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GRADE / DEGREE

Department of Biology
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Detecting Human-induced Changes in Canadian Ecosystem Productivity Using Protected Areas as an Ecological Baseline

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Detecting Human-induced Changes in Canadian Ecosystem Productivity Using Protected Areas as an Ecological Baseline

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Thesis submitted to the Faculty of Graduate and Postdoctoral Studies, University of Ottawa, in partial fulfillment of the requirements for the M.Sc. Degree in the Ottawa-Carleton Institute of Biology.

Thèse soumise à la Faculté des études supérieures et postdoctorales, Université d'Ottawa en vue de l'obtention de la maîtrise en sciences de l'Institut de biologie Ottawa-Carleton

Your file Votre référence
ISBN: 978-0-494-69037-6
Our file Notre référence
ISBN: 978-0-494-69037-6

Dedication

To all who have ever been inspired to safeguard a special place for their children's children's children.

Prefatory Prose

"**A**ll ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in the community, but his ethics prompt him also to cooperate (perhaps in order that there may be a place to compete for).

The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, collectively: the land.

This sounds simple: do we not already sing our love for and obligation to the land of the free and the home of the brave? Yes, but just what and whom do we love? Certainly not the soil, which we are sending helter-skelter downriver. Certainly not the waters, which we assume have no function except to turn turbines, float barges, and carry off sewage. Certainly not the plants, of which we exterminate whole communities without batting an eye. Certainly not the animals, of which we have already extirpated many of the largest and most beautiful species. A land ethic of course cannot prevent the alteration, management, and use of these 'resources', but it does affirm their right to continued existence, and, at least in spots, their continued existence in a natural state." ...

- Aldo Leopold, from "The Community Concept" in A Sand County Almanac, pg.239-40

"**L**and, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals. Food chains are the living channels which conduct energy upward; death and decay return it to the soil. The circuit is not closed; some energy is dissipated in decay, some is added by absorption from the air, some is stored in soils, peats, and long-lived forests; but it is a sustained circuit, like a slowly augmented revolving fund of life. There is always a net loss by downhill wash, but this is normally small and offset by the decay of rocks. It is deposited in the ocean and, in the course of geological time, raised to form new lands and new pyramids. [...]

"The process of altering the pyramid for human occupation releases stored energy, and this often gives rise, during the pioneering period, to a deceptive exuberance of plant and animal life, both wild and tame. These releases of biotic capital tend to becloud or postpone the penalties of violence."

- Aldo Leopold, from "The Land Pyramid" in A Sand County Almanac, pg.253, 255

"**W**ilderness is a resource which can shrink but not grow. Invasions can be arrested or modified in a manner to keep an area usable either for recreation, or for science, or for wildlife, but the creation of new wilderness in the full sense of the word is impossible."

- Aldo Leopold, from "Defenders of Wilderness" in A Sand County Almanac, pg.278

Abstract

Human impacts on ecosystem productivity are seldom measured relative to productivity expectations for pristine areas. I used observations of growing season net ecosystem productivity (gNEP) from strictly protected areas to predict gNEP expected in the absence of human activities across a Canadian study area, controlling for spatial autocorrelation. Contrasting expected gNEP against actual gNEP (satellite-based NDVI) from 1998 to 2005, I measured biologically relevant human-induced positive and negative gNEP deviations from expected levels over 4% and 7.5% of Canada, respectively. Long-term human land-use changes generally related to negative deviations, e.g., urbanization, while positive deviations related to shorter-term changes, e.g., forest removal. gNEP deviations changed at a rate of $\pm 1.6\% \cdot yr^{-1}$ with minor differences between land-use types. Positive deviations expanded in area almost three times faster than negative deviations. Unexpected gNEP deviations strongly related to short-term weather anomalies, suggesting impacts of accelerated climate change.

Résumé

Les répercussions de l'activité humaine sur la productivité des écosystèmes sont rarement mesurées en relation à la productivité attendue des aires intactes. J'ai utilisé des observations de productivité nette de l'écosystème durant la saison de croissance (gNEP) pour les aires strictement protégées afin de prédire la gNEP attendue dans l'absence d'activité humaine à travers d'un aire d'étude Canadienne, sans influence de l'autocorrélation spatiale. Comparant la gNEP prédite avec la gNEP actuelle entre 1998 et 2005, j'ai mesuré les déviations pertinents au point de vue biologique positifs et négatifs causés par l'activité humaine, sur 4% et 7.5% du territoire canadien, respectivement. Les activités humaines à long terme étaient liés typiquement aux déviations négatifs, e.g., urbanisation, tandis que les déviations positifs avaient trait à l'altération temporaire du territoire, e.g., déforestation. Les déviations de gNEP changent à un taux de $\pm 1.6\% \cdot \text{année}^{-1}$ avec quelques différences entres utilisations du terrain. Les déviations positifs croissaient en aire presque trois fois plus rapidement que les déviations negatifs. Les déviations inattendues de gNEP refletaient fortement les anomalies à court terme de la météo, ce qui suggère des impacts des changements climatiques accélérés.

Acknowledgements

I am very grateful to the Natural Sciences and Engineering Research Council of Canada and the University of Ottawa's Faculty of Graduate & Post-doctoral Studies for two years of scholarship support that was essential to my research.

I would like to sincerely thank my thesis supervisor, Dr. Jeremy T. Kerr for all his support, expertise, guidance and mentorship, in addition to thanking my committee members Drs. Antoine Morin and Lenore Fahrig for their feedback and insight during my studies. I also thank Dr. Michael Sawada for his helpful suggestions regarding the final version of the thesis.

For providing the remotely sensed satellite data crucial to my research, I am sincerely grateful to Drs. Rasim Latifovic, Darren Pouliot, Rob Fraser and Josef Cihlar (Canada Centre for Remote Sensing, NRCan). I am also indebted to Dr. Dan McKenney and Pia Papadopol (Great Lakes Forestry Centre, NRCan) for providing geospatial climate data that helped relate my work to anthropogenic climate change. I am also grateful to all contributors to the R Project for Statistical Computing and members of the Comprehensive R Archive Network.

I am sincerely grateful to my colleagues in the Kerr and Currie labs for their tremendous support, patience, good humour, knowledge and advice. They are: Adam Algar, Ryan Burke, Laura Coristine, Prof. David Currie, Rachelle Desrochers (best stats guru of all time!), Jay Fitzsimmons, Zuzu Gadallah, Katie Gibbs, Katie Hierlihy, Heather Kharouba, Manisha Kulkarni, Max Larrivée, Julie Nadeau, Nora Szabo, Hector Vasquez, Kevin Walker and Eric Young (GIS wizard!). I am honoured to have known and worked with all of you. I must also thank Adam Algar individually for providing the R scripts for my CAR analysis and for defining the analytical basis (with M. Ostrovosky) from which my work developed.

I extend a heartfelt thanks to all of my former co-workers, co-volunteers and colleagues in the NGO sector in Nova Scotia and across Canada. In particular I thank the folks at CPAWS Nova Scotia. You kept me inspired to work for better conservation policies and outcomes and helped me pave a tree-lined path toward this exciting phase in my life. Thanks also to Drs. Martin Willison and Chris Miller who taught me the valuable role of 'academic insight' in grassroots conservation initiatives. I also thank Mr. Jim McMullin (Aldershot Elementary School, Kentville, NS) and Dr. Jim Fyles (McGill University) for inspiring me to always enjoy science and think about the natural world around me.

I am grateful to all the 'sonic muses' I had throughout this journey, and particularly CBC Radio 3. I was often re-energized by the beautiful melodies and harmonies of musicians such as *Hey Rosetta!*, *Two Hours Traffic*, *Joel Plaskett*, *Moneen*, *Feist* and *Sigur Ros*.

This work would not have been possible without the indelible patience and support of my family – both MacDonald and Morse – throughout this process and all of the important changes in life happening alongside it: thank you, Mom & Dad, and David & Susan. I also thank my wonderful friends (you know who you are) who kept a smile on my face and made sure I didn't forget who I was throughout this process. Foremost among those friends, I thank my brother, Graham, for always being there to help and for being incessantly selfless, supportive and encouraging at every turn. I must also thank my unofficial 'co-author', Sam the cat, who faithfully sat by my keyboard many a long night to 'help' me see this through.

