogues" are used to track movement of submerged plumes in the open ocean and may also be used in shallower water to estimate drift (below the threshold of most current meters) of the lower layers in a fjord or a large lake. Depending on the mixing in the plume this will suffice only for a few kilometres because the density in the plume will be constantly changing as it mixes with lighter surface and denser deeper water on its upper and lower boundaries. These types of plume behaviour are discussed in more detail in Section 5.

3.8.2 Current Meters

Current meters may be used to describe the hydrodynamics of receiving waters, and in particular the spatial variability in currents for use in a numerical model. Most current meters can record temperature and salinity as well, providing additional information about the types of water masses that are moving. However, current meters are typically more expensive to use than drogues in plume delineation studies.

Current meters are particularly useful for large lakes and marine waters where currents are rotary, or where wind and wave action may be the dominant current inducer. In these environments, current meters may be deployed at near-surface and mid-depth during selected seasons of the year (minimum 30 day deployment) to describe the currents. A good description of modern current meters is given in IEEE (2003).

The Acoustic Doppler current meter is a more sophisticated type of current meter that is versatile and has been used in EEM studies. There are limitations for use of this meter type for plume delineation, including the following: it is expensive; interpretation of the results requires an experienced hydrographer; poor resolution of data obtained close to the water-air and water-bottom substrate interfaces when using the full depth range (this is a problem when tracking buoyant plumes that tend to be initially in the upper meter of water).

3.9 Tracking Effluent Dispersion

Standard guidance is provided in this section for tracking effluent in a simple unidirectional flow receiving environment, using Rhodamine WT as a tracer. Additional guidance is provided in Section 5 for specific types of receiving environments: rivers, small lakes and impoundments, large lakes, estuaries and fjords and coastal marine. Use of an alternative tracer will require appropriate modifications to the recommended procedure. Details on the use of Rhodamine WT are available from fluorometer manufacturers and the U.S. Geological Survey (1996).

For a mill with multiple discharges, each discharge should be traced separately at different times to determine the configuration of each effluent plume. In most cases, the cumulative plume may be evaluated using numerical models. However, most of the mills in Canada have consolidated their effluent discharges so that only one point of discharge is typically relevant.

3.9.1 Sampling in the Initial Dilution Zone

Sampling in the rising plume is difficult and unproductive for the purpose of plume delineation. Instead, sampling should be focused in the area where the plume breaks the surface or is arrested in its vertical ascent. This point may be several tens of meters down drift of the discharge point. Concentrations or dilutions may vary as much as 50% around the point of emergence. Sampling should be undertaken to confirm the variability of effluent concentration at right angles to the flow of the receiving water and also parallel to the flow.

Additional sampling should be undertaken at right angles to the flow approximately 50 to 100 m down-flow from the surface plume break-out to determine the plume width, thickness and depth. From this point on, further mixing would be considered to be beyond the initial dilution zone and sampling should be as recommended below.

3.9.2 Subsequent Dispersion

Beyond the initial dilution zone, the effluent plume typically moves horizontally, borne by the velocity of the receiving waters. At this point, drogues released within the surface plume will provide guidance on plume location. The following description of subsequent dispersion refers to surface plumes; specific guidance for plunging or trapped plumes is provided in Section 5.4.

Sampling traverses should be conducted at right angles to the flow of the plume and at intervals of approximately 5 times the last plume width. The fluorometer or hose intake should be held at a constant depth while the boat traverses the plume. The recommended sampling depth is 1 m in homogeneous water, possibly less in stratified flow, and possibly deeper in homogeneous water if it has been determined that the plume is well mixed with depth. The depth of maximum tracer concentration is used for profiling the tracer concentration.

It is particularly important to locate both edges of the plume and to determine if the edge of the plume touches a shoreline. In the first few traverses, the boat should return to the center of the plume and the fluorometer or hose intake should be lowered to determine the vertical extent of the plume, and this should be compared with the expectation from the conceptualization of dispersion. If necessary, the boat should then return along the traverse with the fluorometer of hose intake at a deeper depth (*e.g.,* 2 to 3m) to better delineate the lower surface concentrations.

Sampling should continue until the 1:1000 dilution (*i.e.,* 0.1% effluent concentration) limit is determined. It should be recognized that at the far edges of the plume, sections of the plume may become separated from the main plume and form independent patches of effluent that float with the current.

Under no circumstances should a flow-through fluorometer be placed within 2 m of the bottom substrate, as this may result in equipment damage or failure. If it is suspected that the effluent plume is in or near contact with the bottom substrate, then bottled samples should be collected for subsequent analysis (see paragraph below on “grab” samples). To confirm that this is the case, at least five samples per cross section should be taken.

Any unusual characteristics in terms of plume location or concentration should be noted. Examples could include high concentrations observed at places beyond where the effluent concentration has dropped below the specified concentration (*e.g.,* accumulation in an inlet or bay), or where an undertow moves effluent downstream or off-shore such that effluent resurfaces elsewhere.

Bathymetry should be measured and recorded at tracer profiling locations. Sonar techniques are generally adequate. Where a detailed hydrographic chart is already available, a survey of bathymetry may not be necessary. It is recommended that bathymetric data for the receiving water be presented on a map of the exposure area.

Measurements of fresh water flow and tidal water level changes should be recorded for at least 24 hours prior to and during the tracer release. At a minimum, these measurements should be taken hourly, but continuous recording is recommended.

Grab samples are recommended only if the plume is not directly accessible by the fluorometer or hose intake. The grab sampling procedure is slower, has poor spatial resolution, and does not provide a continuous profile of the tracer concentrations. Consequently, it is difficult to carry out a mass balance of the tracer. Nevertheless, it is sometimes necessary to collect grab samples. Grab samples should be collected using a water pump or by lowering sample bottles that are under vacuum pressure. Use of a Niskin or similar sample collection bottle for multiple-use is not recommended because of the risk of contamination from previous sampling. Grab samples should be stored in the dark under refrigeration, and be analyzed within 24 to 48 hours. If samples are to be collected only by this method, then at least 12 samples at each transect are recommended from within the plume to adequately define the plume configuration. It is expected that at least 10 cross sections would be sampled for any of the plumes resulting from a discharge.

3.10 Data Quality

Using the site-specific calibration curve (Figure 3.1), fluorescence readings are converted from unit-less values to dye concentrations in μg/L (*i.e.,* ppb), and then to percent effluent. A similar unit conversion is necessary for naturally occurring tracers. Compensation for temperature changes and varying effluent discharge quantities during the field test may be required. The results should be displayed in tabular format listing time (for marine conditions, use time relative to high or low tide), water level, position, salinity (if applicable), immersion depth of the sonde or sampling tube, local water depth (optional), dye concentration and calculated effluent concentration.

A discussion on the confidence limits of the results should consider the effects of such factors as environmental conditions during the test, method of testing to measure fluoresence (*e.g.,* grab samples, pump-through, immersed fluorometer), accuracy of the positioning data, variation in effluent discharge, and confidence in the calibration curve.

3.11 Numerical Modeling

Numerical modeling provides a means of extrapolating from the plume measurements in the field to simulate effluent dispersion over a much wider range of environmental conditions at the site. Numerical models have been developed that superimpose water quality computations onto hydrodynamic processes. The models allow for a qualitative and graphic representation of the transport and dispersion of the effluent (tracer) in time and space.

Depending on the nature of the receiving water, two or three-dimensional models may be used. Principal processes in numerical modeling include model setup, model calibration and verification (both of which use the field tracer study results), and a sensitivity analysis to determine what limitations may have to be placed on input parameters. While model calibration should be carried out against the most recent tracer measurements, verification can be achieved by applying the model to an historical event with different environmental and discharge conditions. After successful calibration, verification and sensitivity analysis, the model is then ready to be applied to a number of environmental conditions that may lead to effluent plume dispersions other than the dispersion observed during the field measurements. A discussion should be provided on the frequency of the various environmental conditions being considered.

As a minimum, the models used should be able to accurately reproduce the hydrodynamic process of the study area and the behaviour of a conservative substance introduced near the discharge. The initial near field dilution may be computed using descriptive models, such as Cormix or Visual Plumes. The tracer concentrations computed for the edge of the near field can then be used as boundary conditions for the far field model. Other typical boundary conditions for far field models are the fresh water input on the upstream end and the water level on the downstream end. In river systems with fast flowing currents, the models have to be able to simulate sub and supercritical flow conditions. In tidal waters, where the shore line near the discharge changes from high to low tide, the model should be able to reproduce wetting and drying of tidal flats.

The near field and two-dimensional far field models are readily available and have been commonly used for effluent plume delineations of pulp mill effluents. The three-dimensional models are very costly to purchase and require a significant effort for data collection, model setup and calibration. Some hydrographic research institutes are well equipped for applying three-dimensional models.

Table 3.2 lists potentially applicable models for a variety of effluent discharge scenarios, and includes models that are commercially available and routinely used. This table is intended as a preliminary guide only because models are constantly being developed and modified, and because there are many models not listed that are developed for in-house use only, and are therefore not commercially available.

Table 3.2 Numerical Models for Describing Effluent Dispersion

Typical Scenario	Information Needs for EEM	Examples of Commercially Available Numerical Models [1]
Plume is highly transitory or there is rapid plume dilution in the initial dilution zone to within target level (*i.e.,* 1% effluent concentration)	Conceptual spatial delineation of 1% and 0.1% limits of effluent concentration. Whether the 1% concentration limit is reached within 250 m from the discharge.	Numerical models such as Cormix and Visual Plumes for the initial dilution assessment only
Effluent is discharged into turbulent, narrow stream; complete mixing is achieved rapidly over a short distance	Linear distance until plume is dissipated to within target levels (*i.e.,* 0.1% and 1% effluent concentration)	1D numerical models, such as HEC-5Q, Qual 1E , WASP5/Dynhyd5
Effluent is discharged into uniform, wide body of water. No stratification is observed.	Length and width distance until plume as dissipated to target levels (*i.e.,* 0.1% and 1% effluent concentration)	Numerical models such as Cormix for initial plume dilution, 2D numerical models, such as RMA 2/RMA 4, Qual 2E, MIKE 21, for subsequent dilution simulations
Effluent is discharged into non-uniform, wide body of water. Stratification is observed as result of thermal or salinity differences in the receiving water or between the effluent and the receiving water. Stratification may be non-uniform and dynamic.	Length, widths and depth dilutions until plume as dissipated to target levels (*i.e.,* 0.1% and 1% effluent concentration)	Numerical models such as Cormix and Visual Plumes for initial dilution assessments, only. 3D numerical models, such as RMA 10/RMA11, WASP5/Dynhyd5, MIKE 3, TELEMAC, DELFT 3D for far field simulations.

[1] Sources for these models vary; some may be obtained directly from the model developers while others may be obtained from one or a number of commercial distributors.

The selected numerical model should be used to estimate the desired regions of maximum extent, average conditions, and minimum dilution. A discussion on the confidence limits of the results should be provided (see Section 3.10).

If current meters are being used to measure ambient currents (see Section 3.8.2), the modeled plume configuration may be modified through statistical analysis of the current meter data. For conditions of a long flushing period, the measured dye concentrations may be used to calibrate a numerical transport-diffusion model. The model can then be used to simulate the effluent delineation and characteristics arising from a continuous discharge. The model can be run for a variety of conditions (*e.g.,* seasonal variations of water movements and wind patterns), thereby overcoming the limitations of the particular conditions recorded in a single field study.

Additional resources for guidance on numerical modeling include: Baumgartner *et al.* (1994), Chung and Roberts (1998), Ettema *et al.* (2000), Frick *et al.* (2000), and Sharp (1989).

4.0 REPORTING

Reporting of the study results should include the following:

1. Summary of information collected to aid in developing the conceptual model of effluent plume behaviour, including:
   - description of the effluent in terms of flow, temperature, specific gravity and TSS (if applicable);
   - description of the effluent discharge configuration and performance;
   - description of the receiving environment in terms of flows and currents, physical and chemical water quality (*e.g.,* thermal and salinity variation horizontally and vertically), climatic conditions, and any other relevant site-specific parameters used to develop the conceptual model of plume behaviour; and
   - confounding conditions, such as pulp and paper mill upsets, atypical climatic conditions.

2. A conceptualized model of plume behaviour.

3. Documentation of tracer study conducted, including:
   - pre-tracer laboratory testing, fluorometer calibration curve;
   - pre-trial field testing; and
   - trial field tracer measurements.

4. The Numerical model used and mapping depicting predicted plume envelopes for:
   - maximum extent (1% and 0.1% effluent concentrations); and
   - long-term average conditions (1% and 0.1% effluent concentrations).

Computer animation is a useful option for depicting effluent plume behaviour in more complex receiving environments, such as estuaries and coastal locations.

The measured tracer concentrations should be provided in the appendix of the report.

5.0 RECEIVING ENVIRONMENT – SPECIFIC CONSIDERATIONS

Five general types of receiving environments are considered for this guidance:

- Rivers – predominantly driven by gravity flow;
- Small lakes or impoundments – with directional flow;
- Large lakes – less predictable currents that are often wind-driven; may exhibit internal waves, or "seiches";
- Estuaries and fjords – tidal areas with both freshwater and marine influences; fjords are special types of estuaries where the shape is narrow and deep with a shallow freshwater surface flow and deep saline layer;
- Marine – tidal areas dominated by salt water.

Specific factors that should be considered in each type of receiving environment are outlined in Table 5.1, and described in this section. The influences of climatic conditions such as ice and wind on plume behaviour are described at the end of this section. This section also provides specific guidance for conducting plume delineations to supplement guidance provided in Section 3.

Table 5.1 Summary of factors to be considered for each type of receiving environment

Field Parameter	Rivers	Small Lakes or Impoundments	Large Lakes	Estuaries	Marine
Freshwater flows (minimum, maximum, average)	YES	YES	YES	YES	YES, IF RIVERS ARE PRESENT
Water levels	YES	YES	YES	YES	YES
Water quality	YES	YES	YES	YES	YES
Thermal variation horizontally & vertically	NOT IF WELL MIXED	YES	YES	YES	YES
Tide times and magnitudes	NO	NO	NO	YES	YES
Salinity variation horizontally & vertically	NO	NO	NO	YES	YES
Wind conditions	NO	YES	YES	YES	YES
Ice conditions	YES	YES	YES	YES	YES

5.1 Rivers

In rivers, currents are typically unidirectional, and flows and water levels are seasonally variable. Considerations for determining plume behaviour include the characteristics of the discharge point, shoreline and bottom attachment and rising or sinking of the plume due to density effects caused by thermal or chemical factors. The river may consist of different zones that should be delineated, including fast and slow flowing, with various depositional and erosional zones influencing any suspended solids transport from the effluent. A discussion on the temporal changes (seasonal and long term) of the river regime on the reaches affected by the plume should be provided.

Plume delineation studies should be conducted during a period that approaches the annual low river flow, which typically occurs in late summer. This will leave the extreme high and medium flows to be predicted using numerical models. Low river flows typically correspond with low overall dilution potential and reduced rates of turbulent mixing in the system. As a result, spatial extent of plumes tends to be larger during periods of low flow.

If a dye tracer is used, it should be added using a continuous flow rate injection system. The number of field tracer measurements to take will be site-specific. It is recommended that concentrations be measured at various distances downstream and that the spatial extent of the plume be determined. Slug tests (*i.e.,* batch release of dye, as opposed to continuous flow rate tracer injection) may be a also a suitable technique for monitoring mixing in some rivers, but this generally requires a very good understanding of the plume behaviour and may require repeated slugs.

5.2 Small Lakes and Impoundments

Guidance for rivers (above) will apply if there are large effluent volume discharges, because there will typically be an easily discernable and measurable flow through the system. However, this guidance will not apply to some small lakes and impoundments where there are residual currents, or where the long-term drift is masked or even reversed by short term effects induced by factors such as wind shear, lake overturning, development of thermocline, or freshets, separately or in combination. It is important to assess the magnitude and significance of each of these comparatively short-term phenomena. This is most easily done using numerical modeling, provided there are adequate field data available for model calibration.

The residual flow, or even transitory currents, may be below the threshold of regular recording current meters. In these cases, a mass balance of the flows entering the body of water and the flows leaving will provide an estimate of the retention time in the system. This retention time may be reduced further by assessment of special circumstances or geometry. However, where currents are very low (*e.g.,* a few cm/min), only field tracer studies can provide the confidence that an effluent will be carried away and that re-circulation does not take place. Re-circulation takes place where eddies from the plume are brought back to the mixing system and used instead of clean new receiving water. After some time this may significantly reduce the dilution of the effluent and significantly extend the 1% concentration boundary.