And from the bottom of my heart I thank my beautiful, loving and gifted wife, Jennifer, for her incredible encouragement, superlative patience, support and advice, and especially for all the sacrifices she made to make this dream a reality. This process has in no way been a solitary journey and both of our lives have changed greatly – and merged into one – during the course of it. She is my guiding light always and I owe her all of my success.

Table of Contents

Table of Figures

List of Tables

Introduction

The current pace and scale of global environmental change demands extensive, systematic monitoring of ecosystems to understand their ongoing condition and capacities to adapt to disturbance (Foley et al. 2005; MA 2005; Parr et al. 2003). As the human population continues to grow (Cincotta et al. 2000; Harte 2007; McKee et al. 2004) and the influences of human activities persist, intensify and expand into new areas (MA 2005; McKee 2003; Sanderson et al. 2002; Srinivasan et al. 2008), ecologists and conservation biologists are faced with the task of tracking many environmental changes and monitoring their effects simultaneously. Further complicating this task are synergies between multiple aspects of environmental change (Brook et al. 2008), such as feedbacks between changes in land-use and climate (Chapin et al. 2008; Pitman et al. 2009; Ramankutty et al. 2006), that may require monitoring over broader spatial and temporal scales to be fully understood (Parr et al. 2003). Remotely sensed earth observation (EO) data provide efficient solutions to these and other monitoring challenges, with the advantage of almost three decades of near-continuous historic data available for use in change detection studies (Kerr & Ostrovsky 2003; Muchoney 2008; Pettorelli et al. 2005).

Earth observation data are invaluable in the monitoring and analysis of broad-scale environmental changes. Examples of their use include estimating ecosystem productivity and function (Garbulsky & Paruelo 2004; Stoms & Hargrove 2000; Wylie et al. 2008), identifying habitat dynamics or habitat quality (Coops et al. 2009a, b; Wiegand et al. 2008), assessing land-use/land cover change and land degradation (Bai et al. 2008; Latifovic &

Pouliot 2005; Mildrexler et al. 2007; Potapov et al. 2008; Potter et al. 2005; Pouliot et al. 2009), linking socio-economic factors to land-use change (Boone et al. 2007; Wu et al. 2008), measuring proxies for species richness (Bailey et al. 2004; Hurlbert & Haskell 2003) and exploring species-productivity relationships (Herfindal et al. 2005; Nilsen et al. 2005), in addition to others. EO data can also be used to monitor progress on international environmental agreements (de Sherbinin et al. 2002; Mellack & Hess 2004; Muchoney 2008; Scholes et al. 2008), such as the Convention on Biological Diversity (Balmford et al. 2005), the Kyoto Protocol (Rosenqvist et al. 2003) and the RAMSAR Convention on Wetlands (Seto & Fragkias 2007).

Remotely sensed baselines of landscape condition are important for change detection in studies of human impacts and other drivers on ecosystem processes and land cover patterns over time (Wallace et al. 2004). Practical examples of EO-based change detection include i) contrasting snapshots of landscape condition against baseline or reference conditions (e.g., historic) for a given area (Fraser et al. 2009; Latifovic et al. 2005a; Olthof et al. 2008); ii) measuring progressive changes in landscape condition for a particular region over time (Gillanders et al. 2008; Griffith et al. 2003; Neigh et al. 2007, 2008); and, iii) measuring changes in variables that relate to ecosystem processes between two or more time periods (Coops et al. 2009b; Del Grosso et al. 2008; Xiao & Moody 2004). Baselines derived from remotely-sensed vegetation indices such as the normalized difference vegetation index (NDVI) help to determine the magnitude and direction of human-induced and natural changes in vegetation conditions over time (Goetz et al. 2006; Pouliot et al. 2009).

To reflect the scope and magnitude of human-induced environmental changes, indices of baseline or reference ecosystem conditions that are independent of human disturbance are helpful (Bennett & Adams 2004; Fernandez et al. 2010; Liu et al. 2009). However, many studies rely on baselines from systems that are influenced by multiple disturbances and not reliably independent of natural and human disturbances (Alcaraz-Segura et al. 2009; Baldi et al. 2008; Goetz et al. 2006; Paruelo & Lauenroth 1998; Potter et al. 2005; Wylie et al. 2008). To truly measure human-induced environmental change, we require reliable baselines of environmental conditions expected in the absence of human activities and their environmental effects, so-called "potential natural vegetation" conditions (Hardtle 1995; Liu et al. 2009). Without these reliable baselines, it is not possible to properly control for the effects of human activities on baseline measures of landscape condition or ecosystem processes, which are therefore not representative of the 'pristine' environmental conditions that provide an optimal scale for change detection.

In this research I demonstrate a method to detect human-induced environmental changes using baseline net ecosystem productivity (NEP) models based on EO data from World Conservation Union (IUCN) category I-III protected areas across Canada. Protected natural areas can provide defensible estimates of ecological reference conditions that reflect only minimal human influences (Alcaraz-Segura et al. 2009; Arcese & Sinclair 1997; Garbulsky & Paruelo 2004; Sinclair et al. 2002). IUCN category I-III protected areas include four distinct levels of protection: Ia) "Strict Nature Reserve"; Ib) "Wilderness Area"; II) "National Park"; III) "Natural Monument" (IUCN 1994). Protected areas designated under these categories are all generally managed for science and the protection of ecosystems and/or natural features (Boitani et al. 2008; Locke & Dearden 2005). Category I-III protected areas ensure the highest and most reliable legislative controls to ensure that human activities have minimal influence on ecological integrity (IUCN 1994). In other research, protected areas within these categories have been found to contain examples of rare or historically more common ecosystem functional types (Fernandez et al. 2010) or provide reference conditions over time to detect the effect of species extirpations of ecosystem function (Berger 2008), among other findings. These 'higher' categories of protection best encompass the biodiversity protection goals underlying many protected areas (Locke & Dearden 2005).

Weather and climatic patterns strongly drive spatio-temporal patterns in NDVI (Cihlar et al. 1991; Xiao & Moody 2004), with temperature variables often most highly correlated to NDVI at mid to high latitudes (Ichii et al. 2002; Pouliot et al. 2009; Schultz & Halpert 1993). Indeed, changes in temperature and precipitation can be reflected in spatial and temporal patterns in NDVI over time. Over the long-term, these relationships may signal the effects of longer-term climate change on the productivity of entire ecosystems. For example, Olthof and Latifovic (2007) found significant correlations between short-term departures from longer term NDVI trends and so-called "temperature anomalies" across northern Canada, suggestive of a "temperature fertilization effect" on NDVI. Neigh et al. (2007) showed similar phenomena across Canada's boreal forest, in addition to pointing out examples in which temperature fertilization can lead to forest desiccation and eventually increased forest fire potential (Gillett et al. 2004). Considering these and other findings, my attempts to detect human impacts on ecosystem productivity should also consider the potential for short-term weather variation (and perhaps longer-term climate change) to influence changes in ecosystem productivity.

Previous studies have successfully used climate-NDVI relationships from protected areas to define and contrast baseline ecosystem productivity measures against actual EO data to detect environmental change (Alcaraz-Segura et al. 2008; Garbulsky & Paruelo 2004; Stoms & Hargrove 2000). Other authors have instead regressed NDVI against weather or climate variables in 'natural' or 'undisturbed' areas to derive baseline conditions and calculate deviations from the baseline over larger areas (Guerschman et al. 2003; Ji & Peters 2004; Wylie et al. 2008; Zhou et al. 2003). However, these studies and others failed to develop a theoretical baseline for NEP that reliably controls for the influence of human activities. Nor did these or other studies apply such a baseline of expected NEP to an area as large as Canada while controlling for the influence of spatial autocorrelation on NEP predictions. My objective in this study is three-fold: i) to measure the difference between actual NEP and expected NEP across a Canadian study area to assess the extent and magnitude of human influences on this aspect of ecosystem function; ii) to determine how well NEP deviations and rates of change in deviations correspond to anthropogenic and non-anthropogenic land cover types; and, iii) to assess the relationship between gNEP deviations and short-term departures of weather patterns from long-term climate trends in remote areas where human activities are negligible. My approach builds on existing environmental change detection methods by demonstrating a baseline for NEP that enhances the ability to detect human disturbances to ecosystems while controlling for the influence of spatial autocorrelation. My approach is a useful contribution given the current pace and scale and global environmental change and the difficulty in finding reliable, reproducible baselines of environmental conditions against which we can measure change.

Methods

Relating remotely sensed vegetation indices to NEP

NDVI is commonly used to estimate vegetation "greenness" based on its relationship to light absorption in plant tissues that ultimately drives CO_2-fixation via photosynthesis. NDVI is directly proportional to the fraction of absorbed photosynthetically active radiation (fPAR) in leaves (Tucker & Sellers 1986), and it relates strongly to aboveground net primary productivity across ecosystems (Monteith 1972; Prince 1991). NDVI combines reflectances in the red (RED; 0.61-0.68 μm) and near infrared (NIR; 0.78-0.89 μm) spectra into a single index (Tucker 1979):

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

NDVI values range from -1.0 to 1.0, where 0 represents a balance in NIR and RED reflectances[1] , and values vary between land cover types and typically range from 0.1 to 0.75 as green vegetation cover increases throughout the growing season (Hicke et al. 2002; Zhou et al. 2001). Green vegetation typically reflects more NIR radiation and will thus have

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[1] This could occur when sparse foliage coincides with exposed substrate and little or no undergrowth.

higher NDVI values than brown or unhealthy vegetation, which reflects more RED radiation, or bare substrate that only reflects RED radiation (Weier & Herring 2000).

Given the relationship of NDVI to aboveground net primary production and its use to estimate ecosystem-level carbon exchange (Turner et al. 2004; Vourlitis et al. 2003), NDVI can be used as a proxy measure of NEP. NEP, sometimes called the net carbon flux for the entire ecosystem, is the difference between gross primary productivity and respiration by autotrophs, heterotrophs and decomposers within the ecosystem; this equates to the remaining photosynthetic biomass in the ecosystem after all respiratory needs have been met. NDVI can also be used to estimate "potential photosynthetic capacity" of this biomass as an indicator of total canopy chlorophyll content (Boehlman et al. 2003; Gitelson & Merzlyak 1996). For the purposes of this study I therefore choose to treat Canada-wide seasonally integrated NDVI as an index of growing season NEP.

Calculating Average Growing Season NEP (gNEP)

NDVI composites were integrated across the peak of the growing season over an 8-year period (1998 to 2005) to determine mean actual NEP at 1 km^2 resolution across Canada (Lambert Conformal Conic projection). I calculated mean annual growing season NDVI by averaging nine 10-day SPOT VGT NDVI composites (S10) from 1 June to 31 August each year, providing an estimate of mean annual growing season NEP, hereafter gNEP. Using peak of growing season NDVI composites reduces productivity underestimates related to variability in growing season length (Latifovic & Pouliot 2005). The mean of the eight resulting annual averages was then used as the mean 8-year gNEP for Canada, excluding the far north (beyond ~75°N) where the SPOT VGT sensor provides no observations (see Appendix A for a description of the remotely sensed data).

Prior to the above steps, all 10-day NDVI composites were processed at the Canadian Centre for Remote Sensing using the ABC3V2 processing algorithm. The ABC3V2[2] algorithm corrects each NDVI composite image, one grid cell at a time, to reduce signal distortions caused by atmospheric haze, atmospheric aerosol contamination, cloud cover, and variations due to shadows within the constituent composites (Cihlar et al. 2004). Grid cells that were not continuously present between 10-day NDVI composites within a growing season or between annual composites were removed to avoid spurious gNEP estimates. NDVI values between -1.0 and 0.0 were also removed to restrict further analyses to vegetated areas.

Sampling design for climate variables and gNEP in strictly protected areas

I used a strict GIS-based sampling design to statistically control for any influence of human activities on baseline gNEP. First, I sampled observed values of the dependent and independent variables only from within the boundaries of IUCN category I-III protected areas (WDPA 2007) across Canada at 1 km^2 resolution. Second, all grid cells classified as

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[2] The acronym is derived from the terms "Atmospheric, Bidirectional, and Contamination Corrections of CCRS"

anthropogenic land-use/cover types (Cihlar et al. 2001; Kerr & Cihlar 2003) were eliminated from training data for expected gNEP. gNEP measurements in the Prairie ecozone are affected by bare soil and seasonal desiccation of vegetation (Paruelo & Lauenroth 1998; Rasmussen 1998) and were also omitted. Third, the final sampling area was restricted to naturally vegetated land covers excluding treeless barrens and other land covers with extremely low vegetation densities defined by Cihlar et al. (2001).

Variable selection for baseline gNEP model

I used ordinary least squares (OLS) regression to initially relate long-term climate variables to mean 8-year gNEP in strictly protected areas. The resulting regression model was meant to predict expected gNEP in the absence of human activity (baseline gNEP) across the Canadian study area. Expected gNEP will hereinafter be used interchangeably with baseline gNEP. I selected the predictors from among an initial group of 19 bioclimatic variables (and elevation), representing annual averages based on 50-year climatic norms interpolated at 1 km^2 resolution from the WorldClim dataset (Hijmans et al. 2005). Four of the 19 bioclimatic variables were excluded because they corresponded to monthly averages only, instead of entire seasons as reflected by my growing season gNEP data, and therefore would not have been as representative of a full season. Because of the number of variables available, not all possible regression models could be examined. As a result, temperature and precipitation variables showing the strongest correlation to gNEP independent of all other predictors were initially selected for inclusion in the model, with an effort to select variables representing seasonal instead of annual means for different parameters again given the use of growing season gNEP as the response. Variables measuring some aspect of the same parameter (e.g., seasonal temperature) that showed high collinearity to one another (i.e., $r \geq 0.50$) were not permitted in the same model. Table 1 lists each of the 15 variables, their means and ranges, and their correlation to gNEP within strictly protected areas.

Derivation of baseline gNEP models

Of all baseline gNEP models examined, the single best model reflecting biologically important determinants of gNEP was selected based on the coefficient of determination, the contribution of each variable to explained variance in gNEP, model parsimony and the homoscedasticity of model residuals (equation 3). All variables in the single best baseline gNEP model were generally Gaussian distributed. The baseline gNEP model was then checked iteratively using manual forward and backward stepwise regressions in *S-Plus* statistical software (Insightful 2007). The baseline gNEP model had the lowest Akaike's information criterion value (AIC) among the parsimonious models I fitted (Burnham & Anderson 2004). However, as discussed by Diniz-Filho et al. (2008) and Hoeting et al. (2006), AIC favours over-fitted, non-parsimonious models when used in the presence of spatial autocorrelation and, for macroecological studies in particular, can make the selection of a "minimum adequate model" difficult. Though the residuals of the expected gNEP model were generally homoscedastic, they were not independent due to spatial autocorrelation.

Because stepwise regression leads to dependence on a single model that may not be the only one with a good fit to the data, a "global" model including all predictors should be used instead (Whittingham et al. 2006). For comparison I fit a second "global" baseline gNEP model using additional terms related to gNEP (equation 4). As indicated by Diniz-Filho et al. (2008), this over-fitted model in fact had a much lower AIC value than the initial model (equation 3). Parameter summaries for the global baseline gNEP model are shown in Table 4. Predictions of and deviations from expected gNEP derived from equation 3 were compared to those from equation 2 based upon Spearman's rank correlation coefficient calculated for 2500 randomly sampled points generated using Hawth's Tools for GIS v3.27 (Beyer 2004).

Controlling expected gNEP predictions for spatial autocorrelation

Spatial autocorrelation is the degree to which observations relate to geographical position. Spatial autocorrelation can bias parameter and probability estimates in OLS regression models (Ji & Peters 2004; Lichstein et al. 2002). To test for the presence of spatial autocorrelation in the OLS model residuals, a random subsample of 10% of the full training data ($n > 19,000$) for the expected gNEP model was used to generate Moran's I correlograms (equation 3). Because positive spatial autocorrelation was present, a conditional autoregressive (CAR) model (Cressie 1993) using the same parameters as the

OLS model for expected gNEP was fitted with the *spdep* package (Bivand et al. 2005) in R 2.9 statistical software (R Development Core Team 2009). The CAR analysis followed methods (Algar Unpublished-a, b) described in Szabo et al. (2009) that were developed following Lichstein et al. (2002) and Legendre and Legendre (1998). Minor variations on those methods were as follows. I used Spatial Analysis in Macroecology software v2.0 (Rangel et al. 2006) to define 14 lag distance classes (Table 2) for equal numbers of pairs of i and j terms using the geographic coordinates of my training data. To predict spatially robust expected gNEP using conditional autoregression, I used three different values of α (1.0, 1.5 and 1.75) in the neighbour weight function $w_{ij} = 1/d_{ij}^{\alpha}$, where w is the weight applied to terms i and j separated by distance d_{ij} (Lichstein et al. 2002). Values of $\alpha=0$ were used to calculate neighbour weights for data separated by distances greater than the maximum lag distance (Lichstein et al. 2002; Szabo et al. 2009). It is computationally impractical to perform CARs on very large samples requiring extensive pairwise comparisons to calculate w_{ij}, so I ran separate CAR processes on 8 equal, random subsets of the $n > 19{,}000$ subsample and averaged the coefficients from the 8 resulting CAR models to determine parameters for the final model used to predict expected gNEP (see Tables 3 a&b and Appendix B for parameter summaries). To partition variance between different components of the model, final R^2 values for the full CAR plus spatial autocorrelation, the OLS model, the pure autocorrelation model and the CAR model were calculated following Nagelkerke (1991) and Lichstein et al. (2002).