The residual flow through the area should be estimated as well as the currents that are induced by wind at various strengths and from various directions. An onshore wind will typically trap water against the shore and cause the surface water layer to thicken. Conversely, an offshore wind will cause deeper water to be brought inshore and upwell to replace the water being carried offshore by the wind.

The relative density of effluent and receiving water may be important to determine, because if a thermocline is present, most water movement in the lake will take place above it. If the plume stays above the thermocline, vertical mixing will be restricted and dilution will result more from horizontal mixing. Should the initial dilution be such that the plume is entrapped below the thermocline, mixing will likely be slower and movement could almost approach the volume being displaced by the effluent discharge.

Tracer studies should be designed to fulfill the general requirements and to consider seasonal variations. Prevailing currents will influence the duration and timing of each study. The recommended method for the delineation of the effluent plume for a lake discharge is the continuous flow rate injection system using a dye tracer. This is particularly true if there is any likelihood of eddies and re-circulation or entrapment back into the plume. The slug test can be used to determine dispersion characteristics, but does not give as good a visual picture, nor the same guidance regarding re-circulation.

To measure water currents, drogues should be released and tracked concurrent with dye tracing. For buoyant surface plumes, drogue vanes should be set with the upper edge at or just below the surface (within top 50 cm). For submerged plumes, drogues should be weighted and sails set so that they travel at the same initial depth of the plume, which can be determined on site from the initial tracer monitoring. If clusters of drogues are released, dispersion for a batch release may be obtained from the paths of the individual drogues by determining the variance of the individual drogues about the centroid.

Unlike the river receiving water where the plume configuration can be predicted using simple numerical models, plume behaviour in lakes is not as easily predicted. If data on water currents in the vicinity of the discharge are lacking, current meters (see Section 3.8.2) may be needed to obtain information for use in the numerical model. Climatic data may be obtained from the local airport or other local weather data source. The statistical relationship between the dilution and travel time of the effluent should be combined with the statistical characteristics of the water currents to develop spatial dilution zones around the discharge. This may be depicted as a graph showing the frequency of the dilution factor as a function of dilution and travel time.

The dilution zones should show the probability of the effluent plume being present at any receiving water location and the mean and standard deviation of the effluent concentration at any location in the receiving water. The dilution zones do not show the configuration of the effluent plume under specific current speed and direction conditions.

5.3 Large Lakes

Water currents in large lakes are often wind driven, seasonally variable, and generally less predictable that those encountered in fluvial and tidal areas. Thermal and density stratification is important to understand because the effluent may be more dense than lake water due to chemical factors, or less dense than lake water due to thermal factors. Wind and wave advection, seiches, shore-line and bottom attachment are all important. Many of the factors considered for small lakes and impoundments are also relevant to large lakes.

In large lakes, it is useful to have information on the variability in long-term water movement and the resulting residual movement. This information may be obtained using moored current meters with a low current threshold. Temperature recorders on the current meters may be used to determine whether internal waves or seiches occur. On shore anemometers may be used to obtain concurrent wind data if wind data are otherwise unavailable.

Initial dispersion of the surface plume into a relatively quiescent lake will be significantly influenced by the volume of the upwelling plume. Numerical modeling is the strongest tool to delineate the plume to this stage. Subsequent dispersion using numerical modeling will require estimates of horizontal and vertical dispersion coefficients, as well information about water currents obtained from current meters. The dispersion coefficients are best determined by either a slug release of dye or by continuous release and subsequent monitoring of a tracer in the effluent plume. If wind is present, an estimate of induced wind drift current can be determined using wind drift forecasting curves (see Section 5.6.2). Winds can also induce tilting of the water surface and of the thermocline, which may result in seiche motions that oscillate within the basin. See Section 5.6.2 for more discussion on wind-induced seiches.

Two-dimensional numerical modeling may be adequate, however in situations where there is stratification, three-dimensional modeling may be necessary.

5.4 Estuaries and Fjords

Estuaries and fjords are complicated environments in which to conduct plume studies. An understanding of the nature of the receiving waters is very important for planning the field study. This section will first provide a description of hydrographic considerations in estuaries and fjords, followed by guidance for conducting field studies.

5.4.1 Hydrographic Considerations

The most significant influences on effluent dispersion in estuaries and fjords are tidal flows and density differences between freshwater and saltwater. Tides cause water to flow into an estuary on the rising tide and flow out again during the falling tide, causing mixing to take place. Effluents are typically similar in density to fresh water and will therefore tend to follow the fresh water in their mixing pattern. Freshwater has a specific gravity of about 1.00. Effluent and freshwater will typically rise and flow along the top of saltwater, which has a specific gravity of about 1.026.

Figure 5.1 depicts a "salt wedge estuary" in which a large river flows into an estuary with small tides and creates a sharp interface between fresh and salt water. Figure 5.1 (a) shows the fresh water layer thinning as the estuary widens and extends seaward. If the freshwater velocities get high, there will be shear created at the interface and salt water drawn into the upper layer. Figure 5.1 (b) shows how the turbulence of the tide coming in creates shear at the interface, creating waves and causing mixing to occur.

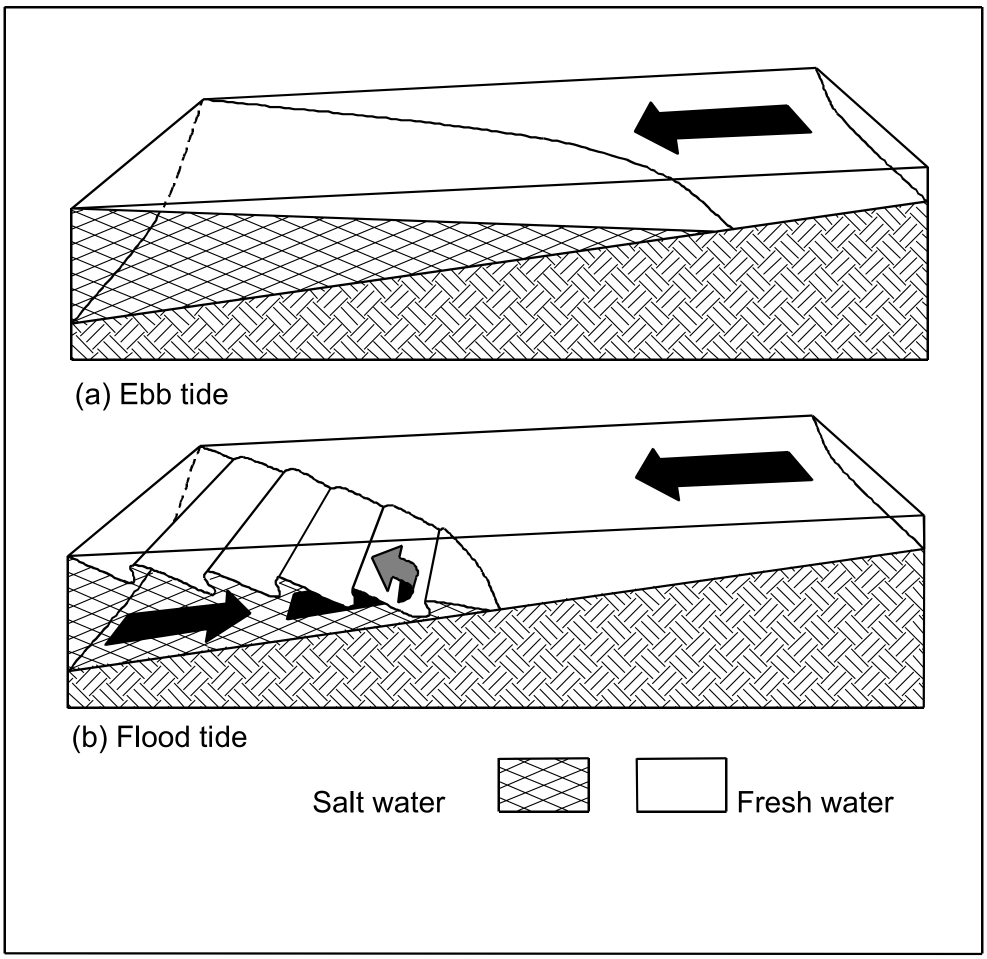

Figure 5.1 Generalized Profile of an Estuary, Showing Circulation During Ebb Tide (a) and Flood Tide (b).

The amount of shear and mixing that occurs between the freshwater and saltwater lays depends on the relative volume and velocity of freshwater (confined by the estuary sides) and of saltwater (confined more by depth). Figure 5.2 depicts stratification in a salt wedge estuary under different levels of tidal energy. A highly stratified estuary (a) can occur if tidal energy is relatively low and the gradual rise of the tide causes some mixing. As the tidal energy ("tidal prism") increases relative to freshwater flow, more mixing takes place to produce a partially mixed (b) and fully mixed (c) estuary.

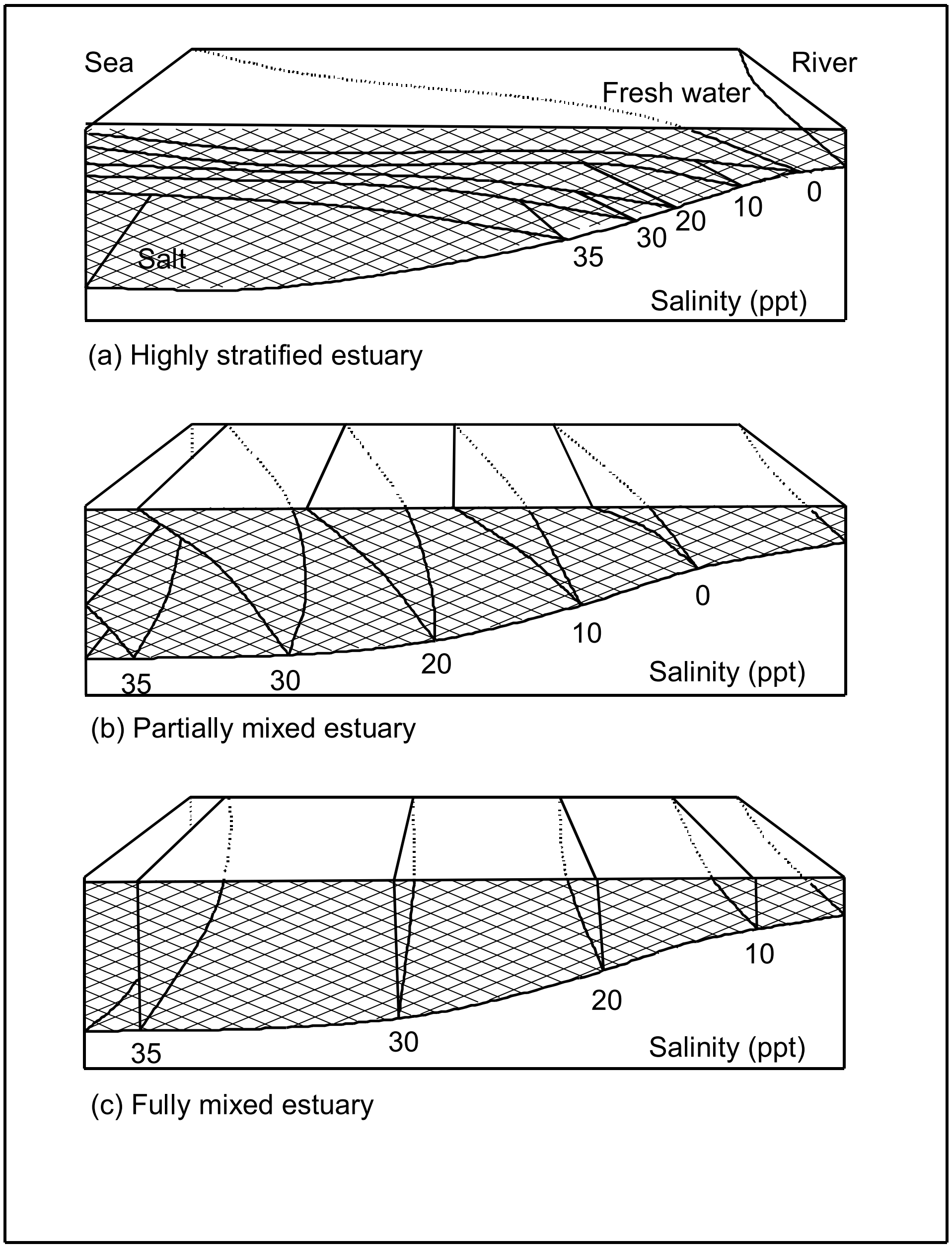

Figure 5.2 **Profiles of typical estuarine water masses, showing an highly stratified estuary (a), a partially mixed estuary (b), and a fully mixed estuary (c).**

Tidal frequency and magnitude are considered when planning a plume delineation study and in subsequent numerical modeling. Tides in Canadian estuaries typically rise and fall with approximately 12.42 hours between high waters. The vertical range between high and low water, even within one coastal system, can range is from a few centimetres to several metres. Also, there is a beat every 7, 14 and 29 days indicating the "spring and neap" cycles where the forces of the sun and moon first act together and then oppose. In some areas of Canada every second high or low water differs considerably from its predecessor. These differences are generally referred to as semidiurnal and diurnal responses of the particular water mass to the differing pulls of sun and moon.

Other considerations for conducting plume delineation studies in estuaries include the following:

- duration of the tidal cycle: it is not uncommon for the duration of the falling tide to exceed 7 hours and the time of the rising tide to be significantly less than 6 hours; and
- slack tide: in some estuaries, a slack period can occur in vertical and horizontal movement around high and low water; this can amount to a few minutes or in exceptional cases almost an hour (in this case generally low water only); lack of significant horizontal movement for a period can lead to considerable pooling of effluent in the area of the discharge, leading to possible expansion of the boundary of the zone of >10% effluent concentration.

A special case occurs in fjords where the depth of the estuary is well over ten times the thickness of the tidal prism. Here the longitudinal profile will look like a salt wedge estuary or a well-stratified estuary with the fresh water lying in a layer at the surface and very significant water depth below. The tide can rise and fall, causing negligible mixing, except possibly at the entrance where there is typically a sharp sill. In some fiords there may be a 2 to 10 m thick layer of fresh water that extends the full length of the estuary with an interface of less than a meter thick. In longer fjords extending over several tens of kilometres, diffusion and other influences such as wind and internal waves will cause this interfacial layer to thicken and the upper layer to become brackish.

Estuaries may demonstrate two or more estuarine types along their length or during seasonal variation in river flow or in the spring to neap tidal cycle. In partially mixed estuaries or well stratified estuaries, there is often little seaward movement along the bed during the ebbing tide creating an increase in stratification during this period. On the flood tide, the stronger currents run deep and conditions closer to well mixed are more likely to occur. In Canada, because of the Coriolis force and the difference in density between salt and fresh water, ebb currents tend to run stronger and salinity tends to be lower towards the right hand bank (looking seaward) of an estuary when looking seaward. Similarly, flood tide currents are stronger and salinities higher towards the left when looking seaward. This can be very marked in wide estuaries. Where an estuary has a high fresh water discharge or a narrow exit to the open coastal waters, a fresh or brackish water plume can extend well out to sea particularly during the ebb tide. Depending on the dynamics at such an entrance a portion of this plume may re-enter the estuary with the flood tide.

An estuary can change from one stratification type to another, either with distance or with time. During spring run-off, freshwater may dominate the upper reaches of the estuary and create a higher degree of stratification downstream. During lower flow periods, the upper reaches of the estuary will return to partially mixed conditions and the lower salinity water will penetrate much further upstream. Internal waves (or seiches) may form along the fresh or brackish water/salt water boundary in fjords and estuaries as a result of wind action, and may temporarily affect plume dispersion. These seiches are discussed in more detail in Section 5.6.2.

During slack tide, a significant pool of effluent can gather in the vicinity of the discharge pipe and at a concentration close to that delivered at the top of the rising plume. Once the horizontal tidal currents begin to move again, this large effluent pool is the leading edge of the effluent plume and may take some time to dissipate. As the tidal currents strengthen, the effluent leaving the discharge area will behave more like a standard streaming pool. If the effluent pool gathered during the low water slack, the rising tide will typically come underneath the plume as denser water and carry the effluent pool upstream. The somewhat diluted effluent in the pool may pass down through the discharge area on the falling tide and provide already polluted water to the discharging effluent. If the effluent pool gathered during the high water slack, it will tend to stream off downstream in a very thin layer due to density differences. When the tidal currents strengthen, this high water pool of effluent will tend to disperse more quickly than the low water effluent pool, but it may substantially extend the limit of the plume at the surface, particularly if it is shore-attached.