Internal validations (bootstrapping) of the final CAR-based expected gNEP model were performed by splitting the initial training dataset 70:30 into training and testing subsets over 500 iterations. The difference between intercepts for the observed vs. predicted lines and the model standard error was assessed in each iteration, based on a confidence interval around the observed vs. predicted 1:1 line. The terms of the CAR-based expected gNEP model were also externally validated (bootstrapping) using new data sampled from 2500 equal-area polygons situated randomly across Canada. Five hundred iterations were again performed to assess the difference intercepts for slopes of observed vs. predicted lines and model standard error.

Calculating NEP deviations based on actual and expected gNEP

I assessed the degree to which human or natural environmental changes caused actual gNEP to deviate from expected gNEP for each year from 1998 to 2005. I used the following equation to determine relative deviations of gNEP from expected values:

$$\text{Rel. Dev. in gNEP} = ((\text{Actual gNEP}_i - \text{Baseline gNEP}) / \text{Baseline gNEP}) \cdot 100 \quad (2)$$

where actual gNEP_i is the average integrated growing season[3] gNEP observed across Canada for the 8-year average or year *i* between 1998 and 2005 (Figure 2b). Negative gNEP deviations in any year indicated that actual gNEP values were lower than modeled expected gNEP, while positive deviations indicated that actual gNEP was higher than baseline gNEP. I

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[3] From 1 June to 31 August each year.

also calculated the positive and negative deviations as a proportion relative to baseline gNEP values. Relative gNEP deviations are exclusively reported hereinafter unless otherwise indicated. To estimate the trend, or magnitude and direction of deviations from expected gNEP over time, I calculated the between-year differences in deviations measured each year from 1998 and 2005. The average of those seven inter-annual comparisons indicated if gNEP deviations were increasing or decreasing over time compared to expected gNEP values at a given location, e.g., negative deviations in a dense urban area getting farther from expected gNEP (becoming more negative) during the study period.

In addition to statistical controls used during data sampling described above, I applied two more controls to limit non-anthropogenic correlates of gNEP deviations. I reduced the land area on which gNEP deviations were calculated by removing all pixels falling within a) naturally non-vegetated land cover types, e.g., talus rock, barren tundra; and b) the boundaries of forest fires that occurred between 1998 and 2005 (Fraser et al. 2005; Stocks et al. 2002), as well as areas classified as recovering post-burn forests (Cihlar et al. 2001).

Identifying biologically relevant deviations from expected gNEP

Not all gNEP deviations fell outside the normal range of variation in gNEP that could be expected in pristine environments during the study period, and therefore were not categorized as 'biologically relevant' deviations (e.g., Bogaert 2003; Sanderson et al. 2002b; Semlitsch 1998). Because biologically relevant deviations should have fallen outside of the normal variation in gNEP that would be expected in pristine environments using my definition, I interpreted them to be changes in productivity that could, for example, impact organisms in an ecosystem, e.g., large decreases in productivity leading reduced food supply for herbivores. However, it must be noted that any assumptions about the broader impacts of biologically relevant deviations were beyond the scope of my study. To identify biologically relevant deviations, I first visually inspected a histogram of gNEP deviations across the Canadian study area, identifying potential thresholds using the frequency distribution of positive and negative deviations (Figure 1). I then carefully calibrated the thresholds by checking more than 150 areas of known human disturbance using very high resolution imagery in Google Earth v5.1 (from the *IKONOS*, *QuickBird* and *Landsat* sensors at 1 to 30 m resolution; http://earth.google.com) against the gNEP deviations I measured. I used this technique to determine precisely where the thresholds should be placed to capture known human impacts on ecosystem productivity, e.g., large urban centres, open-pit mines. In sum, biologically relevant deviations occurred above 14% and below -8%, hereinafter called biologically relevant positive and negative deviations, respectively.

I also applied thresholds to trends in gNEP deviations to isolate potentially biologically relevant increasing or decreasing differences from expected gNEP over time, or biologically relevant trends. The thresholds encompassed one standard deviation around the mean trend for positive gNEP deviations (mean = 0.21 $\%\cdot yr^{-1}$, SD ± 1.21) and negative deviations (mean = 0.34 $\%\cdot yr^{-1}$, SD ± 1.26). Different maps were developed for biologically relevant gNEP positive and negative deviations and then recombined into a single coverage showing increasing and decreasing trends in deviations from expected gNEP across the Canadian study area during the study period.

Assessing gNEP deviations by land cover using very high resolution control points

I determined the level of agreement between estimated gNEP deviations and actual spatial and temporal patterns in land cover change across the study area using very high resolution imagery from the satellite-based *IKONOS*, *QuickBird* and *Landsat* sensors displayed in Google Earth. I identified 1044 control points in Google Earth matching a variety of anthropogenic and natural land cover types across Canada based on a stratified random sampling method. The land cover at each control point was then described by direct visual interpretation of the satellite imagery (see Appendix C), for which data published through Google Earth are well-suited (Butler 2006; Lisle 2006; Nourbakhsh et al. 2006). The geo-referenced control points were exported from Google Earth and into ArcGIS v. 9.2 (ESRI) using a KML to SHP data conversion script (Parent et al. 2008) and overlaid on subsequent layers for data extraction at each control point. I first extracted the SPOT VGT-based land-use (Cihlar et al. 2001; Kerr & Cihlar 2003) for each control point to verify expectations of different levels of gNEP deviations being associated with anthropogenic and non-anthropogenic land-use types. The twenty-five SPOT VGT-based land-use categories are listed in Appendix D. I then extracted data on the land cover and average gNEP deviation at each control point using bilinear interpolation to verify the median gNEP deviations associated with various anthropogenic and natural land cover types.

I performed non-parametric one-way Kruskal-Wallis tests and *post hoc* non-parametric multiple comparison tests to look for differences in gNEP deviations between land cover categories across the control points. These tests looked at gNEP deviations for the control points using different treatment levels, based sets of three- and ten-category of land-use descriptions that I developed (Tables 5 a&b, see Appendix C for detailed land cover descriptions). I used the residuals of a spatially-lagged pure autoregressive model generated in SAM v3.1 (Rangel et al. 2006) to remove the effects of significant positive spatial autocorrelation on gNEP deviations analyzed in the Kruskal-Wallis one-way ANOVA and multiple comparison tests. Behrens-Fisher-type all-pairs and many-to-one comparisons between the different treatment levels were performed in the multiple comparison tests, according to methods described by Munzel and Hothorn (2001), using the R packages mvtnorm (Genz & Bretz 2009; Genz et al. 2009) and npmc (Helms & Munzel 2008). Munzel & Hothorn (2001) recommend Behrens-Fisher-type *post hoc* comparisons because they are more conservative and therefore more reliable for non-parametric, unbalanced and heteroscedastic datasets. The Behrens-Fisher comparison statistic, $\dot{p}$, varies between 0 and 1 and measures the relative effect between two groups being compared. The many-to-one comparisons contrasted all categories against the "natural", "urban/developed", "forest removal" and "forest regeneration" land-use categories as control treatments in separate tests. Using different land-use categories interchangeably as the control treatment could shed light on how sensitive my method was for detecting differences across multiple land-use categories. Asymptotic two-sided p-values[4] were used in each multiple comparison since no assumptions were made about the relative direction of differences between groups beforehand.