Plunging plumes may occur in estuaries and fjords. Effluents with a fairly high initial dilution on the rising jet can pick up salinity from the lower layers such that the plume attains a density greater than that of the surface layer. If the rising momentum is sufficient, the plume may break the surface and then slowly plunge or sink down to a water layer consistent with its density and travel and mix with this lower layer. This is depicted in Figure 2.1 (i).

In other situations, particularly where the surface layer is thick or very distinct, the jet will rise but be trapped at the interface between the upper and lower layer. This is likely to be the case in fjords if the initial discharge is located in the deep saline layer. Effluent mixing into the upper layer is more likely during an ebbing tide. During a rising tide, the strength of the current in a shallow estuary is close to the sea floor and may cause significant mixing with, and entrainment into, the lower layers.

Submerged plumes may resurface when the plume encounters an influx of differing density water coming into the receiving water. In this case, surface water will initially plunge, but will resurface down drift. This scenario may occur if there is an influx of less dense water downstream of the discharge, such as from a tributary or another major effluent discharge.

5.4.2 Conducting the Field Work

Two boats are recommended for tracer studies in estuary environments. The recommended technique for dye tracer measurement is use of a fluorescence sensor or sampler intake off the bow of the boat, as described in Section 3.3.3. Salinity and temperature verticals should be taken along the centre line of the estuary and in the vicinity of the discharge. The sampling time should be noted relative to time of high or low water, and sampling should always proceed in a counter current direction relative to the receiving water movement.

It is important to consider the differences between successive high waters and between spring and neap tidal ranges and reconcile them with establishing the representative density regime in the estuary and also the objectives of the plume delineation study. The vertical range relative to the water depth at low tide gives some indication of potential turbulence. Another method, but requiring more work, is to estimate the water volume passing various sections during flood and ebb and hence to obtain the average velocities. This is particularly valuable where there are large inter-tidal volumes or additional river flows added at particular points along the estuary.

If using a dye tracer, injection should begin about half an hour before the turn of the tide so that the study may begin around low water. For most estuary studies, the plumes can be delineated in the field in the same way as a river plume. When sampling, the boat should always work against the tidal currents to avoid just drifting with the receiving water and possibly sampling the same water mass. If a separate boat is doing the drogue work or when being done on a separate day, it is useful to check salinity and temperature at the drogue depth each time the position is confirmed. Care must be taken when the tide reverses and the partly diluted effluent comes back over the discharge point as there will probably be a new thin poorly diluted plume on top of a thicker well mixed plume. When the difference in flood and ebb tide surface excursions is small (*e.g.,* < 20% of the excursion) there may be a build up of effluent from more than one tide. Generally the numerical model can provide the most effective predictions of this phenomenon.

For plunging plumes, drogues can be set to follow the plume at depth. However, caution should be taken to ensure that the vertical dimension of vanes is not too large, because the upper and lower edges may get caught in two different water flows. If the depth of the plume is known from initial field sampling, the plume may be tracked as outlined in Section 3.9, except that instead of air there is a layer of water above the plume. This is one case where a fluorescence sensor or sampler intake may be towed astern, because it is likely to be well below the influence of mixing from the boat hull and propulsion unit. This technique requires more boat operator skill to maintain constant speed either with a water speed gauge or a revolution counter. A depressor will hold the fluorometer head or intake down, but a depth gauge (either pressure or upward looking sonar) is essential to record depth.

It is much more challenging to follow a plume that rises to the surface and then plunges and also where there is no well marked interface. Initial field measurements of salinity taken to characterize the environment will demonstrate how the naturally occurring surface layer behaves relative to the lower layer down drift.

Numerical modeling may need to be carried out over a number of tidal cycles to show short-term and long term effluent dilution fields. Three-dimensional modeling may be required for stratified receiving waters.

5.5 Marine

Thermal and salinity stratification are important features to assess for coastal marine environments because the effluent is usually less dense than sea water due to chemical and thermal factors. In very calm weather, the plume may be contained within a few centimetres of the water surface. Significant influences in this environment include wind and wave advection, shore-line attachment, bottom attachment, and tidal activity (often with rotary currents). Oceanic receiving waters are distinguished from estuaries in that the main circulation is not dominated by fresh water in the vicinity of the discharge. The effluent plume is diluted and transported by currents. Tidal activity, while present, does not always provide the main contribution to net effluent movement, but does affect effluent dispersion. A continuous dye release of one tide cycle is generally sufficient, but the duration of the numerical modeling program may be over several tidal cycles.

The residual current patterns may be dominated by a coastal circulation pattern or by local wind and wave influences. It is useful to have local water current data, such as may be obtained from positioning coastal current meters near the discharge. Likewise, local salinity, water temperature and wind records are also useful.

Prior to any dye release, the tidal heights and times at the site should be correlated to the nearest recording tide gauge maintained by the Canadian Hydrographic Service. This is of value for the dye study and also in the use of current and other longer term records. Spatial salinity and temperature profiling should also be conducted at this time.

The initial concept of effluent dispersion should be useful for planning the dye release. Field delineation of a surface plume may follow the standard practice outlined in Section 3.9, although judgement will be required on the spacing of the transects, particularly if the rotary current is marked and the plume begins to come back over the discharge area. Tracking of submerged plumes should be conducted as described in Section 5.4 above. It is usually beneficial to use larger scale drogues with radar reflectors and GPS receivers in coastal areas, especially if wave action is present.

From the dye tracer profiles, the effluent plume envelopes will be developed and related to the measured currents, wind and waves on that day. The probability of the occurrence of these envelopes may be determined using statistical data from available data on water currents, and numerical models used to extend these envelopes over a broader time period to represent "average" conditions.

5.6 Climatic Conditions

Ice and wind may have significant effects on effluent dispersion. The following sections provide guidance on incorporating ice and wind conditions in interpreting plume behaviour. The applicability of numerical models using ice are very limited at this time.

5.6.1 Ice

Ice is a common occurrence in many Canadian water bodies during winter. Its general effect on the effluent discharge is two-fold. Ice cover shields the receiving waters from the effects of wind stress and may also alter or cause stratification in the water column and hence modify water circulation. However, in the case of land fast ice, the underside of the ice provides a solid rough boundary to flow and creates turbulence similar to flowing over the stream bottom.

Most effluents are warm and this will cause some melting and a weakened ice surface. The buoyant plume will cling to this ice surface in the same way that a dense plume will cling to the bottom substrate. As far as is known, no detailed effluent plume field studies have been made under ice conditions, but it is reasonable to assume that mixing is likely to be decreased. This can result in the extent of plume concentrations being under-estimated when based on open water considerations alone.

Land fast ice cover removes wind stress mixing from the surface waters. In the presence of fresh water discharges (*e.g.,* river discharges), mixing will be reduced between the effluent and river water. Ridges may appear in the formation of the ice surface. Some of these ridges may be the result of early ice flows colliding, and others may be formed by thermal expansion of the ice. Ridges may form in the same position each year and may have a keel or downward projection as much as 7 times the height of the surface ridge. These ridges can interfere with the plume and may divert it in a very different direction to its normal open water mode.

Moving ice still generally shields the surface water from direct wind effects. However, wind influences may be greater than initially predicted, because wind motion will be transmitted from the below water profile of ice flows to the receiving water and/or the plume. Where moving ice comes in contact with land fast ice or an island, a significant ice ridge may form.

The standard numerical models for plume delineation are generally not appropriate for considering ice conditions since they assume a free water surface (*i.e.*, open channel flow).

5.6.2 Wind

Wind acting on large bodies of water induces currents and waves in direct proportion to its strength, its duration, and fetch over the water body. Fortunately, nomographs are available to provide estimates of current speed, and wave height and period that can contribute to understanding wind effects on the dispersion of effluents. One of the most valuable sources of information is literature relating to oil spill trajectory modeling, or ocean search and rescue. For wind currents, the James wind-drift forecasting curves (James 1966) are probably the easiest to use to obtain a magnitude. When using the James curves, the direction is usually taken as being 20 degrees to the right of the wind direction, due to Coriolis forces.

In more detailed work this can be modified to accommodate variations in duration, fetch, wind speed and water depth, among other factors. In many coastal areas it is the predominant wind direction coupled with local underwater topography that provides the driving force for currents along the shore. The momentum built up can make these currents very persistent. Wind waves also transport water, particularly when they get into shallow water. These waves can run out of the wind field and continue to transport their energy over hundreds of miles.

The nomograms most commonly used for wave predictions are those developed by the U.S. Army Corps of Engineers (1984). Wind wave energy is transmitted in two ways: first, on the surface by water particles orbiting in a circular motion with a radius of half the wave height at the surface; and second, at depth with the radius diminishing to almost zero at a depth of half the wave length. Typical coastal waves have periods of 4, 6, and 8 seconds, and have wave-lengths of 25 m, 56 m and 100 m, respectively. When this motion at a depth of half wave length comes in contact with the bottom substrate, friction causes the wave to slow and the circular particle motion changes to elliptical. On a long beach, this will cause the wave crests to try to align themselves parallel to the contours and eventually the shore. This has two effects on the plume: increased mixing within the plume and currents along the shore generated by the waves.

Internal waves, or seiches, moving along the interfacial boundary between two water masses can also impact the dispersion of a plume. The generation of these waves is not well understood but they are formed as eddies by the shear forces acting between the two opposing water layers, and they may be found moving along the thermocline in lakes, the sharp fresh water/salt water boundary in fiords, or between the estuarine and marine water in large estuaries or coastal waters. These internal waves can be of large amplitude (*e.g.*, on the order of meters) with waves of 80 m being recorded in the St Lawrence off the Saguenay. Their impact on the plume is transitory, and are mentioned here only for guidance should an anomaly occur during a dye test. Their occurrence would be picked up on the records of recording thermographs or salinometers.

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Northwest Territories Lands

JUL 03 2015

Mr. Chuck Hubert
Mackenzie Valley Environmental Impact Review Board
PO Box 938
YELLOWKNIFE NT X1A 2P1
VIA EMAIL

Dear Mr. Hubert:

Dominion Diamond Ekati Corporation's (DDEC) Jay Project Environmental Assessment – GNWT Round Two Information Request Responses (EA1314-01)

The Government of the Northwest Territories (GNWT) is committed to fostering balanced and sustainable land management decisions in accordance with the Land Use and Sustainability Framework, and therefore participates in environmental assessments of NWT resource development proposals. The GNWT has reviewed the information requests (IRs) directed to it, and is pleased to provide the following responses to those IRs.

The GNWT anticipates that these IR responses will assist in informing the Review Board and all parties about the nature and significance of the proposed project's potential impacts on the environment. As the EA progresses the GNWT looks forward to further opportunities to participate. If the Mackenzie Valley Environmental Impact Review Board or any of the parties to the Jay Project EA has questions regarding the GNWT's IR responses, please contact Lorraine Seale, Manager, Project Assessment Branch, at lorraine_seale@gov.nt.ca or 867-765-6786, or Melissa Pink, Project Assessment Analyst, at melissa_pink@gov.nt.ca or 867-765-6784.

Sincerely,

G. Ridgely

Gina Ridgely
A/Director, Land Use and Sustainability

Attachment:
GNWT Responses to Round Two Information Requests Jay Project EA

Northwest Territories Lands

Mr. Chuck Hubert
Mackenzie Valley Environmental Impact Review Board
PO Box 938
YELLOWKNIFE NT X1A 2P1
VIA EMAIL

Dear Mr. Hubert:

<u>Dominion Diamond Ekati Corporation's (DDEC) Jay Project Environmental Assessment – GNWT Round Two Information Requests (EA1314-01)</u>

The Government of the Northwest Territories (GNWT) is committed to fostering balanced and sustainable land management decisions in accordance with the Land Use and Sustainability Framework, and therefore participates in environmental assessments of NWT resource development proposals. GNWT departments have reviewed DDEC's responses to GNWT's round one information requests (IRs), as well as the transcripts and undertaking responses from the April Technical Sessions, in light of their respective mandates and responsibilities related to the Jay project. The GNWT is pleased to provide the attached round two IRs accordingly. The GNWT anticipates that responses to these IRs will assist in informing the Review Board and all parties about the nature and significance of the proposed Jay project's potential impacts.

If the Mackenzie Valley Environmental Impact Review Board or any of the parties to this EA have questions about the GNWT's IRs, please contact Lorraine Seale, Manager, Project Assessment Branch, at lorraine_seale@gov.nt.ca or 867-765-6786, or Melissa Pink, Project Assessment Analyst, at melissa_pink@gov.nt.ca or 867-765-6784.

Sincerely,

T. Hall

Terry Hall
Director, Land Use and Sustainability

Attachment:
Information Requests in MVEIRB ORS (Online Review System) format

GNWT Round Two IR Responses for the Jay Project:

IR#	Topic	Comment	Request	GNWT Response
MVEIRB IR#31	Health and well-being indicator levels of significance	Section 14.6 of the Developer's Assessment Report (DAR) states that "... Dominion Diamond Ekati Corporation the Project's effects on health and well-being are not assessed as significant". Indicators within the 2014 Communities and Diamonds report (PR#415) suggest adverse trends in several health and well-being indicators in communities effected by diamond mining (See Summary table on p7 of the 2014 Communities and Diamonds report for a list of these indicators). The Review Board needs to understand what parties and the developer deem a reasonable rate of change to health and well-being indicators that have an adverse trend. The Board also seeks to understand parties' and the developer's views on significance thresholds for these health and well-being indicators.	a) Please provide an opinion on what rate of change would be acceptable for health and well-being indicators that are currently trending adversely in potentially affected diamond mine communities as listed in the 2014 Communities and Diamonds report. b) Please describe thresholds beyond which significant adverse effects to people and communities might be expected to occur for the health and well-being indicators referenced above.	The annual Communities and Diamonds report tracks current trends against historical data. Departments comment on: • The direction of a trend in the pre-mine phase; • The direction of a trend in the post-mine phase; • The direction of current trends relative to historical data; and • An historical increase or decrease that has a probable cause (such as an outbreak or natural disaster). A 'threshold', as requested by MVEIRB, does not exist. The departments monitor programs and services to strategically plan territory wide programming to best meet the need of Northwest Territories (NWT) residents. It is important to differentiate negative trends from 'significant adverse impacts'. There are a number of factors influencing the wellness of individuals, families, and communities and negative trends may be attributable to rapid social, cultural or environmental change at both a local and territorial level, in addition to potential impacts from resource development. The departments consider data that includes capturing changes in the population, employment and education levels, trapping, hunting and fishing activity across the territory and are committed to using this data to be both proactive and responsive in the programs and services delivered to minimize negative health and well-being changes. Data, such as that found in the Communities and Diamonds report, demonstrates a correlation between resource development activity and community wellness – it does not provide causality or speak to the magnitude of a trend. The departments have programming in place addressing social, cultural and economic wellbeing issues and actively adapt programs and services through ongoing performance measurement. The departments also meet regularly with the developers to identify areas for targeted collaboration.

IR#	Topic	Comment	Request	GNWT Response
NSMA IR#2	Ekati SEA	GNWT agreed to consult with Boards, communities and organizations to review the results of the health and wellness report on how to improve the results. NSMA has no awareness of the results of consultations between GNWT and the Boards. Please clarify in your answer, which group the "Boards" refer to. If the originally intended organizations no longer exist, please explain how this commitment has been followed up since, by which alternative organizations, or through other consultative means.	Please provide the outcome of the consultation meetings between GNWT and the Boards, and how they improved the results. Please also provide specific data, consultations outcome, and initiatives undertaken on "establishment of daycare programs" (5.2.6) and prevention of spousal abuse (5.2.7)	The Department of ECE is responsive to the needs of all NWT residents. The point of hire communities are a targeted group covered by the SEA; however, benefits of initiatives accrue to all NWT residents. In 2014, ECE released a Framework and Action Plan for Early Childhood Development in the NWT. Under that plan, a series of actions were identified that would encourage community members to become involved in early childhood development by participating in the workforce in their communities. ECE is moving toward having a more qualified staff in its early childhood development programs, which will support participation in the workforce by community members. By increasing the incentive to work in the area of Early Childhood Development (ECD) and building capacity in ECD, there is more of an opportunity for all community members, particularly parents, to participate in the workforce. Under the Action Plan for ECD, Action #21 strives to increase the number of qualified early childhood development professionals in licensed programs. This action supports all existing early childhood staff to have the required minimum postsecondary education and ongoing annual professional development, as specified in the NWT Child Daycare Standards Regulations This action provides a tiered grant approach for people currently working in the ECD area. Participants are encouraged to use the grant to obtain qualifications; however, this is not a condition of the award. This also addresses the issue of the low income earning potential for Early Childhood Development workers. In 2014, ECE awarded ten $5000 Scholarships to support Northerners to complete an ECD diploma or degree program. This provides further incentive for individuals to complete the necessary training to provide a high quality of service in ECD. In 2014, ECE held its first ever Early Childhood Symposium. The Department paid for one individual from every childcare center to come to Yellowknife to participate in the Symposium and had representation from every community. This leads to a better informed and equipped workforce which strengthens the services in the community and contributes to participation in the community.

				Action #15 of the Action Plan commits to restructure administration and finance processes for all early childhood development programs to promote equity, inclusion, quality and stability. All communities will benefit from the work that is underway. In June of 2015, a Feasibility Study of Universal Affordable Day Care in the NWT was tabled in the Legislative Assembly; the study refers to “day care” as “early childhood education and child care”. The study is evidence of ECE’s commitment to assess opportunities and challenges for improvement. HSS collaborates with Health Authorities to address and reduce family violence through prevention, intervention services and funding to support the five family violence shelters and victims living in regions without shelters. The Department and Authorities spent approximately $3.2 million annually toward family violence prevention and intervention services, including funds for the Territorial Family Violence Shelter Network, which enables shelter staff to collaborate and build capacity to serve women and children fleeing violence. The Department’s 2015/16 family violence prevention initiatives include: o Working with regions where no shelters exist on the development of protocols and response teams in their communities. o Providing recovery and support programs for children who have witnessed and/or have been victimized by family violence; and o Expanding the *“What Will it Take?”* (*WWIT*) social marketing campaign aimed at changing attitudes and beliefs about family violence. In the 2015/16 fiscal year, the Department will be supporting communities to deliver *WWIT* workshops as well as promoting the campaign to all NWT residents and those interested in having a workshop in their community or in becoming a facilitator can contact the Department of HSS. The *WWIT* campaign was launched in October 2014. A Territorial workshop was held in February 2015 with representation from all regions of the NWT. The workshop equipped participants to deliver *WWIT* workshops in their communities.

				The focus in 2015/16 is to expand the *WWIT* campaign, including dissemination of a recently developed promotional video and financial support to enable communities to deliver workshops. HSS supports the Premier's involvement with the National Roundtable on Missing and Murdered Aboriginal Women by providing program and funding information; the feedback and direction from the Roundtable informs future planning on family violence programs and services across the NWT. HSS is also exploring a partnership with FOXY (Fostering Open eXpression among Youth) to target a youth audience. The Department of Justice is also actively involved in the prevention and mitigation of abuse across the NWT; several initiatives are currently in place to help prevent and address family violence and spousal abuse: • The 'New Day' Healing Program is a Justice-led pilot program under the *Family Violence Framework* that provides supports for adult men so that they can stop using violence in their intimate and family relationships. The goals of the program are to reduce violent behaviours and re-offending rates among violent men. Men over the age of 18 can self-identify, be referred by an agency or organization including NWT Corrections and Corrections Services Canada (CSC) to participate. They must be ready to make changes in their behaviours. The program is currently offered in Yellowknife. • The CSC Family Violence Prevention program is available to eligible offenders serving sentences at the North Slave Correctional Facility. The goal of the program is to reduce violence and abuse towards intimate partners. • The Domestic Violence Treatment Options (DVTO) Court is an option for low-risk offenders who are willing to take responsibility for their actions (plead guilty) and participate in a *Planning Action Responsibly Towards Non-violent Empowered Relationships* ("PARTNER") program. Offenders are carefully screened and are required to attend the eight-module program as ordered by the Court. Successful completion of the program is a mitigating factor in sentencing.

				The goal of the PARTNER program is to provide individuals with information and tools to reduce future incidents or escalation of domestic violence in their relationships. The Department provides support to the program in the areas of assessment of offenders, ongoing monitoring (bail supervision), delivery of the program, support for victims, and referrals to outside agencies (e.g. addictions treatment, counseling services). To date, 37 participants have successfully completed the program in Yellowknife. DVTO has been offered in Yellowknife since March 2011 (offenders from Behchoko who are willing to attend treatment sessions in Yellowknife are encouraged to participate). On April 27, 2015, DVTO expanded to Hay River and may also include residents of K'atl'odeeche and Enterprise. • The *Family Violence Coordinator* position at RCMP "G" Division is there to strengthen the RCMP's front line response to family violence by monitoring high risk files, providing training and support to members responding to family violence situations, and representing the RCMP on family violence committees. • The *Protection Against Family Violence Act* provides legal tools such as emergency protection orders for people who feel threatened with family violence. The process for applying has been simplified with 24-hr a day services available. • The GNWT continues to work with the Coalition Against Family Violence, along with other non-governmental organizations in exploring new ways to engage communities in the development and promotion of education and awareness campaigns and in identifying family violence prevention strategies that address the specific needs of each community. As outlined in the "Communities and Diamonds 2014" Report prepared by the GNWT, when the mines first became operational circa the mid-1990s, the rate of spousal assault had been going down in the small local communities (Behchokö, Detah, Gameti, Lutsel K'e, Wekweètì, and Whatì). Over the years, there have been increases and decreases in these communities, reaching a high point in 2011 and declining since. Data from the RCMP "G" Division shows that in 2013, the rate of spousal assault in these communities had dipped below the pre-mine rate. The rate of spousal assault in Yellowknife has also experienced peaks and lows since the opening of the mines, but returned to its pre-mine rate in 2013. At this time, there is insufficient evidence to conclude that mining activity is influencing the rate of spousal assault in NWT communities.

IR#	Topic	Comment	Request	GNWT Response
NSMA IR#3	Ekati SEA, Schedule D	GNWT has agreed to monitor selected indicators", which will be used to identify activities which strengthen benefits and mitigate negative impacts of social chage.	Please describe what activities were chosen to strengthens the benefits and mitigate the negative impacts. Please describe how the programs are evaluated, and data are utilized. If analyses were undertaken to isolate the effects of the DDEC (or diamond mine) development(s), please make the results available.	The GNWT has administered various programs to mitigate negative impacts, as well as maximize the benefits to Northerners in relation to indicators found in Schedule D of the Ekati SEA. Programs generally fall within the scope of human resource development, business development, and health and well-being. Human resource development programs aim to pair Northerners with jobs in the mining industry through training and promotion of these jobs. Examples include career fairs and counselling support, training programs, apprenticeships and skills development, and student financial assistance. ECE houses the student financial assistance (SFA) program to provide assistance to eligible NWT residents to help them with their postsecondary education-related expenses. Improvements to the program are in progress. The SFA Policy Manual, Regulations, and the Act are made available to the public in order to provide a foundation for fair and equal treatment for all SFA recipients. Assisting students with postsecondary education expenses contributes to a trained and skilled northern workforce. ECE along with Aurora College, Skills Canada and the Mine Training Society work together to promote apprenticeship and occupation certification in the NWT. ECE, through the Advanced Education Division, administers the NWT Apprenticeship and Occupation Certification (AOC) program. This program supports the development, maintenance and delivery of trade and occupation training programs which contribute to the expansion of a trained and skilled northern workforce. ECE is leading a Skills 4 Success Initiative in partnership with key stakeholders to take a systematic look at our adult and postsecondary education, and skills training programs, supports, and pathways with the goal to improve employment success for NWT residents, close skill gaps for in-demand jobs, and more effectively respond to employer, industry, and community needs.

				ECE works in partnership with Aurora College, training providers, other government agencies, non-government organizations, industry, businesses, and employers to coordinate the delivery of training programs. This includes working closely with Service Canada and Aboriginal Skills and Employment Training Strategy (ASETS) agreement holders, who are responsible for delivering training or skills upgrading to help Aboriginal Canadians prepare for, find, and maintain jobs. Business development programs seek to help Northern companies conduct business directly with the mines, as well as in support industries. Examples include business training thorough Aurora College and the Small Business Development Program (SBDP), business counselling through Economic Development Officers, and business support through the Community Futures Program, amongst other programs. Health and wellbeing programs and services are delivered territory-wide to help residents of the NWT achieve the best possible physical, emotional and mental health and are offered in both clinical and non-clinical environments at the community and regional levels. The programs and services offered range from routine medical care, physical therapy and preventative medicine, to mental health and addictions counseling, family programs and programs for youth. These services are available to all residents of the NWT. The Department of HSS monitors selected indicators of health and wellbeing as part of ongoing territory-wide performance measurement and system accountability. Patient/Client satisfaction and feedback are among the most popular methods to assess whether programs are meeting the needs of NWT residents, and when combined with health data, can provide the basis to inform program improvement across the NWT. Results are made public on the Department's website and the most recent reports will be put on the Public Registry. GNWT programs and services are provided territory-wide. Some communities are affected by multiple mines, development, cultural change, and other determinants of individual, family, and community well-being. Given the broad scope of GNWT

				programs and external factors, data and analysis cannot separate the effect of a single mine or mining project but rather take into account the multitude of factors that contribute to change. Programming is developed and monitored accordingly.
IR#	**Topic**	**Comment**	**Request**	**GNWT Response**
LKDFN #2	Technical Session Undertaking #17; GNWT response to YKDFN IR7	In the GNWT's response to YKDFN, the GNWT indicated that an MOU had been signed between the GNWT and De Beers to govern emissions from Gahcho Kue, but that no similar MOU was necessary with Dominion as emissions would be governed by regulations currently in development. LKDFN would suggest that if a long-term development, such as the Jay Project, is to be governed by air quality regulations not yet in force, as explicitly stated by the GNWT, then the expectations of these regulations should be incorporated into the project design to the extent possible. The project has defined significance in terms of	LKDFN requests that the GNWT provide as much information as possible on the status of these regulations and enforcement measures. LKDFN also requests an approximate timeline for the implementation of these regulations. Lastly, LKDFN requests information on the measures being taken by the GNWT to prepare DDEC for these regulations to help ensure that Ekati and the Jay Project are compliant.	At this time it is difficult to provide exact details on the regulatory framework, as we are in the early stages of development; however, as part of this process, significant emission sources without clear regulatory guidance are being identified and prioritized. The Department of Environment and Natural Resources (ENR) is researching what regulatory tools could or should be established and enforced under the *Environmental Protection Act* (EPA) to address air emissions from developments. A timeframe for these regulatory tools has not yet been established; however, the types of regulatory tools implemented will be determined by what is most effective and timely. ENR has identified waste incineration as a high priority and is currently working with the Land and Water Boards (LWBs) and our legal counsel to develop tools to effectively regulate this emission source. ENR agrees that it is important to prepare DDEC for potential air regulatory tools that may be implemented to aid the Company in achieving future compliance. ENR has been consistent in promoting key principles for air quality and emissions management throughout EA or LWB processes, which will ultimately provide the basis for any regulatory tools that may be developed under the EPA. These include ENR's policy of Keeping Clean Areas Clean, reducing emissions at the source, monitoring the receiving environment, and incorporating adaptive management strategies based on those results. Correspondingly, ENR has requested that DDEC incorporate the following components into their air emissions management initiatives for the Jay Project: 1) Conduct incinerator air emissions stack testing every 3 years and comply with the applicable Canadian Council of Ministers of the Environment (CCME) standards. It is ENR's understanding that DDEC has committed to this request.

		air quality as occasionally exceeding the limits set by the only official guidance available. If legally enforceable regulations were to incur consequences at these levels, it would be easier to address now rather than when operations have already started.		2) Apply a procurement policy such that all emission-generating equipment be selected using the principle of Best Available Technology in order to minimize emissions from the mine. 3) Implement adaptive management, incorporating ENR's Guideline for Ambient Air Quality Standards and establish appropriate pollutant threshold values and associated actions, into their air quality monitoring and management plan (AQMMP). DDEC has confirmed they are committed to developing and implementing this type of adaptive management system for air emissions. ENR believes that requesting DDEC implement these air emission management strategies now will help prepare the Company for future air regulatory tools that may be established.
IR#	**Topic**	**Comment**	**Request**	**GNWT Response**
LKDFN #4	Greenhouse gas emissions/alternative energy Paths to a Renewable North: Pan-Territorial Renewable Energy Inventory (link in ORS)	At the 2009 Northern Premiers' Forum, the three territorial Premiers committed to developing an inventory of current and future renewable energy resources. In the resulting presentation, the first priority mentioned for the Northwest Territories is the possibility of new mining developments using alternative energies. It would be good to know how this	LKDFN would like to know what steps the GNWT has taken to encourage the project proponent to use alternative energies, as per the intention listed in "Paths to a Renewable North."	Following the release of the Pan-territorial "Paths to a Renewable Future" inventory, the GNWT prepared a renewed Greenhouse Gas Strategy for the Northwest Territories. Building on earlier experience to identify actions to control greenhouse gas emissions, the 2011 Strategy included a commitment to encourage adoption renewable energy and installation of energy efficient systems. Subsequently the Biomass Energy Strategy was updated and a new Solar Energy Strategy was introduced to support adoption of these renewable energy sources. Based on the experience gained through these actions, the GNWT provided earlier responses through this review process to the project proponent, encouraging them to undertake an analysis of the opportunity to install photovoltaic solar panels to produce electricity and reduce their greenhouse gas emissions. After the proponent indicated they would not accept this as an undertaking, the GNWT requested the Arctic Energy Alliance prepare a desktop analysis of installing 50 kW of solar at the Ekati Mine based on GNWT experience with solar power installations.

		approach applies to this specific project.		The results of the Arctic Energy Alliance's analysis (provided as attachments to this IR response) indicate a 50 kW solar installation could generate about 48,000 kWh annually costing $0.208/kWh with an equity payback of 16.3 years from the savings over the cost of producing the same amount of electricity using conventional diesel generation. These systems have on operational life expectancy of over 25 years and it would become an asset with ongoing power production during the abandonment and restoration phase of the mine if no new kimberlite pipes are developed. Roof top space at the mine site could easily accommodate up to 1 MW to provide considerably more power and greenhouse gas emission reductions than the 50 kW system considered in this analysis.
IR#	**Topic**	**Comment**	**Request**	**GNWT Response**
LKDFN #6	Coordination of Bathurst herd conservation effort	The Bathurst caribou herd has suffered a dramatic decline. GNWT has made efforts to address this population crash through various efforts including hunting bans and range planning. The project proponent has stated that the project will not impact the caribou's ability to be "self-sustaining and ecologically effective;" however, it has admitted that there will be some impacts to the caribou population. GNWT ENR has been in discussions with aboriginal groups, other	LKDFN would like to know what measures ENR has taken above and beyond established protocol to address the admitted impacts of this project on the Bathurst caribou herd population and how these measures are being coordinated with the efforts being taken on other fronts, such as hunting and range planning.	When ENR comments on potential impacts of the Jay Project to the Bathurst herd throughout the Jay EA process, it is always in the context of other factors impacting the herd including human impacts on the range and harvest as well as other processes that are currently in place to address these. For example, in addition to specific comments made throughout the regulatory process on the Jay DAR and associated wildlife plans, ENR is working with partners to manage disturbance on the range through the Bathurst Range Planning process. In addition, ENR recognizes the need for a coordinated overall approach to conservation of the Bathurst herd and will continue to promote development of a management approach for this herd that includes all parties as envisioned in the Tlicho Agreement. As this process remains in the early stages, ENR will continue to engage in and provide consistent advice on environmental assessment processes in NWT and NU that may affect Bathurst caribou, and further development of the Bathurst range plan (which includes other government departments, NU agencies, and industry). Short-term and medium-term management measures such as harvest limitation will be re-visited with all affected parties in fall 2015 once survey numbers are available. Further meetings this coming fall and winter should provide LKDFN and others with ample opportunity to raise any issues that need to be addressed.

		government departments and other territorial governments to determine ways that the Bathurst caribou herd can be protected. These efforts have sometimes included sacrifices by some, such as hunters foregoing harvesting from the Bathurst herd. It is LKDFN's opinion that the effective protection of the Bathurst herd can only be achieved through coordination of all implicated parties, including government, industry, and aboriginal groups.		

Topic: Hydrology Model Reliability

Comment:

The DAR contains only subjective descriptions of model reliability - i.e. the developer makes subjective statements on the reliability of the model he himself developed. In the first round of IRs, and during the April 2015 Technical Session, the GNWT expressed a number of concerns as to the lack of objective and quantitative evaluations of the accuracy and error limits of the hydrologic modelling. An outcome of the Technical Sessions was Undertaking 07, by which the Developer agreed to undertake a quantitative evaluation of model performance, using measurement parameters and procedures such as outlined in Moriasi *et al*. 20071.