Using the methods described above I also assessed differences in trends in deviations from expected gNEP over time between anthropogenic and natural land cover types. In this case I extracted data for trends in gNEP deviations at each control point, capturing the deviations recorded over the 8-year study period at each point. I then used the residuals of a spatially-lagged pure autoregressive model generated in SAM v3.1 (Rangel et al. 2006) to remove the effects of significant positive spatial autocorrelation on the magnitude of trends in gNEP deviations across the study area. Trends for different land cover types were again compared using Kruskal-Wallis one-way ANOVA and non-parametric multiple comparison tests, as described above.

Detecting spatial and temporal trends in human-induced gNEP deviations

The proportional area of biologically relevant gNEP deviations and their geographic expansion or contraction over time is ultimately of interest for conservation planning and natural resource management. This information answers the question: where and in which

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[4] The p-value is not exact and is instead determined based on a test statistic with an asymptotic chi-square distribution for a given number degrees of freedom (SAS Institute Inc. 2004).

ecosystems is the geographic area of deviations changing most rapidly over time? To highlight the overall direction and rate of change in the geographic extent of gNEP deviations, I extracted the area of biologically relevant gNEP deviations for each year between 1998 and 2005 from 210 ecoregions across Canada (Ecological Stratification Working Group 1996). I then determined the proportional area of positive and negative gNEP deviations per year (1998-2005) within each of the ecoregions to develop a temporal trend in the area of both types of deviations. Summarizing trends by ecological regions ensures that similar land cover types, climate and environmental conditions are combined to measure change (Brydges & Lumb 1998; Goetz et al. 2006), and ecological regions are a common and consistent unit of analysis that allow my research to be more easily used by other researchers, land managers and decision-makers (Ecological Stratification Working Group 1996).

Time-series data such as those described above are frequently non-normally distributed and lack serial independence (Yue et al. 2002). To account for these problems in my 1998 to 2005 time series, I used non-parametric trend-free pre-whitened Mann-Kendall tests (Yue et al. 2003) to calculate the direction, rate and significance of changes in the proportional area of gNEP deviations by ecoregion over time. As described by Yue et al. (2003), this method uses the Theil-Sen approach (Sen 1968; Theil 1950) to calculate a slope and then calculates the Mann-Kendall statistic (S) (Kendall 1970; Mann 1945) on autocorrelation-adjusted data to determine the significance of the overall trend. These tests have been used to determine trends in non-parametric serially and spatially autocorrelated remotely sensed geospatial data to detect rates of change and their significance (Fernandes & Leblanc 2005; Latifovic & Pouliot 2007). The test is considered suitable to detect trends for sample sizes n ≥ 8 (Bouza-Deano et al. 2008; Kendall 1970). I completed the analysis using the R packages *Kendall* (McLeod 2006) and *zyp* (Bronaugh & Werner 2009) with the Yue-Pilon method for pre-whitening and accounting for lag(1) autocorrelation (Yue et al. 2003). The results identified ecoregions with significant monotonic trends in the geographic expansion or contraction of gNEP deviations.

Short-term weather anomalies and gNEP deviations

Previous studies have found significant effects of climate change on ecosystem productivity dynamics across Canada (Neigh et al. 2008; Olthof & Latifovic 2007; Pouliot et al. 2009). I questioned whether some gNEP deviations I detected in areas of negligible human impact could be related to short-term weather variation, which could potentially indicate an effect of longer-term climate change. I therefore conducted tests of independence between the gNEP deviations I measured and departures of summer temperature and precipitation during the study period from their respective 50-year averages for each ecoregion across Canada. To do so, I first determined average growing season temperature and precipitation (McKenney et al. 2006) within the boundaries of biologically relevant positive and negative gNEP deviations, respectively, for each year (1998-2005) and within each ecoregion (n=210) (i.e., 2 types of deviations over 8 years in 210 separate ecoregions = n = 3,360 samples). I then determined the average 50-year summer temperature and summer precipitation within the same boundaries of positive and negative gNEP deviations for each ecoregion (n=3,360 again; Hijmans et al. 2005). By comparing the annual average summer temperature and precipitation for positive or negative deviations separately in each ecoregion to the 50-year summer temperature and precipitation averages for the same area, I identified positive or negative weather anomalies relative to the 50-year average. The final sample size was n=3,224 given 136 instances over the 8-year count period in which positive and/or negative gNEP deviations were not recorded in a given ecoregion. The counts for precipitation and temperature anomalies in each ecoregion were paired to look at their interaction given the interaction between the variables representing these terms in the expected gNEP model (equation 2). Using similar methods I also developed a Canada-wide, ecoregion-based map to show the distribution of positive temperature anomalies greater than 1.0° C above the 50-year average within areas of positive and negative gNEP deviations in each ecoregion (Figure 10). This reflects the minimum temperature increase (relative to 1990 levels) associated with 5 "reasons for concern" around climate change listed by the Intergovernmental Panel on Climate Change in its Third Assessment Report (Smith et al. 2009).

To conduct the statistical test of independence (or association), I constructed a 4 x 5 contingency table to analyze the count frequencies of gNEP deviations and weather anomalies (Table 6). The counts for gNEP deviations had 4 different states: "negative gNEP deviation", "No data – neg dev", "positive gNEP deviation", and "No data – pos dev". Five different states were used to count weather anomalies: "+P/-T", "+P/+T", "-P/-T", "-P/+T", and "No data", where P stands for precipitation and T for temperature. Both symmetrical and directional tests were performed in SPSS statistical software (SPSS Inc. 2009) to measure the strength of association and directional dependency between the gNEP deviations and weather anomalies, in addition to chi-square and G tests to determine the degree of independence between the variables.

Results

Selecting a predictive model for expected gNEP using OLS regression

The final OLS regression-based expected gNEP model included terms for average summer temperature and precipitation and the year-round stability of temperature, as shown below:

$$\text{Expected gNEP}_{\text{OLS-based}} = 0.4956 + 0.308\cdot(\text{Isot}) - 0.0045\cdot(\text{Isot})^2 - 0.018\cdot(P_{summer}) + 0.0015\cdot[(P_{summer})\cdot(T_{summer})] + \varepsilon_i \quad (3)$$

where "Isot" represented isothermality or the mean of monthly temperature range divided by the annual temperature range (Hijmans et al. 2005), "P_{summer}" represented summer precipitation, "T_{summer}" represented summer temperature and ε_i represented a random noise component. The quadratic terms for Isothermality captured the latitudinal gradient in the temperature-gNEP relationship across Canada. Beta coefficients for P_{summer} and the $P_{summer}\cdot T_{summer}$ interaction in the expected gNEP appeared to be very small, but values for those variables were an order of magnitude larger than gNEP, as shown in Table 1, and therefore still had an important influence on gNEP. It should be noted that the main effect of P_{summer} became negative due to the inclusion of the $P_{summer} \cdot T_{summer}$ interaction term in the model. The model residuals were generally homoscedastic, though not independent due to spatial autocorrelation. Model selection diagnostics are listed in Tables 3 a&b.

The "global" model I fitted to predict gNEP, again using ordinary least squares regression, took the following form:

$$\text{Baseline gNEP}_{global} = 0.013 + 0.0011 \cdot (\text{Elev}) - 0.000001 \cdot (\text{Elev})^2 + 0.244 \cdot (\text{Isot}) - 0.00345 \cdot (\text{Isot})^2 - 0.00158 \cdot (\text{Dirng}) + 0.0093 \cdot (T_{summ}) - 0.0102 \cdot (P_{summ}) + 0.001 \cdot [(P_{summ}) \cdot (T_{summ})] + \varepsilon_i \qquad (4)$$

where the terms common to equation 2 were the same and "Elev" represented elevation and "Dirng" represented average daily temperature range throughout the year (Hijmans et al. 2005). Model selection diagnostics for the "global" model are listed in Table 4.

Defining a spatially robust predictive model for expected gNEP

Spatial dependency between residual values in the above models violated one of the assumptions of OLS regression, justifying the use of conditional autoregression (CAR) to identify an expected gNEP model that was robust to spatial autocorrelation. Indeed, Moran's *I* correlograms of the OLS regression residuals against lag distances showed that significant positive autocorrelation, e.g., Moran's $I > 0.01$ ($p<0.001$), was never present in the residuals beyond the third lag distance (556 km). Lag distances are listed in Table 2.