The submitted Undertaking 07 covers the following aspects:

1. The only hydrologic model component assessed is the discharge at the Desteffany Lake station. Although that location has the most data and is thus suitable for evaluation of the model as such, it is located some distance downstream of the project and may not represent how well the model performs nearer to the project. There are more upstream locations where project effects are of greater concern - notably Lac du Sauvage and Lac de Gras and their outlets. Due to a lack of observational data at the former, only the Lac de Gras location would be amenable to quantitative evaluation of model performance.

2. Model performance was computed using four parameters as listed below, with GNWT's comments listed where applicable.

    a. Coefficient of Efficiency (Nash-Sutcliffe Coefficient) - NSE. *No comment.*

    b. Root-Mean-Square Error standard deviation ratio - RSR. *No comment.*

    c. Average percent error in annual maximum peaks - APEP. *There appears to be a typographical error in the equation used - the second equal sign should be a multiplication sign.*

    a. Percent Bias - PBIAS. *There appear to be typographical errors in each of the three equation used - the 1/n, 1/m and 1/l terms, as well as the second equal sign should be eliminated.*

3. Model performance was rated based on the results of the computed parameter values, as summarized in Table 7-1.

Table 7-1 Statistical Evaluation of Model Performance

Performance Metric	Sample Size	Daily	Monthly	Annual	Model Performance Rating
NSE	6,318 D 214 M	0.40	0.56	-	Satisfactory
RSR	6,318 D 214 M	0.78	0.66	-	Satisfactory
PBias (%)	6,318 D 214 M 12 Y	18	18	13	Satisfactory
APEP (%)	19 Y	-	-	8.7	Good

Source: DAR-MVEIRB-UT-07 (http://www.reviewboard.ca/upload/project_document/EA1314-01_Tech_Session_Undertakings_submitted_by_Dominion.PDF)

AMEC conducted check computations for the above parameters and confirms the values listed in Table 7-1 except that a value of 13.1 was found instead of the listed 8.7 for the APEP.

It is noted that the model shows a consistent bias in over-predicting discharges and runoff volumes, in the order of 13 - 18 %. That result agrees with Figure 7-1 which shows that a large portion of the percent exceedance probability curve for modelled flows lies above that of the observed flows. Those results then put into doubt the claim in the DAR and IR responses that the model was calibrated to the mean runoff volume or yield.

The use of the **average** percent error in annual maximum peaks obscures the large variation in the percent error from year to year, which AMEC found to range from 109 % to - 39 %, i.e. modelled peaks were 109 % greater to 39 % lower than the observed values for specific years. Those values do not seem to support the performance rating of "good".

Request:

The GNWT requests DDEC:

a) Conduct additional quantitative evaluation of model performance, using the same parameters, but applied to Lac de Gras water levels using the available five years of data as per IR-33 Figure 33.3. Water levels should be expressed as stage above estimated zero flow rather than geodetic elevation.

b) Confirm the appropriate form of the parameter equations used.

c) Provide an explanation for the consistent over-estimation of annual runoff volume, especially when that parameter is claimed to have been a primary basis for model calibration. Perhaps one or more runoff coefficients have been set at unrealistically high values.

d) With respect to annual peak discharges, DDEC provide;
   i. The APEP value in Table 7-1 be checked and confirmed.
   ii. The skill of the model in simulating annual peaks be further evaluated by preparing a correlation plot of modelled versus observed annual peaks for the years of record.
   iii. A discussion be provided as to the factors leading to the divergence between modelled and observed values in the correlation plot.

In conclusion, GNWT requests that the range of uncertainty in model simulations, as found from the computations presented in Undertaking 07, and supplemented as necessary to further quantify that uncertainty, should be applied to the predictions of project effects made by the model.

Reference:

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bigner, R. D. Harmel, and T. L. Veith. (2007). *Model evaluation guidelines for systematic quantification of accuracy in watershed simulations*. Transactions of ASABE, American Society of Agricultural and Biological Engineers, 50(3): 885-900.


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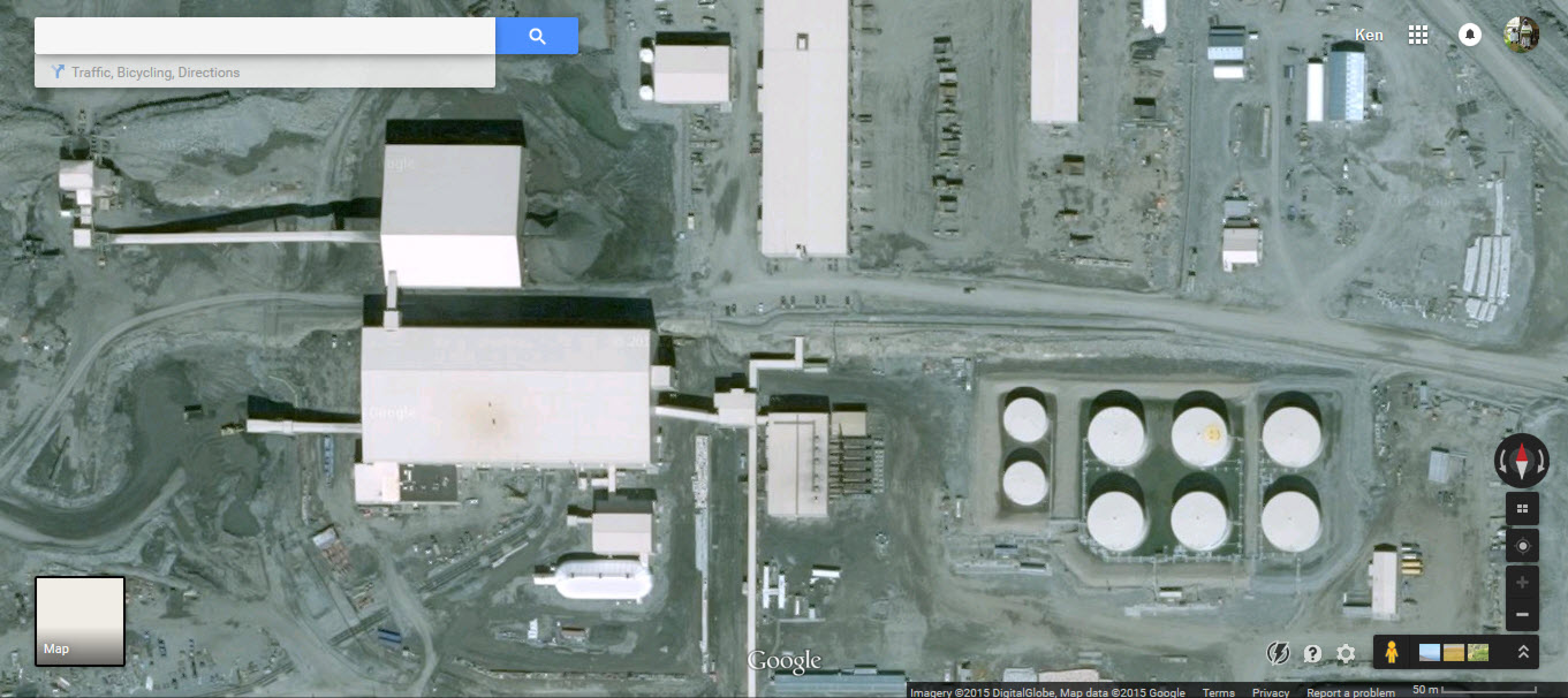
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Dominion Diamond Ekati Corporation – Jay Project (EA1314-01 [2013])
Government of Canada
Second Information Request Responses

Information requests directed to Fisheries and Oceans Canada:

MVEIRB IR#12 – Response included in attached letter

MVEIRB IR#16 – Response included in attached letter

Information requests directed to all parties:

MVEIRB IR#11 – Environment Canada, Transport Canada and Fisheries and Oceans Canada have provided responses to this information request in the first round.

MVEIRB IR#31 – This information request is outside the mandates of Environment Canada, Transport Canada and Fisheries and Oceans Canada. As such, these parties will not be providing a response to this request.

Independent Environmental Monitoring Agency
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June 5, 2015

Chuck Hubert
Senior Environmental Assessment Officer
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Dear Mr. Hubert

Re: Jay Project (EA1314-01) Second Round Information Requests

The Agency is submitting a number of Information Requests on the proposed Jay Project. We note that the developer, Dominion Diamond Ekati Corporation (DDEC), submitted five management plans that deal with monitoring and mitigation to be applied to the proposed Jay Project. The Agency has not had an opportunity to review all of these most recent submissions that were made available four days ago.

The Agency in no way wishes to delay the ongoing Environmental Assessment of the Jay Project and we have met all the deadlines set by the Review Board and responded to informal requests from DDEC and its consultants in an efficient and timely manner.

There were considerable discussions at the April 2015 Technical Sessions regarding the need for detailed management plans in relation to the proposed Jay Project. Given the limited time for the review of the recent DDEC management plan submissions and the importance of these documents, the Agency believes there should be some form of additional review beyond the current round of Information Requests that are due today. Some form of review will benefit the scoping and resolution of issues before the public hearing in September 2015.

The Agency would like to suggest a couple of options for the review of the recent DDEC management plan submissions. DDEC could hold workshops or meetings to allow for an exchange of information and reviews, and a record of these events would be submitted to the public registry. The Review Board could also allow for a focused and efficient Information Request process on these new submissions.

We look forward to an opportunity to review these recent DDEC submissions. We would be pleased to discuss these options with you, DDEC and the other parties as necessary.

Sincerely,

W.A. Ross

Bill Ross
Chairperson

cc. Society Members (DDEC, GNWT, AANDC and Aboriginal Society Members)

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Original article

Estimating the zone of influence of industrial developments on wildlife: a migratory caribou *Rangifer tarandus groenlandicus* and diamond mine case study

John Boulanger, Kim G. Poole, Anne Gunn & Jack Wierzchowski

Wildlife species may respond to industrial development with changes in distribution. However, discerning a response to development from differences in habitat selection is challenging. Since the early 1990s, migratory tundra Bathurst caribou *Rangifer tarandus groenlandicus* in the Canadian Arctic have been exposed to the construction and operation of two adjacent open-pit mines within the herd's summer range. We developed a statistical approach to directly estimate the zone of influence (area of reduced caribou occupancy) of the mines during mid-July-mid-October. We used caribou presence recorded during aerial surveys and locations of satellite-collared cow caribou as inputs to a model to account for patterns in habitat selection as well as mine activities. We then constrained the zone of influence curve to asymptote, such that the average distance from the mine complex where caribou habitat selection was not affected by the mine could be estimated. During the operation period for the two open-pit mines, we detected a 14-km zone of influence from the aerial survey data, and a weaker 11-km zone from the satellite-collar locations. Caribou were about four times more likely to select habitat at distances greater than the zone of influence compared to the two-mine complex, with a gradation of increasing selection up to the estimated zone of influence. Caribou are responding to industrial developments at greater distances than shown in other areas, possibly related to fine dust deposition from mine activities in open, tundra habitats. The methodology we developed provides a standardized approach to estimate the spatial impact of stressors on caribou or other wildlife species.

Key words: Arctic, barren-ground caribou, dust, industrial disturbance, open-pit mining, Rangifer tarandus groenlandicus, resource selection functions, zone of influence

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The impact of industrial development on wildlife is a frequent and worldwide concern, and this is especially true for long-distance migrants whose traditional routes can be threatened by industrial developments (Berger 2004). Those long-distance migrant species include migratory tundra caribou *Rangifer tarandus groenlandicus*, and shifts in caribou distribution in response to human activities have been the focus of much research (e.g. Nellemann et al. 2003, 2010, Vistnes & Nellemann 2008, Polfus et al. 2011). However, comparing findings among studies is complicated by different methodologies and scales of disturbance (Stankowich 2008). Differences in results from analyses of the same data sets can trigger controversy (Noel et al. 2004, Joly et al. 2006), detracting from effective conservation and mitigation for species that may be impacted by industrial development.

We became interested in measuring displacement of migratory tundra caribou when investigating the impact of mine development on the Bathurst caribou herd on the central Canadian tundra (i.e. Northwest Territories and Nunavut). Migratory tundra caribou is a gregarious and migratory ungulate with ecological similarities to other open habitat, gregarious ungulates in Africa and Asia which face industrial developments on their ranges (e.g. Mongolian gazelles *Procapra gutturosa*; Ito et al. 2005).

The Bathurst caribou herd has declined since 1996 from an estimated 349,046 (± 204,975 CI) to 31,897 (± 10,932) caribou in 2009 (Nishi et al. 2010, Boulanger et al. 2011). The decline adds urgency toward understanding the cumulative effects of industry, harvest and other stressors. From the early 1990s onward, Bathurst caribou have been exposed to a boom in mining exploration, which culminated in the construction of two open-pit mines and one underground diamond mine on the tundra range of the herd between 1996 and 2005. During and after environmental assessment hearings for the diamond mines, strong concerns were expressed about how the mines would affect caribou movements and distribution (Boulanger et al. 2004, Johnson et al. 2005). The distance at which caribou change their behaviour, habitat selection and distribution relative to disturbance, which we term the 'zone of influence', has implications for measuring the cumulative effects of industrial activities on wildlife, especially where there are multiple projects (Duinker & Greig 2007).

Previous estimates of the distances over which caribou were displaced from industrial disturbance were based on recording the frequencies of caribou occurrence relative to distance from the source of disturbance (e.g. Nellemann et al. 2000, Cameron et al. 2005, Joly et al. 2006), and fitting polynomial curves to distances of caribou from disturbances (Boulanger et al. 2004, Johnson et al. 2005, Golder Associates Ltd. 2008a,b). Estimates of displacement for the Bathurst caribou herd using satellite collar and aerial survey data using polynomial-based methods ranged from 17 to 130 km (Boulanger et al. 2004, Johnson et al. 2005, Golder Associates Ltd. 2008a,b). We suspected that the large differences in the apparent zone of influence were the effect of scale (ranges of distances considered in the analysis), and uncertainty in the exact distance due to the curvilinear nature of polynomial curves. A recent literature review and simulation study by Ficetola & Denoel (2009) demonstrated that the method used to detect threshold effect distances in ecology had substantial effect on estimates, which further supported our suspicion.

The primary objectives of our study was to derive a robust statistical measurement of the zone of influence and determine mechanisms for estimated zones of influence We adopted a piecewise regression method that fit the hypothesized asymptotic zone of influence threshold relationship by estimating the exact distance out to which mines affected caribou distribution while accounting for habitat selection. We furthered the piecewise methodology by fitting models that were robust to sample biases in our data sets and by estimating confidence limits on zones of influence and associated statistics. The scale of the zone of influence raises the question of possible mechanisms. Given the zone of influence, we explored dustfall as a potential mechanism that may contribute to the changed caribou distribution beyond behavioural responses to people, physical structures and vehicles. We suggest that this methodology is applicable to the estimation of spatial response of any wildlife species to stressors.

Material and methods

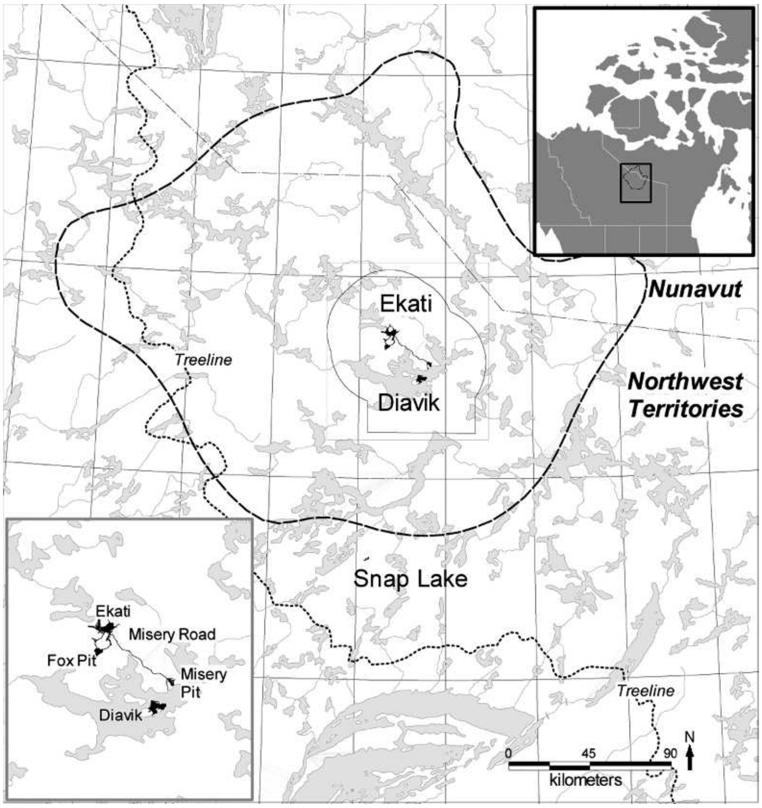
Study area

Our study area is approximately 300 km northeast of Yellowknife, Northwest Territories, Canada (Fig. 1) and is within the southern Arctic ecozone (Ecological Stratification Working Group 1996). The glaciated landscape has esker complexes, boulder moraines, ancient beach ridges and numerous lakes. Shrub communities of willow *Salix* spp., shrub birch *Betula* spp. and Labrador tea *Ledum decumbens* dominate areas with adequate soil development. Mats of lichens, mosses and low shrubs are found across exposed rocky and gravel sites.

The Bathurst herd of migratory tundra caribou annually moves hundreds of kilometres from wintering ranges below the treeline, to calving and summer range on the open tundra (Gunn et al. 2001). It is during the post-calving through summer seasons that the caribou are most likely to be in the vicinity of the mines, so we restricted our analyses to 15 July-15 October. During this period, Bathurst caribou occupy about 100,000 km^2 of tundra with a high-use area (70% kernel) of about 53,000 km^2 and a core (50% kernel) of about 33,000 km^2, all based on satellite-telemetry of cows from 1996 to 2008 (Environment and Natural Resources, Government of Northwest Territories, unpubl. data).

We analyzed caribou distribution relative to two of the three existing diamond mines within the

Figure 1. Location of the Ekati, Diavik and Snap Lake diamond mines in the Canadian Arctic. The broken line polygon represents the area of high use (70% kernel) of the distribution of collared caribou during 15 July-15 October 1996-2008. The largest extent of the aerial survey study areas is also shown around each mine. The treeline represents the northern extent of continuous forests.



Northwest Territories (see Fig. 1): Ekati (BHP Billiton Canada Inc.) and Diavik (Diavik Diamond Mines Inc.). The main Ekati mine and Diavik are 30 km apart. Both mines are open-pit mines with accommodation complexes, ore-processing buildings and airstrips. Ekati has a separate camp and an open pit (Misery), which is connected by a 29 km all-weather road to the main Ekati site. The Misery camp and pit are 7 km from the Diavik mine, which is restricted to a large island in Lac de Gras. Because of the juxtaposition of the Ekati and Diavik operations, we modelled these mines as a combined unit. Caribou data were available for the mine sites from preconstruction (Diavik: 1996-1999) and construction (Ekati: 1996-1998, Diavik: 2000-2002) through to full operation (Diavik: 2003-2008, Ekati: 1998-2008), which allowed description of caribou distribution relative to mine areas across a range of mine footprints and activities. The total footprint of the Diavik and Ekati mines in 2008 were 9.7 km^2 and 29.9 km^2, respectively.

General approach

We used a multi-step approach to analyses, which is summarized in Table 1 and described in detail in the following paragraphs. We first organized the aerial survey and satellite collar data and developed methods to confront sampling biases inherent to each of the data sets. Secondly, we developed a base habitat model using logistic regression with habitat covariates used to predict caribou distribution based on caribou locations from aerial survey and satellite collar data. Thirdly, we used the base habitat model to iteratively estimate a zone of influence (area of reduced caribou occurrence) around the mine sites through the use of a piecewise regression procedure with distance from mine site as an additional predictor variable. Separate analyses were conducted for aerial survey and satellite collar data. Finally, we tested dustfall predictions as a possible mechanism for the observed zone of influence distances.

Caribou data sources

We used two sets of caribou location data. First, we obtained caribou sighting data from weekly helicopter surveys during July-October, which used systematically spaced strip transects (BHP Billiton 2009, Diavik Diamond Mines Inc. 2009; Appendix I). Transect route, spacing and width, study area size and frequency of data collection (collectively called

Table 1. Summary of hierarchical steps used to estimate zone of influence (ZOI). Each item is covered in detail in the manuscript text.

Input data	Problem or rationale	Test procedure
Step 1. Define caribou, habitat data and analysis methods		
Caribou locations - aerial transect data/habitat class/NDVI data	Presence/not detected from aerial transect cells	Logistic regression with ROC goodness-of-fit tests
	Spatial autocorrelation of adjacent transect cells	Generalized estimating equation model
	Annual and seasonal variability in abundance	Relative caribou abundance as predictor variable
	Detection bias in transect surveys	Use odds ratios to interpret relative habitat selection
Caribou locations - telemetry data/ habitat class/NDVI data	Compare random and used locations	Conditional logistic regression with GOF tests
	Availability of habitat	Availability based on 95% movement buffers
	Relative habitat use from used/random locations	Use odds ratios to estimate relative habitat selection
Step 2. Select habitat covariates to develop caribou base habitat model		
Aerial survey and telemetry data/ habitat data defined in step 1	Univariate tests of individual habitat predictor variables	Individual logistic regression analyses
Identify significant predictors from univariate analyses	Multivariate habitat selection model	Type 3 χ^2-tests and empirical standard error estimates
Step 3. Estimate ZOI using base model from steps 1 and 2		
Base habitat models output (from steps 1 and 2)	Natural variation in caribou selection/ distribution	
	Estimate ZOI when habitat selection/ distribution is not affected by mines using distance from mine as predictor variable	Piecewise regression to determine when distance from mine does not influence habitat selection (the ZOI)

survey design) varied within and between the mines. Most transects, however, were systematically placed at 4- or 8-km spacing to provide a coverage of 15-30 km radius study areas out from mine infrastructure and were flown at an altitude of 150 m and at a speed of 145-160 kph. The transect width was 600 m on both sides of the helicopter, and the transects were divided into 1-km long cells. For analysis we considered surveys in which $>$ 1 cell had caribou present ($>$ 0.2% relative occupancy/survey), resulting in 168 useable aerial surveys flown between 1998 and 2008 with a mean of 10.5 surveys/year (range: 8-18 surveys). For these surveys, the mean relative proportion of cells in which caribou were observed was 5.1% (SD = 6.4%; range: 0.3-41.0%).

The second data set of caribou locations was obtained from satellite transmitter collars fitted to adult cow caribou tracked from April 1996 to October 2008 (Gunn et al. 2001, Environment and Natural Resources, Government of Northwest Territories, unpubl. data). The number of collared caribou annually available for analysis that could encounter the mine sites ranged from four to 19 (see the section Treatment of satellite collar data below; see Appendix I). The satellite collars varied from transmitting every seven days beginning in 1996 to every five days beginning in 1998 with the addition of daily duty cycle for mid-July-mid-August beginning in 2002. We used 3,705 point locations during our period of interest (57.1% daily, 36.9% 5-day and 6.0% 7-day) from an annual average of 11.5 ($\pm$ 1.25 SD) individual cows.

Habitat variables

We used two sets of data to describe habitat. First, we used vegetation classes and landform features from the Land Cover Map of Northern Canada (NLC; Olthof et al. 2009) and Earth Observation for Sustainable Development of Forests land cover classification (EOSD; available at: http://www.geobase.ca/geobase/en/data/landcover/index.html). Esker coverage was extracted from 1: 250,000 scale National Topographic Data Base maps (Natural Resources Canada; available at: http://geogratis.

cgdi.gc.ca/geogratis/en/index.html). We used 12 habitat classes pooled between the NLC, EOSD and eskers coverage.

Second, we included data on plant phenology and productivity, which could influence caribou habitat use and movements (Russell et al. 1993). We used Normalized Difference Vegetation Index (NDVI) imagery to track plant phenology and productivity within the study area (Appendix II). We generated NDVI values for 10-day intervals for each year thus accounting for differences in seasonality for each year in the analysis.

Treatment of aerial survey data

We applied resource selection functions (RSF; Manly et al. 2002) to assess habitat selection using caribou locations from both aerial survey and satellite collar data. We treated the aerial survey observations as presence or absence of caribou rather than absolute abundance to minimize the effect of contagious behaviour and group size (Millspaugh et al. 1998). We compiled the observations of presence or absence into successive 1-km cells that were 1.2 km wide and calculated the proportion of habitat classes within each cell. We determined the distance from the mine site for all transect cells using the distance from the centroid of each transect cell to the nearest mine site centroid or mine road. When we added outlying components of the Ekati development (Misery and Fox pits), we used the distance to the nearest infrastructure component or associated road.

To address spatial autocorrelation, we used a generalized estimating equation model (GEE; Ziegler & Ulrike 1998) to estimate correlations and robust empirical standard errors between successive observations on the same transect line for the most supported base habitat model. We used an exchangeable correlation matrix structure to account for spatial autocorrelation. We used type 3 χ^2 tests, which are less sensitive to order of parameters in the models, to test for significance (SAS Institute 2000). We used ROC curves to estimate the goodness-of-fit for how well a model predicts presence or absence through a range of probability cutpoints. A cutpoint was the probability level at which presence or absence was declared in each cell. ROC scores vary between 0.5 and 1. A score of 0.5 would correspond to a model with no predictive ability and a score of 1 would correspond to a model with perfect predictive ability. Models with scores of > 0.7 are considered to be of 'useful' predictive ability (Boyce et al. 2002). We used SAS PROC GENMOD or PROC LOGISTIC for all analyses (SAS Institute 2000).

The abundance of caribou varied annually and seasonally, which created variation in habitat selection. We therefore used the relative abundance of caribou in the survey area, as indexed by the number of cells in which caribou were detected relative to the number of cells sampled, as a 'nuisance' predictor variable. This minimized the influence of abundance on habitat selection by allowing the probability of habitat being selected to increase linearly with abundance.

We explored the effect of varying survey design between mines and over time by estimating the interaction of different designs (as a categorical variable) and the estimated zone of influence predictor variables. We assumed that any issue with detection of caribou during aerial surveys occurred evenly across all habitat classes. This was a reasonable assumption given that all surveys occurred in open tundra areas with minimal topography or vegetation to obscure caribou. We expressed all estimates as odds ratio given that detection probability could bias absolute estimates of occupancy of caribou around mine areas (MacKenzie 2006).

Treatment of satellite collar data

We defined habitat availability for the satellite collar data set based on each caribou location and estimated movement rates. We determined the proportion of habitat classes in a 1-km buffer radius (the maximum error of the satellite collar locations) around collar locations. Then we compared each buffered point with the buffered area around six random points that were within a circle around the previous location of the collared caribou. The circle was the 'availability radius' defined by the 95th percentile of the distance moved for caribou for the interval between successive point locations (Arthur et al. 1996, Johnson et al. 2005). We tested the satellite collar data for interactions between availability radius (duration between fixes; i.e. duty cycle), which determined the size of the buffer where available locations were placed, and habitat variables.

Caribou can select habitat at a finer scale than the scale reflected by the availability radius, as the radius depends on the time between successive telemetry fixes. For this reason, we considered the interaction of each habitat variable with the availability radius. This accounted for possible scale effects and allowed all the data to be simultaneously considered in a single analysis. We included locations from caribou which could encounter the mine sites (as indicated by the availability radius) at least once in a given year in the analysis. This filter excluded only 4.8% (seven of 145) of the caribou-year combinations from the analysis.

We compared caribou location points (used) and random points using a conditional logistic regression (Hosmer & Lemeshow 2000). The analysis defined each used and six accompanying random points as a cluster. This cluster centred each comparison on the habitat available to the caribou at the time when the location was taken. This approach avoided issues with pseudoreplication caused by pooling telemetry data from different individual caribou (Pendergast et al. 1996, Johnson et al. 2005). We used k-fold cross validation to test goodness-of-fit of the used-random satellite collar data (Boyce et al. 2002). For this analysis, we subdivided the data into training and testing data sets based on Huberty's rule of thumb (Huberty 1994). We then tested the goodness-of-fit of a model developed with the training data set with the testing data set. We estimated the Pearson correlation (Zar 1996) of successive RSF score bins with the frequency of used locations in each bin (adjusted for availability area of each bin). If the model fitted the data, then the RSF bin score and area-adjusted frequencies should be positively correlated (Boyce et al. 2002). We expressed all estimates from the logistic model as odds ratios given that absolute probability of presence cannot be estimated using used/availability analyses (Boyce et al. 2002).

Procedure for base model habitat variable selection

To build a base habitat model, we applied individual logistic regression analysis tests (as previously described for aerial survey and satellite collar data) to determine the statistical significance of individual habitat predictor variables (Hosmer & Lemeshow 2000). We pooled yearly data for this analysis. The general form of the model was:

response = habitat variable + habitat variable^2 + habitat variable*movement rate + habitat variable*season + habitat variable*mean NDVI score + buffer scale*habitat variable (satellite collar analysis only).

The quadratic term (habitat variable^2) tested for situations when stronger associations with habitat values were likely to occur in the midpoint of the habitat variable value as opposed to a linear relationship. The interaction between habitat variables and movement rate was tested for cases when a habitat was used transitionally, as indicated by a significant relationship between movement rate and the given habitat variable. We used the interactions among habitat variables and mean NDVI to test for seasonal selection of habitats and account for yearly differences in seasonality. We also tested for seasonal selection of habitats due to factors such as insect harassment and other factors not accounted for by NDVI by modelling the interaction of habitat type and season. Seasons were defined as early summer (15-18 July), mid-late summer (21 July-20 August), fall migration (25 August-5 October) and rut/late fall (6-14 October). We standardized habitat variables to allow easy interpretation of slope coefficients and to minimize issues with varying measurement scales.

We then added significant variables from univariate tests into a multivariate model in the same order as in the univariate model (i.e. linear habitat variable and habitat variable*movement rate). We evaluated the fit of individual terms by Type 3 χ^2 tests and empirical standard error estimates (SAS Institute 2000). From this, we derived a base habitat model, which we then used to test for the zone of influence of mine sites.

Estimation of the zone of influence of mine areas

To test for zone of influence, we used logistic regression for analyses with caribou presence/absence as the response variable and the base habitat selection model with distance from mine as the additional predictor variable. The habitat selection model accounted for caribou distribution due to habitat selection, with a 'zone of influence' predictor variable (abbreviated to and symbolized as ZOI) and associated regression coefficient (β_{ZOI}). We used a procedure analogous to piecewise or segment regression to determine an optimal cutpoint (Hudson 1966). For example, when a 1.5-km distance was tested, all presence or used locations > 1.5 km were set to 1.5 km, regardless of how far out they were. By doing this, the odds ratio of selection relative to the mine site (as estimated by distance from mine*β_{ZOI}) was allowed to change linearly up to the hypothesized ZOIs, at which point it would asymptote and remain constant for distances greater than the ZOI (as estimated by ZOI*β_{ZOI}; Fig. 2). We assessed the overall fit of each sequential ZOI distance model by its log-likelihood. If fit was improved by the β_{ZOI} term, then the log-likelihood should increase to a maximum at the statistically most probable ZOI before decreas-

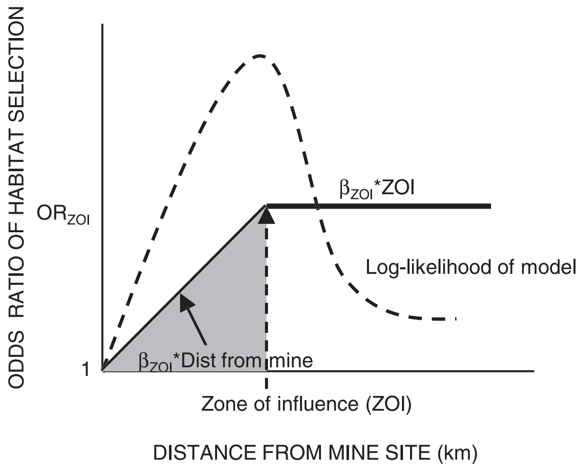


Figure 2. Model used to estimate the ZOI and the magnitude of the ZOI. If a ZOI exists (grey area), habitat selection (as reflected by odds ratio of selection compared to the immediate mine area) should increase until the distance where the mine has no influence on selection. At this point, the model should best fit the data as indicated by the highest log-likelihood value. The slope of the increase in odds ratio is estimated by β_{ZOI}. At distances beyond the ZOI, the ZOI predictor variable was set constant (i.e. all distances < 10 km were set to 10 km), therefore creating an asymptote in the ZOI curve.

ing at larger distances (see Fig. 2). If there was no ZOI, then the log-likelihood would remain constant across the range of distances. The distance at which the log-likelihood was maximized is, then, the estimate for the ZOI (i.e. the maximum distance where an influence of the mine on caribou distribution could be detected). In addition, the relative magnitude of the difference in habitat selection caused by the mine could be estimated by the odds ratio of habitat selection at the estimated ZOI ($OR_{ZOI} = e^{(\beta_{ZOI} * ZOI)}$). The odds ratio in this case was the relative increase in habitat selection at distances further than the ZOI relative to habitat selection at mine sites.