The final, CAR-based model for expected gNEP was determined based on the average of model parameters derived from CARs performed on 8 randomly sampled subsets from the original model training data. The CAR-based expected gNEP model took the following form:

$$\text{Expected gNEP}_{\text{CAR-based}} = 0.659 + 0.284\cdot(\text{Isot}) - 0.004\cdot(\text{Isot})^2 - 0.017\cdot(P_{\text{summer}}) + 0.0013\cdot[(P_{\text{summer}})\cdot(T_{\text{summer}})] + \rho + \varepsilon_i \quad (5)$$

where "ρ" was a term representing spatial autocorrelation and all other model terms were the same as those described for equation 3. In each of the 8 CAR iterations performed, the influence of neighouring points, w_{ij}, for α=1 always best accounted for the spatial autocorrelation in the residuals of the original OLS model. Approximately 4.6% of the variation in expected gNEP in all models was explained by rho (ρ), or spatial autocorrelation, alone (range in R^2_ρ=0.033 to 0.053 for the 8 CAR processes).

Internal and external validations of the final, CAR-based expected gNEP model using bootstrapping techniques verified the stability of its predictions. For internal validations, the difference between the intercept of the observed vs. predicted line and the model standard error was significant 7% of the time, corresponding to a 93% confidence interval, or a 93% consistency rate for the model's predictions. In external validations based on new, independent data sampled from 2500 randomly placed, equal-area polygons, the difference between intercepts for the observed vs. predicted line and the model standard error was significant in approximately 10% of 500 iterations. This corresponded to a 90% confidence interval and a 90% rate of consistency for the model's predictions.

Spatial Patterns in Actual and Expected gNEP across the Canadian Study Area

Net ecosystem productivity expected in the absence of human activities showed strong north-south and elevation gradients across Canada, with higher gNEP typically found in southern ecozones at lower elevations (Figure 2a). Mean expected gNEP values varied across ecozones from low to high positive values, with abrupt changes in expected gNEP related to sudden changes in regional topography, e.g., the Taiga Cordillera ecozone in the Yukon Territory. In addition to the large-scale gNEP gradient, expected gNEP varied at finer scales based on local geographical features, visible as clusters of $1km^2$ grid cells with similar expected gNEP values.

The spatial pattern of actual gNEP (Figure 2b) was similar to that of expected gNEP, showing underlying latitudinal and elevation gradients across Canada with some exceptions. Low levels of actual gNEP were associated with areas of concentrated human land-uses, such as around major cities. Also, several regions showed unexpected clusters of gNEP values that were either relatively high or relatively low compared to surrounding areas. Unlike baseline gNEP that changed gradually, actual gNEP sometimes varied greatly from one $1\ km^2$ area to the next, especially where abrupt changes in natural land cover occurred, as in the case of patchy clear cuts or open pit mines. Patterns in actual gNEP appeared to change little from year-to-year during the study period aside from minor local variation resulting from changes in land cover or 'greenness' of entire ecosystems.

There was little difference between expected gNEP and actual gNEP when average values for each were compared across large areas. Within IUCN category I-III protected areas across Canada, the 'training areas' for the expected gNEP model, there was little difference between the actual and expected values of gNEP. Figure 3a showed a reasonably strong fit between observed (actual) mean 8-year gNEP and predicted (expected) gNEP values in strictly protected areas, with constant variance around the 1:1 line (β_0=1.051). Actual and expected gNEP were also strongly related when averaged across ecozones (Figure 3b), with less than 10% difference in gNEP for ecozones exposed to human activity from those assumed to be 'free' of human influence. In the Mixedwood Plains ecozone where human activities are highly concentrated (Gibbs et al. 2009; Kerr & Cihlar 2003), actual gNEP differed by 19% from the level of gNEP expected for this region were it still dominated by 'natural' land cover.

Relative Deviations from Expected gNEP within Strictly Protected Areas

Prior to analysing the full study area I examined the distribution of deviations from expected gNEP across strictly protected areas, in an effort to identify regions and/or land covers for which expected gNEP may have been routinely over- or under-predicted. It is important to identify such spatial patterns because over- or under-prediction of expected gNEP by the model can affect the validity of my results (e.g., increase type I error, identifying a biologically relevant deviation when one is not actually present). The distribution of relative gNEP deviations across the training areas for my expected gNEP model ranged from -81% to +84% below and above expected gNEP, respectively (Figure 5a). I isolated 'outliers', or gNEP deviations that fell beyond an approximate 95% confidence interval (CI; 2·SD ± mean gNEP deviation), which accounted for only 4.6% of the total area of protected areas used to train the model.

Northern coniferous forest, very low density forest and treed barren land cover types all corresponded to mean gNEP deviations below the negative 95% CI, indicating a tendency toward under-prediction associated with these land covers. Alternately, deciduous forest showed a tendency toward over prediction with a mean deviation above the positive 95% CI. Notwithstanding, each of these land cover types showed a broad range of gNEP deviation values that varied across the full range of positive and negative deviation values. Figure 5c shows the percentage of the total area of each land cover type found in the expected gNEP model training data that corresponded to deviations outside the 95% CI. Figure 5d shows the mean gNEP deviations associated with each of the sampled land cover types across strictly protected areas. Very generally, outlying negative deviations tended to appear in high altitude parks or parks characterized by very sparse vegetation. No obvious trend was apparent for outlying positive deviations.

My method relied on the assumption that expected gNEP patterns in strictly protected areas were representative of expected gNEP across the Canadian study area. I verified this assumption by examining the proportional area of each land cover type within IUCN category I-III protected areas (Figure 5e), as well as the proportional area of each land cover type across the study area (Figure 5f). Differences in the proportional area of each land cover between the two 'measurement areas' were minimal and, where present, did not exceed ±5% of the total area. Therefore, I verified that protected areas were indeed representative of the distribution of land cover types across the full study area.

Relative deviations from expected gNEP

Actual gNEP levels tended to be lowest in areas with substantial human activity but were similar to, or exceeded, expected values in areas absent of obvious human land-use changes. As a result, spatial gradients between positive gNEP deviations (expected gNEP < actual gNEP) and negative gNEP deviations (expected gNEP > actual gNEP) were apparent across Canada. This was true except where observed land cover changed abruptly relative to the surrounding region due to natural disturbances or human activities. gNEP deviations were recorded across more than 4.4 million km^2, or approximately 49% of Canada's land area[5]. Within that area positive gNEP deviations were detected over approximately 2.6 million km^2 (58% of the study area) while negative deviations occupied approximately 1.8 million km^2 (42% of the study area). The pattern of gNEP deviations differed slightly from year to year during the study period (see Appendix E).

Deviations in gNEP calculated using equation 3 were very similar to those calculated using a 'global model' (equation 4). Expected levels of gNEP determined by equations 3 and 4 were very highly correlated (Spearman's rank correlation ρ=0.952), meaning that while my expected gNEP model represented one of many plausible climate-gNEP relationships, its predictions were not substantially different from those of a 'global model' – one that should simultaneously account for a number of different climate-gNEP relationships that

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[5] This area estimate excludes non-vegetated land covers, the Prairies ecozone, all category I-III protected areas and all forest fire scars between 1998 and 2005.

may or may not have been represented in my initial model. gNEP deviations calculated using both equation 3 and equation 4 at 2500 randomly selected points across Canada reflected the high positive correlation between the models that is noted above (Figure 4). The relationship between deviations for equations 3 and 4 was strongest for extreme positive and negative gNEP deviations, which are arguably of greatest interest in terms of biological relevance and the potential influence of outliers on my conclusions.

Thresholds for Biologically Relevant gNEP deviations and Trends in gNEP Deviations

Applying thresholds for biologically relevant gNEP deviations across the study area revealed the greatest negative deviations in areas of concentrated human activity and the highest positive deviations in some remote areas where human activities were thought to be minimal (Figure 5b). Deviations not considered to be biologically relevant tended to occur in less densely inhabited or remote regions where the effects of human activities – if present – appeared to influence ecosystem productivity to a lesser degree. Using 8-year average gNEP deviations, I detected biologically relevant positive deviations over an area of ~382,000 km^2 (8.2% of the study area and about 4% of Canada's total area), compared to a total area of ~678,000 km^2 (14.5% of the study area and about 7.5% of Canada's total area) for biologically relevant negative gNEP deviations. Biologically relevant negative gNEP deviations (measured as percentages relative to expected gNEP) ranged from -8% to -100% in magnitude, while positive deviations ranged from +14% to approximately +92% in magnitude. The footprints of biologically relevant gNEP deviations did not perfectly align with the extent of each area of gNEP deviations originally detected because applying the thresholds had the effect of reducing the geographic extents of positive and negative deviations, respectively. I confirmed this using very high resolution satellite images from northern Ontario and central Quebec to informally compare the outlines of actual landscape disturbances to the shapes of negative gNEP deviations I detected both before and after applying the thresholds.