The relative shape of the likelihood curve assessed the strength of the ZOI. For example, an irregular shaped likelihood curve, or a curve without a peak indicated that other spatial factors were influencing caribou selection relative to the mine (and which were not already accounted for in the base habitat model). We estimated the confidence intervals for the likelihood curve from the range of ZOI distances in which the log-likelihood was within 1.92 of the maximum likelihood ZOI (Hudson 1971, Hilborn & Mangel 1997).

We accounted for underestimation of standard errors of the odds ratio (OR_{ZOI}) due to repeated statistical tests (to determine the optimal cutpoint in Fig. 2) by correcting OR_{ZOI} estimates and accompanying confidence intervals using the shrinkage methods of Holländer et al. (2004). In addition, we adjusted P-values for statistical tests of β_{ZOI} using the methods of Lausen & Schumaker (1992).

We also analyzed the effect of temporal changes in mine activity by grouping years into phases of mine development. To retain sample size, we combined data for 1996-1999 (1998-1999 for the aerial survey analysis), 2000-2002 and 2003-2008 (when Ekati and Diavik were both in full operation). We accounted for the expanding footprints of the Ekati-Diavik mines by adding the Misery pit and road to the footprint in 2000 and the Fox Pit in 2003.

We did not base habitat models on pre-mine data which potentially could confound habitat selection with the effects of the mine. However, we suspected that our analysis was robust to this issue given the large area used to formulate base habitat models compared to areas affected by the mines. To check for any effects, we reevaluated the base model habitat coefficients after the ZOI term was added to assess the relative sensitivity of the base habitat model habitat coefficients to the estimated impact of mines on habitat selection.

Estimation of dustfall as a possible mechanism for the ZOI

Rescan (2006) applied a CALPUFF atmospheric transport and dispersion model for Ekati and Diavik to predict deposition of finer dust particles (total suspended particles, TSP; mean mass ~ 10 μm in size). The model generated isopleths of predicted dust deposition based upon wind strength and direction, dust types and other atmospheric factors, and we interpolated the grid values between successive contours (20-5,000 kg/ha/year). A value of 0 was assumed to occur 5 km outside of the 20 kg/ha/year contour based on the average distance between the contours 20 and 50, and adjusted for the interval increment.

We entered predicted fine dustfall (TSP) as a covariate to the base model for the Ekati-Diavik area to generate predictions of the odds ratio of habitat selection relative to TSP levels. We then contrasted these results with ZOI predictions to test whether TSP might explain the larger ZOI distances that we estimated. We used the dustfall model predictions for the period when both mines were operational (i.e. during 2003-2008).

Table 2. ZOI estimates for Ekati-Diavik mine areas as a function of time period from aerial survey data. The ZOI estimate, confidence limit (CI), relative precision (CI divided by estimated ZOI), significance of ZOI model term (β_{ZOI}), goodness-of-fit (GOF; ROC score) and the magnitude of ZOI effect as described by the odds ratio (OR_{ZOI}) are given. ZOI estimates are based upon units of 0.5 km.

	ZOI			Significance of β_{ZOI}		GOF	OR_{ZOI}	
Period	(km)	CI	CI/ZOI (%)	Z	P	ROC	Estimate	CI
1998-1999	4	3.0-7.0	100	9.12	0.002	0.786	5.8	1.6-10.0
2000-2002	-[a]							
2003-2008	14	13.0-15.0	14.3	-9.91	< 0.001	0.786	9.9	5.7-14.1
Pooled	14	12.0-15.5	25	10.94	< 0.001	0.795	4.2	1.4-8.4

[a] No peak in the likelihood curve was observed making estimation of ZOI not possible.

Results

Aerial survey analysis

For the base habitat model, significant predictors of habitat selection included relative caribou population abundance, eskers, low shrub habitat, tundra habitat, tundra*NDVI and water bodies (Appendix III). The base model fit the data with a ROC score of 0.793.

Using the base model with additional ZOI terms, the asymptote of the likelihood curve corresponded to an estimated ZOI of 14 km (CI = 12.0-15.5 km) for all years of data collection (1998-2008; Table 2 and Fig. 3). Odds ratios of the ZOI effect for the Ekati-Diavik mine sites suggested that caribou were 4.2 times (SE = 1.08, CI = 1.4-8.4) more likely to select habitat at distances > 14.0 km from the mine sites compared with the immediate mine site areas, with a gradient of increasing habitat selection between the mine site areas and the zone of influence (see Fig. 3). The ZOI model terms were significant for the pooled Ekati-Diavik complex (Z = 10.94, P < 0.001), and the overall fit of the model was adequate (ROC = 0.795). The significance of base habitat model terms did not change (at $\alpha = 0.1$) with the addition of ZOI terms, suggesting that our base model variable selection procedure was robust to the effects of the ZOI on habitat variables.

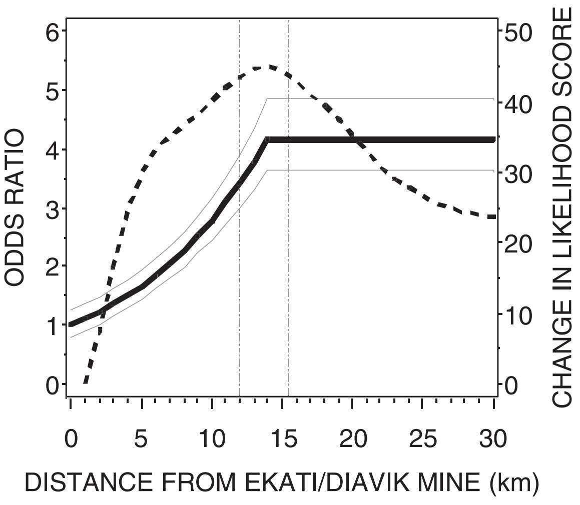


Figure 3. Predicted change in odds ratio (— with confidence limits) and likelihood curve (- - - - -) as a function of distance from the pooled Ekati-Diavik mine complex as determined from aerial survey data during 1998-2008. The confidence limit for the ZOI estimate which is based upon change in the likelihood score is delineated by vertical dashed grey lines. Estimates are modeled upon the aerial survey design that flew both Ekati and Diavik mine sites in the same survey (2004-2005).

Differences in survey design also affected ZOI estimates as suggested by a significant interaction of survey design and ZOI term ($\chi^2 = 20.3$, df = 2, P < 0.0001). We set all predictions to correspond to the aerial design in which both Ekati and Diavik were simultaneously surveyed under the assumption that this was the best data set to estimate the ZOI for the pooled mine complex.

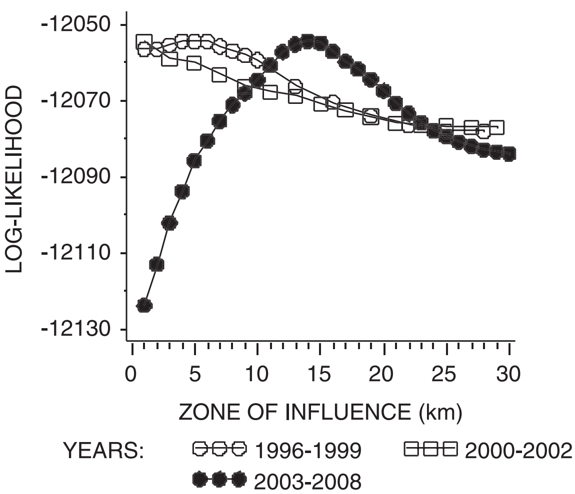


Figure 4. Likelihood curves based on aerial survey data as a function of time periods for the Ekati-Diavik pooled mine complex analysis during 1998-2008.

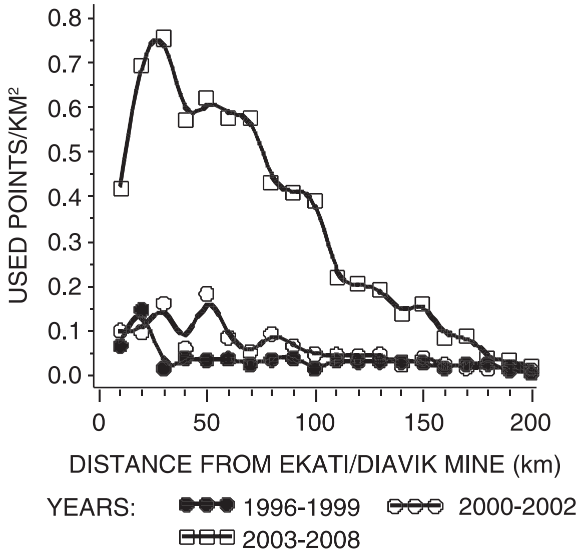


Figure 5. Satellite collar point densities used for the Ekati-Diavik mine complex during 1996-2008. The number of collared caribou was different for each time period, therefore each curve should be interpreted in terms of relative distribution rather than the actual densities of caribou near the mines.

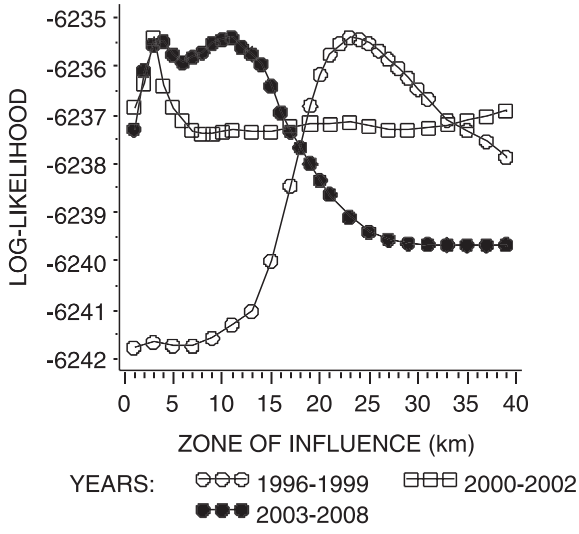


Figure 6. Likelihood curves based on satellite collar analysis for time periods of the Ekati-Diavik mine complex during 1996-2008.

When each phase of development was considered separately, the ZOI changed as mine footprint increased (see Table 2 and Fig. 4). In the initial time period (1998-1999: Ekati construction), a weak ZOI was evident at 4.0 km. In the middle period (2000-2002: Ekati operation and Diavik construction), no ZOI was evident, as indicated by a lack of peak in the likelihood curve. When both mines were in operation (2003-2008 with seven open pits in total), the ZOI was evident at 14.0 km (CI = 13.0-15.0 km) from the mine sites, which was the same as the pooled estimate but with tighter confidence limits (see Table 2 and Fig. 3).

Satellite collar analysis

For the satellite collar base habitat model, significant predictors of habitat selection included bedrock/boulder*season, forest, low shrub, tall shrub, tundra and water as predictors as well as interactions between some of the predictors with season and scale (see Appendix III). The base habitat model displayed an adequate fit to the data as determined by Pearson correlation of area-adjusted frequencies and ordinal odds ratio bins ($\rho = 0.902$, $P < 0.0001$).

The proportion of daily fixes for the satellite collar locations increased after 2001, which resulted in higher densities of used points during 2003-2008 (Fig. 5). Although the caribou satellite collar locations were fewer near the mine areas and then peaked from 25-50 km from the mines before decreasing at further distances, habitat influences such as lakes were affecting the distribution as well as the mine activities.

Analysis of the ZOI by mine development phase suggested that initially, there was no effect or attraction to mine areas, but avoidance in later years (Fig. 6 and Table 3). A ZOI of 23.0 km (CI = 19.0-35.0 km) was evident for the early period (1996-1999) of the Ekati-Diavik complex development; however, the odds ratio of the ZOI was considerably < 1,

Table 3. Summary of ZOI estimates for the Ekati-Diavik mine complex based on used/random analyses of satellite collar data. The ZOI estimate, confidence limit (CI), relative precision (CI divided by ZOI), significance of ZOI model term (χ^2), goodness-of-fit (ρ) and the magnitude of ZOI effect as described by the odds ratio are given. ZOI estimates are based upon 0.5 km units.

				Significance of β_{ZOI}		GOF		Odds ratios		
Period	ZOI (in km)	CI	CI/ZOI (in %)	χ^2	P_{cor}	ρ	P	Estimate	SE	CI
1996-1999	23	19.0-35.0	69.6	18.3	0.0119	0.93	0.0007	0.09	0.02	0.02-0.16
2000-2002	3	1.0-39.0	1266.7	0.07	0.8	0.97	< 0.0001	2.26	0.07	1.32-225.7
2003-2008	11	1.0-17.0	145.5	18.27	0.0145	0.94	0.0003	3.22	1.46	1.64-10.13
Pooled	3	1.5-12.0	350	2.48	0.1148	0.95	0.0002	14.7	3.92	8.61-20.91

indicating attraction to the mine areas rather than avoidance. Inspection of the raw data revealed large aggregations of caribou near and at mine areas in August-September 1996 and July-August 1999 that likely caused the apparent attraction. A ZOI of 3.0 km (CI = 1.0-39.0) was evident for the middle period (2000-2002) with an odds ratio of 2.26 (CI = 1.32-225.70) suggesting avoidance; however, the confidence limits on the ZOI estimate were large. A tighter ZOI of 11.0 km (CI = 1.0-17.0 km) was evident for 2003-2008 when both mines were in operation, with an odds ratio of 3.22 (CI = 1.64-10.13) also suggesting avoidance of the mine areas. The significance of base habitat model terms did not change (at $\alpha = 0.1$) with the addition of ZOI terms, again suggesting that our base model variable selection procedure was robust to the effects of the ZOI on habitat variables.

The precision of ZOI estimates and odds ratio estimates were generally lower for satellite collar data (see Table 3) than for aerial survey data (see Table 2). The years 2003-2008 had the highest sample size of collars (see Appendix I) and may be the best representation of the current ZOI of the Ekati-Diavik mine areas based on the collar data.

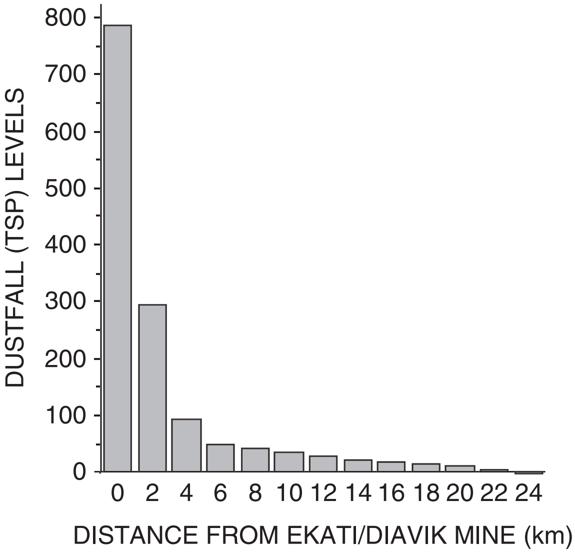


Figure 7. Mean total suspended particles (TSP) levels (kg/ha/year) as a function of distance from the Ekati-Diavik mine complex during 2003-2008. The mine complex included Misery Road and Fox Pit. Estimates are based on CALPUFF model predictions (Rescan 2006).

Predicted dustfall and the ZOI

The CALPUFF model predicted that TSP declined rapidly > 2 km from mine development (Fig. 7; Rescan 2006). Using aerial survey data, the log of TSP as a covariate for the base Ekati-Diavik habitat model was a significant predictor ($\chi^2 = 117.1$, df = 1, $P < 0.0001$); the resulting model had a ROC score of 0.795, which suggested predictive ability. Plots of predictions suggested a steep decline in the odds ratio of caribou occurrence at relatively low levels of TSP (Fig. 8). A similar analysis for the satellite collar data using only caribou locations that were within 50 km of the Ekati-Diavik mine complex indicated that the log of TSP was also a significant predictor ($\chi^2 = 13.9$, df = 1, $P = 0.0002$).