Trends in gNEP deviations revealed areas in which human activities or natural disturbances may have caused gNEP deviations to increase or decrease in magnitude relative to expected gNEP over time (Figure 6a). gNEP deviation trends for a given area were largely independent of the direction and magnitude of the average 8-year gNEP deviation recorded for that area (Verbesselt et al. 2010); the average 8-year gNEP deviation was just a static measure of the magnitude and type of change over time (i.e., positive or negative deviation), not the rate and direction in which change occurred during a given period. Trends in relative gNEP deviations showed a range of approximately -13 to +13 % during the 8-year study period (i.e., $\pm 1.6\% \cdot yr^{-1}$ change from expected gNEP), with increasing trends occupying 63% of the study area and decreasing trends in gNEP deviations found in the remaining 37% of the Canadian study area.

Areas where gNEP deviations became increasingly negative over time did not exclusively coincide with areas of negative gNEP deviations, and vice versa for gNEP deviations that become increasingly positive over time. In fact, the distribution of increasing and decreasing trends in gNEP deviations contrasted noticeably with the distribution of positive and negative gNEP deviations. Of the total area of increasing gNEP trends, approximately 58% was associated with areas showing positive gNEP deviations and only 42% with areas showing negative gNEP deviations. Positive gNEP deviations more often coincided with areas showing decreasing gNEP trends (70% of area of decreasing gNEP trends) compared to areas showing negative gNEP deviations (30% of the same area). The fact that positive gNEP deviations were predominantly associated with both increasing and decreasing trends was reflective of the greater percentage of the study area showing positive gNEP deviations before the biologically relevant thresholds were applied (Figure 5b). A test of independence between the direction of trends and the type of gNEP deviation observed showed that they were statistically independent (Contingency table-based Pearson's χ^2=2.63, with Yates' continuity correction, df=1, $p>0.10$). This verified that positive or negative deviations did not automatically correspond to increasing or decreasing trends in gNEP deviations, respectively.

Only 22% of the study area remained after isolating biologically relevant trends in gNEP deviations (Figure 6b). Of this area, 65% showed gNEP deviations becoming more positive over time, and 35% showed decreasing trends in gNEP deviations. Areas of positive and negative gNEP deviations were roughly equal (c.13% of area) across regions that showed biologically relevant increasing or decreasing trends, respectively.

Human land-uses, biologically relevant gNEP deviations and associated trends

Biologically relevant positive and negative gNEP deviations corresponded well to areas of human activity based on comparisons to land cover types using very high resolution satellite imagery at 1044 geo-referenced points[6] across Canada (Figures 5b & 7). The land cover observed at each point using Google Earth was first categorized as "natural" (n=111), "anthropogenic" (n=749) or "unknown" (n=60), respectively (Table 5a), and was subsequently broken down into 10 categories (Table 5b) to permit more detailed comparisons between the points (Appendix C). I expected that the median values of gNEP deviations associated with "anthropogenic" points would be lower than those for "natural" points based on the gNEP deviations associated with SPOT VGT-based land cover for Canada (Figure 8a.1). To make a further comparison of land covers and gNEP deviations, I summarized the medians of all deviations recorded within each SPOT VGT-based land cover class (Figure 8a.2). Again, anthropogenic land covers showed lower median gNEP deviations compared to natural land covers, except for the bare rock/ice cover type for which gNEP values would be extraneous. Land covers that were indefinable in the high resolution satellite imagery were described as "unknown" to reduce the number of points falsely labelled as another category.

I found significant differences in the median gNEP deviations associated with anthropogenic and natural land covers using both the 3-category and 10-category land cover descriptions of the points. The difference between "natural" and "anthropogenic" land covers was highly significant (Kruskal-Wallis χ^2=8.26, df=1, $p<0.005$; Figure 8b), while more detailed analysis using the 10-category land cover indicated a very significant

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[6] n=921 after removing points with no data that fell beyond the biologically relevant thresholds or occurred on land cover types not included in this analysis.

difference in median gNEP deviations for the "urban/settlement/developed" and "regenerating forest" categories in a Kruskal-Wallis one-way ANOVA (Kruskal-Wallis χ^2=155.68, df=8, p<0; Figure 8c); points in each of these categories fell under "anthropogenic" in the original 3-category land cover description. Non-parametric multiple comparisons between all pairings of the 10 land cover categories showed significant differences in median gNEP deviations for "urban/settlement/developed" and points in all other categories except "protected natural areas" (Behrens-Fisher comparison statistic $\dot{\rho}$>0.66 for all significant differences, approx. two-sided p<0.05). The only other significant differences were detected between both the "forest removal" and "regenerating forest" categories compared to the "mining" ($\dot{\rho}$=0.34 and 0.28 for the comparisons, respectively, two-sided p<0.05) and "agriculture" ($\dot{\rho}$=0.32 and 0.24 for the comparisons, respectively, two-sided p<0.05) categories. Effect sizes ($\dot{\rho}$) here were smaller than those above, suggesting weaker difference between these land cover types when all land cover types were compared. The "protected natural areas" category was removed to test its influence on comparisons given the low sample size and considerable skew it showed relative to other categories. The same results were achieved when the "protected natural areas" category was excluded from multiple comparisons and the Kruskal-Wallis one-way ANOVA. Multiple comparison tests could not be performed for the 25 SPOT VGT-based land-use categories due to computational limitations; however, Kruskal-Wallis one-way ANOVAs indicated a significant difference in median gNEP deviations for the "grasslands/pasture" and "mixed forest" land cover types.

Comparisons of gNEP deviations for many land-use categories to a single 'control' category demonstrated how closely median gNEP deviations for each land-use category were related across the Google Earth control points. These many-to-one-style comparisons were done several times with a different land-use category set as the control in each case. The "natural", "urban/settlement/developed", "regenerating forest" and "forest removal" land-use categories were each set as the control in separate tests based on the *a priori* assumption that those land-uses would show the greatest deviations from expected gNEP compared to the other land cover types. Using "natural" as the control category showed only one significant difference in the median gNEP deviation compared to "urban/settlement/developed" ($\dot{\rho}$=0.75, approx. two-sided $p<0.0005$). Excluding the "protected natural areas" category from this comparison yielded additional significant differences in median gNEP deviations (two-sided $p<0.05$) between "natural" and both the "agriculture" and "mining" land-use categories.

I also used anthropogenic land-uses as controls in the many-to-one comparisons between land cover types and found strong differences in deviations between some human land-uses. Using "urban/settlement/ developed" as the control yielded significant differences between it and median gNEP deviations for all land-use categories except "protected natural areas" (two-sided p-value=0.94). Setting "regenerating forest" as the control revealed significant differences compared to the "urban/settlement/developed" ($\dot{\rho}$=0.93, two-sided $p<0.000001$), "mixed disturbance" ($\dot{\rho}$=0.80, two-sided $p<0.05$), "agriculture" ($\dot{\rho}$=0.90, two-sided $p<0.005$) and "mining" ($\dot{\rho}$=0.84, two-sided $p<0.005$) categories. Therefore, median gNEP deviations for the "forest removal", "natural", "protected natural area" and "oil & gas exploration" land-use categories were not significantly different from that for "regenerating forest", despite a priori expectations. Excluding the "protected natural areas" category from this comparison resulted in the same significant differences. Setting "forest removal" as the control, I detected significantly different gNEP deviations for the "urban/settlement/developed", "agriculture" and "mining" land-use categories ($\acute{\rho}$>0.66 in all three comparisons, two-sided p<0.01), indicating that median gNEP deviations associated with forest removal were not distinguishable from those for regenerating forests, mixed disturbances, natural land covers, protected natural areas and oil & gas exploration areas. The above results were unchanged when the "protected natural area" category was excluded from the comparison.