To explore dust fall as a mechanism for the estimated ZOI, we referenced the mean predicted TSP level at 14 km from the CALPUFF model (23.0 kg/ha/year, SD = 11.1; range: 0-43.0) which corresponded to the estimated ZOI from aerial survey analyses during 2003-2008 (see Table 2). For the aerial survey data, the model predicted odds ratios of 0.55 (CI = 0.49-0.62) at TSP levels of 23.0 kg/ha/year, meaning that a caribou was 0.55 times as likely to occur at areas with this TSP level compared to areas with a TSP level of 0. From the satellite collar analysis, a caribou was 0.63 (CI = 0.51-0.81) times as likely to choose areas with TSP levels of 23.0. At TSP levels of < 23.0, odds ratios quickly approached 1 suggesting

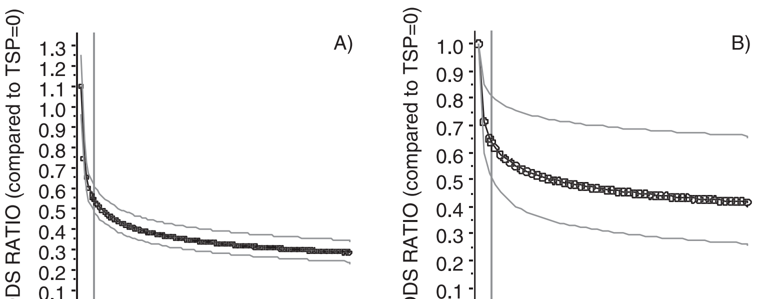


Figure 8. Predicted odds ratio of caribou occurrence as a function of predicted total suspended particles (TSP) level (kg/ha/year) for the Ekati-Diavik mine complex area from aerial survey data (A) and satellite collar data (B). The odds ratios did not change appreciably at concentrations > 500 kg/ha/year. A reference line is shown at TSP levels of 23.0 kg/ha/year, which corresponds to the estimated ZOI distance of 14 km from the mines as determined from aerial survey data.

that negative habitat selection decreased rapidly at lower TSP levels.

Discussion

Our analyses suggest that migratory tundra caribou respond to open-pit mining operations on summer range by reduced probability of occurrence in a ZOI of about 14 km (using the aerial survey data set). The reduced occurrence around the Ekati-Diavik mine complex was most evident during the operation phase of both mines and less evident during initial operation of Ekati and the construction of Diavik. Using the aerial survey data set, caribou were about four times more likely to select habitat at distances > 14 km from the mine complex, with a gradation of increasing selection between the mine site areas and the estimated ZOI (see Table 2 and Fig. 3).

The strengths of our analyses were that first we used two independent data sets (aerial surveys and satellite collars) that generated similar results. Second, our analyses accounted for patterns in habitat selection, as we tested the goodness-of-fit of the base habitat model without the ZOI variables. Third, we constrained the ZOI curve to an asymptote, such that the average distance from mine complex could be estimated along with confidence limits on the ZOI and the strength of the ZOI. Finally, our approach also allowed exploration of mechanistic factors for ZOI while controlling for other factors influencing caribou distribution.

Effect of scale on estimation of ZOI

We ran models to ensure that we had not confounded the different scales of habitat selection. For example, we ran a model using satellite collar data that extended up to 100 km from the Ekati-Diavik area and found that the log likelihoods initially peaked at the estimated mine ZOI (of ~ 11 km), but then peaked again at larger distance from mine values (of ~ 70 km) with odds ratios of < 1. For the larger distances, we estimated that the ZOI models the core of summer range, as also indicated by the highest used point densities (see Fig. 5), rather than the ZOI of the mine area.

We suspect that it is the scale of our analyses that allowed us to detect a larger ZOI than previously published response distances. Most regional studies reveal that *Rangifer* spp. reduce their use of areas within 1-10 km of development (Murphy & Curatolo 1987, Wolfe et al. 2000, Nellemann et al. 2001, Mahoney & Schaeffer 2002, Cameron et al. 2005, Joly et al. 2006, Weir et al. 2007, Vistnes & Nellemann 2008, Polfus et al. 2011; but see also Nellemann et al. 2010). However, our study addressed the effects of large open pit mines (of ~ 40 km^2 cumulative footprint), which is a different configuration of stimuli to caribou than, for example, a road, transmission line or a tourist lodge. The scale at which caribou are selecting habitat relative to the imposed scale of measurement is also likely a mechanistic factor in determining the extent of influence of mines (Vistnes & Nellemann 2008). The open tundra habitat likely allows caribou to respond at greater distances, however, other studies such as at the Prudhoe Bay oilfield were also on tundra post-calving ranges (Wolfe et al. 2000, Vistnes & Nellemann 2008).

Effect of statistical methods on estimation of ZOI

We assumed that the base habitat model accounted for spatial variation in habitat selection, and that the primary factor influencing habitat selection relative to mine sites was the effects of mines. Inspection of the likelihood plots and the associated odds ratios of β_{ZOI} assesses the overall adequacy of the ZOI model and the presence of other gradients or factors that confound ZOI estimates. Also, comparison of base model habitat selection coefficients with and without ZOI terms allows a test of the effect of the ZOI on base habitat selection coefficients.

Earlier analyses of the Bathurst herd using polynomial methods suggested larger ZOI around diamond mines (of $\sim$ 17-30 km, out to 130 km; Boulanger et al. 2004, Johnson et al. 2005, Golder Associates Ltd. 2008a,b). With the polynomial approach, however, other habitat selection gradients, which occur beyond the ZOI, can influence the overall shape of the curve. For example, satellite collar data indicate a steep gradient of habitat use evident at distances > 50 km from mines as indicated by declining point densities (see Fig. 5). A quadratic curve fit to these data would be influenced by both the gradient from mine ZOI but also the other gradients, which would cause the peak of the curve to be shifted to the middle of the gradient. A ZOI based on the peak of the quadratic curve would therefore be overestimated due to the influence of the other gradient. The main issue with polynomial regression is that it can only approximate a ZOI since the asymptote is not clearly defined, as demonstrated in a recent simulation comparison of the estimation of thresholds by polynomial and piecewise regression, which concluded that piecewise regression provided the most robust threshold estimate (Ficetola & Denoel 2009).

Effect of data type on estimation of ZOI

The aerial survey data provided the strongest analysis of ZOI. However, although less influenced by larger summer range selection gradients, these surveys were constrained by the extent of survey area. Our modelling assumed that the areas surveyed encompassed both the zone influenced by the mine and areas beyond the influence of the mine to allow an estimate of the asymptote of the ZOI curve. Even in the early years of the Ekati-Diavik monitoring, there was reasonable coverage out from development (of ~ 22 km for Ekati-Diavik).

The aerial survey data were not corrected for sightability bias (Buckland et al. 2004), but we assumed this had little impact on the analyses, as we considered the relative change (OR) in habitat selection to estimate ZOI rather than estimating the probability of presence/occupancy within habitat classes near mines. We assumed that sightability was constant across all habitat classes; a reasonable assumption given that all surveys were conducted in open tundra habitat.

The satellite collars provided less precise estimates of ZOI, largely due to limited sample sizes (resulting in fewer data available for areas near the mines) and less frequent duty cycles for the early years of study. Although Vistnes & Nellemann (2008) recommended the use of satellite collars, we suggest that particular attention has to be paid to sample size. In contrast, stringently designed aerial surveys sample areas adjacent to mine sites are a more consistent indication of presence and absence of caribou relative to mine areas.

Mechanisms for ZOI

Responses of wildlife to human activities can be considered as analogous to responses to predation with associated trade-offs in energetic costs (Frid & Dill 2002). Predation risk is often structured in space and time, and prey will shift their distribution at different scales to accommodate predation risk (Tolon et al. 2009). However, the spatial and temporal scales of predation risk for caribou in the vicinity of open-pit mines are unknown as a contributing mechanism to the ZOI.

One factor that correlates to the scale of the response is dustfall. Although dustfall has been described for its effects on vegetation (Myers-Smith et al. 2006), little is known about the response of herbivores to dust on forage. The mines used an atmospheric transport model (CALPUFF; Rescan 2006) to predict TSP deposition rates in excess of 5,000 kg/ha/year (1,360 mg/m^2/day) close to mine activity in summer. Deposition rates decreased rapidly with increasing distance from mine activities, and the dust constituents were identified in lichens; however, our analyses suggest that caribou avoid habitats with even low levels of predicted TSP. While caribou distribution around the immediate mine area may also be affected by non-dustfall sensory disturbance, we show that the larger 14-km ZOI for caribou did coincide with the predicted geographic scale of dustfall (see Figs. 7 and 8), suggesting that TSP may be a mechanism for reduced use by caribou of areas within the estimated ZOI.

Implications of our analysis

Our results demonstrate a quantifiable ZOI from open-pit diamond mines on caribou distribution. Our results suggest that researchers studying impacts of industrial development on caribou and other wildlife species should consider a larger range of scales than those caused by immediate behavioural responses to noise or other smaller-scale disturbances. Alternative larger-scale spatial impacts, such as dust deposition on forage, should be considered in addition to behavioural responses that have been the main focus of past ungulate studies (Stankowich 2008). We also suggest that interaction between spatial thresholds of responses to human activities have to be considered in relation to the spatial and temporal scales of predation risk (*cf.* Tolon et al. 2009).

The area of reduced caribou occurrence from the Ekati-Diavik mine complex is ~ 6.7% of the core and ~ 4.2% of the high use area of summer range of the Bathurst herd. Cumulative impacts from other sources of disturbance on the landscape (Johnson et al. 2005) could have wider implications for the herd, but our study was not designed to measure any effects from the reduced use of the summer range (*cf.* Nellemann et al. 2000, Cameron et al. 2005, Vistnes & Nellemann 2008, Polfus et al. 2011).

Our methods can be further applied to explore the effects of industrial disturbance on other wildlife species by allowing a robust estimate of displacement while accounting for variation in habitat selection and scale effects. We suggest that this standardized robust approach will allow improvement in monitoring and mitigation measures to manage the impact of mines and other developments on wildlife species.

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Appendices

Appendix I: Yearly sample sizes of aerial surveys and collared caribou

Appendix I. Table 1. Number of aerial surveys where caribou were observed in > 1 cell, and the number of collared caribou used for analysis. Satellite collar data include only caribou which had a mine area within their availability radius at least once in a given year.

	Aerial surveys[a]		
Year	Ekati	Diavik	Number of collared caribou[b]; all mines
1996			9
1997			7
1998	17		-[c]
1999	18		14
2000	12		13
2001	11		9
2002	8	8	11
2003	9	9	10
2004	9 combined		4
2005	10 combined		18
2006	10	8	14
2007	9	10	19
2008	10	10	10

[a] BHP Billiton 2009, Diavik Diamond Mines Inc. 2009.
[b] Gunn et al. 2001; Environment and Natural Resources, Government of Northwest Territories, unpublished data.
[c] Satellite collars in 1998 provided sporadic and unreliable data and were therefore removed from analysis.

Appendix II: Habitat classification and NDVI indices used in the analysis of ZOI

We condensed habitat categories by blending two sources to provide complete coverage of the study areas, based on similarities in descriptions, low frequency of some types and logical assumptions about caribou biology (Appendix II, Table 1). We pooled habitat classes using the Land Cover Map of Northern Canada (NLC; Olthof et al. 2009) and Earth Observation for Sustainable Development of Forests (EOSD; available at: http://cfs.nrcan.gc.ca/subsite/eosd/mapping) land cover classification. The NLC classification coverage was generally north of the treeline and was given precedence where coverage from both products overlapped. Esker coverage was obtained from 1: 250,000 scale National Topographic Data Base maps (Natural Resources Canada; available at: http://geogratis.cgdi.gc.ca/geogratis/en/product/search.do?id=8147). We converted linear eskers into polygons with a standardized width of 100 m.

Appendix II, Table 1. Habitat associations used in base habitat models.

Pooled habitat associations	Acronym	Description
Bedrock-boulder	Bedbould	Exposed bedrock or boulders, barren or sparsely vegetated
Moss-lichen	Mosslichen	Bryophytes or lichen
Tundra	Tundra	Non-tussock graminoids, prostrate dwarf shrubs
Tussock	Tussock	Tussock graminoid tundra
Sedge wetland	Sedgewet	Wet sedge and wetlands
Low shrub	Lowshrub	Low shrub (< 40cm and > 25% cover)
Tall shrub	Tallshrub	Tall shrub (> 40cm and > 25% cover)
Treeline herb	Treeherb	Wetland herb near forests
Forest	Forest	Conifer, broadleaf and mixed forests of all crown closures
Esker	Esker	Esker features from NTDB
Water	Water	Lakes, rivers, streams
Other	Other	

NDVI is related to the proportion of photosynthetically absorbed radiation and is calculated from atmospherically corrected reflectance from the visible and near infrared channels from Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA-series satellites (James & Kalluri 1994). We used 1-km resolution NDVI amalgamated by 10-day composite periods for 1996-2006 (Latifovic et al. 2005) and calculated the mean values for each 1×1 km cell within the study area.

Appendix III: Results of base habitat models using aerial survey and satellite collar

Aerial surveys

For Ekati and Diavik, the univariate tests revealed linear relationships between caribou distribution and

Appendix III, Table 1. Base habitat model for aerial survey analysis for the Ekati and Diavik mine area aerial surveys. Standardized slope estimates are given for habitat variables (see Appendix I).

Parameter	Estimate	SE	CI	χ^2	P
Intercept	-3.33	0.04	-3.40 - -3.26	8737.26	< 0.0001
Esker	0.04	0.02	0.01-0.07	5.52	0.0188
Reloccupancy	0.58	0.01	0.56-0.61	2656.08	< 0.0001
Lowshrub^2	-0.06	0.03	-0.11 - -0.01	6.28	0.0122
Sedgewet	0.15	0.04	0.08-0.23	15.71	< 0.0001
Tundra^2	-0.10	0.02	-0.14 - -0.06	28.18	< 0.0001
Tundra*NDVI	0.49	0.25	0.00-0.97	3.87	0.0492
Water	-0.14	0.08	-0.29-0.02	2.97	0.0848
Water^2	-0.23	0.05	-0.32 - -0.14	25.7	< 0.0001

relative occupancy, esker, sedge wetland and the water predictor variables (Appendix III, Table 1). Quadratic relationships were suggested between low shrub, tundra and water predictor variables. In addition, an interaction between tundra and NDVI suggested a positive seasonal influence of the use of tundra.

Satellite collars

The base habitat model displayed adequate fit to the data as determined by Pearson correlation of area-adjusted frequencies and ordinal odds ratio bins ($\rho = 0.902$, $P < 0.0001$). The base habitat model analysis revealed linear or quadratic selection of forest, tall shrub, tundra and the water habitat variables (Appendix III, Table 2). Seasonal selection was evident for bedrock-boulder, low shrub, treeline herb, tundra and forest (interaction with NDVI) habitat categories. The selection of forest treeline herb and low shrub was also dependent on scale as determined by the availability buffer width and corresponding fix interval.

Appendix III, Table 2. Base conditional logistic regression habitat model used to estimate ZOI from satellite collar data for the Snap Lake and combined Ekati-Diavik mine sites.

Parameter	Group	Estimate	SE	χ^2	P
bedbould*season	Fall migration	-0.222	0.05	19.836	< 0.0001
	Rut/late fall	-0.137	0.072	3.549	0.0596
	Early summer	-0.489	0.301	2.641	0.1041
Forest		0.948	0.132	51.665	< 0.0001
Forest^2		-0.146	0.022	44.379	< 0.0001
Forest*scale	1	0.044	0.094	0.217	0.6413
	5	-0.203	0.08	6.474	0.0109
Forest*NDVI		-1.032	0.178	33.476	< 0.0001
Forest*movement rate		-0.016	0.004	13.657	0.0002
Lowshrub*scale		-0.039	0.011	11.723	0.0006
Lowshrub*season	Fall migration	0.075	0.07	1.147	0.2842
	Rut/late fall	0.158	0.091	2.988	0.0839
	Early summer	0.148	0.096	2.382	0.1227
Tallshrub		-0.061	0.024	6.241	0.0125
Treeherb*scale	1	0.021	0.033	0.41	0.5222
	5	-0.141	0.055	6.627	0.01
Treeherb*Summer/fall	Fall	0.137	0.051	7.213	0.0072
Tundra		-0.043	0.054	0.641	0.4233
Tundra*rate		-0.011	0.004	9.811	0.0017
Tundra*season	Fall migration	-0.102	0.068	2.281	0.1309
	Rut/late fall	-0.139	0.144	0.926	0.336
	Early summer	-0.38	0.131	8.447	0.0037
Water		-0.649	0.034	365.589	< 0.0001