Positive spatial autocorrelation in the above data was removed prior to analysis using the residuals of a spatially-lagged pure autoregressive model in place of data for the response variables ($\rho_{spatial}$=0.592 ± 0.41 (SE), $r_{Y|\hat{Y}}$=0.60, $r^2_{ARmodel}$=0.36). Control points categorized as "unknown" and "protected natural areas" that were excluded from the Kruskal-Wallis and multiple comparison tests in some cases were included in the data to fit the pure autoregressive model. Despite the low level of explained variation with the pure autoregressive model, results for the KW and multiple comparison tests using the original, spatially dependent data as the response variable did not differ largely from those reported above. Indeed, fewer significant differences were detected between land-use categories after the effects of space were controlled, providing more conservative results than would have been achieved using the original data.

Few significant differences existed between the median values of trends in gNEP deviations when compared by land-use category among the control points (Figure 8d). While tests for overall differences in trends in gNEP deviations were significant for both the 3-category (Kruskal-Wallis χ^2=11.94, df=1, p<0.0001) and 10-category land-use descriptions (Kruskal-Wallis χ^2=39.64, df=8, p<0.00001), only the "forest removal" category had a trend that was marginally significantly difference compared to the other land-use categories in multiple comparison tests. Trends in gNEP deviations for "forest removal" areas differed from those of the "natural" and "oil & gas exploration" areas ($\dot{\rho}$=0.34 and 0.28, respectively, approx. two-sided p<0.10). These differences became less likely due to chance (p<0.05) in many-to-one comparisons where "natural" land-use was the control category. The magnitudes of median trends in gNEP deviations for the "forest removal" and "oil & gas exploration" categories were larger than those for the other land-use categories, as shown by the K-W test above. No other land-use categories showed significantly different trends in gNEP deviations when compared to the "natural" category as a control group (two-sided p<0.05).

Data for the response variable in comparisons of trends was adjusted for spatial autocorrelation using the residuals of a spatially-lagged pure autoregressive model ($\rho_{spatial}$=0.562 ± 0.44 (SE), $r_{Y|\hat{Y}}$=0.58, $r^2_{ARmodel}$=0.33). Results for comparison tests using the data controlled for spatial autocorrelation were more conservative than results obtained with the original data, with fewer significant differences detected at low significance thresholds (two-sided p<0.10). The relative location of the median trend for each land-use category to the others changed noticeably after controlling for the effect of space, which was reflected in the decrease in the number of significant differences detected between the original and the spatial autocorrelation-adjusted data.

Geographic expansion and contraction of gNEP deviations over time

One hundred fifty-nine of the 210 ecoregions (>75%) comprising the study area showed changes in the geographic area of both biologically relevant positive and negative gNEP deviations during the 8-year study period (Figures 9a&b, respectively). The rate of change, measured by the Kendall's tau statistic, was significant for 23 of these ecoregions ($\tau > \pm 0.62$ for all $p<0.10$). A lower significance threshold was used given the conservation interest attached to tracking changes in the total area of human or natural influences on gNEP over time (Field et al. 2004). Temporal autocorrelation in the data was removed using a lag-1 autoregressive process through the trend-free pre-whitened Mann-Kendall trend test (Bronaugh & Werner 2009; Yue et al. 2003). Geographic expansion of areas that fall below expected gNEP should typically occur in areas where human activities drive changes in land cover and ecosystem productivity, while expansion of areas that exceed expected gNEP may correspond to human land-uses that can result in increased gNEP (e.g., forest regeneration or high biomass agriculture) or changes in regional climate.

Expansions and contractions in the area of both positive and negative gNEP deviations during the study period coincided in 159 of 210 ecoregions (>75% of ecoregions). The changes in geographic area of gNEP deviations over time varied from +5.84% ecoregion area$\cdot yr^{-1}$ to -2.55% ecoregion area$\cdot yr^{-1}$ for positive gNEP deviations, and from -6.25%

ecoregion area·yr^{-1} to +1.61% ecoregion area·yr^{-1} for negative deviations. Expansions in the area of positive deviations coincided with shrinkages in the area of negative deviations within the same ecoregion in 133 or >63% ecoregions, meaning that the same overall change in the geographic area of deviations was measured within an ecoregion. Similarly, shrinking areas of positive gNEP deviations coincided with expanding areas of negatives deviations in 39 ecoregions, with only one of these ecoregions having a marginally significant rate of change over time ($p<0.10$). By contrast, 94 ecoregions showed a combination of expanding areas of positive deviations and shrinking areas of negative gNEP deviations. The rate of change in geographic area of deviations was significant in 22 of these ecoregions having (significant of at least $p<0.10$). The numbers of ecoregions with shrinking areas of negative deviations (136 or 65% of all ecoregions) and expanding areas of positive deviations (106 or 50% of all ecoregions) were most commonly observed across the study area.

Short-term weather anomalies and their relationship to gNEP deviations

Short-term temperature and precipitation patterns in most ecoregions differed from their respective 50-year averages and tended to coincide with positive and negative gNEP deviations across ecoregions during the study period. These differences from the 50-year averages were described as short-term weather anomalies. Increases in temperature and precipitation compared to long-term averages (positive anomalies) were more frequently related to both gNEP deviations across ecoregions over time, with increases in temperature occurring slightly more often than increases in precipitation (see Table 6). Notwithstanding direct relationships between weather variables and gNEP deviations, the relationship between gNEP deviations and the interaction of temperature and precipitation at the ecoregional level was most pertinent to the analysis, given the interaction of those two variables included in the expected gNEP model (equation 3) and therefore used in calculating gNEP deviations. Negative gNEP deviations occurred more frequently than positive gNEP deviations in relation to weather anomalies across all ecoregions. Increased temperature (positive anomaly) was most frequently associated with gNEP deviations, while there was no clear pattern between gNEP deviations and increases or decreases in precipitation. Northern ecoregions more predominantly showed positive temperature anomalies >1.0°C in association with gNEP deviations (Figure 10).

I found that gNEP deviations and short-term precipitation and temperature anomalies (particularly their interactions) were significantly and strongly associated. I tested this using a contingency table of all possible variable combinations of gNEP deviations, interacting temperature and precipitation variables and no data points for each (Contingency table-based Pearson's χ^2=2704, df=12, two-sided asymptotic p≈0; G-test of independence likelihood ratio=2138.1, df=12, two-sided asymptotic p≈0). Given the observed frequency and direction of temperature and precipitation anomalies, the prediction of gNEP deviations was improved by between 22% and 32% (Goodman & Kruskal tau=0.22, approx. two-sided p≈0; Uncertainty coefficient (*U*)=0.32, approx. two-sided p≈0), with the effect size for this response-predictor relationship between gNEP deviations and weather anomalies being greater than that of non-directional or reverse causal relationship between the two variables (Chico et al. 2002). There were strong, significant symmetric relationships between the variables (Phi=0.92, approx. two-sided $p \approx 0$; Cramer's V=0.53, approx. two-sided $p \approx 0$; Pearson's Contingency Coefficient (C)=0.68, $p \approx 0$), where Pearson's contingency coefficient is roughly analogous to the Pearson correlation coefficient but modified for nominal data (Chico et al. 2002) and is more appropriate to measure correlation in r x c-style contingency tables.

Discussion

This research presents a method to detect human influence on natural ecosystems using a novel baseline for patterns of ecosystem productivity expected in the absence of human activities. Applying my methods across a predominantly forested Canadian study area, I showed that almost 12% of the country's land area is affected by biologically relevant deviations from expected gNEP. I also showed that those deviations were related to human activities, especially throughout inhabited regions in Canada's south. Looking at trends in human impacts on gNEP over an 8-year period, I detected both increases and decreases in relative gNEP deviations of roughly +1.6% and -1.6% per year, respectively. Interestingly, increasingly positive gNEP deviations covered more of Canada's land area (18%) than other combinations of trends and deviations. Those increasingly positive gNEP deviations also showed higher rates of geographic expansion within ecoregions over time. Unexpected but biologically relevant deviations in remote, uninhabited regions across the study area showed a strong, significant association with short-term weather anomalies indicative of climate change (Pearson's C=0.68). My methods are particularly useful for change detection in Canada, as they were largely calibrated for temperate and sub-arctic vegetated lands where ongoing anthropogenic climate change will likely increase the potential for encroachment of human settlement and agriculture into more northerly ecosystems (IPCC 2007; Motha & Baier 2005; Prowse & Furgal 2009; Prowse et al. 2009a; Prowse et al. 2009b).

Making sense of gNEP deviations at a broad scale

Areas of concentrated human activity appeared to be associated with biologically relevant negative gNEP deviations throughout southern Canada, based upon the map of deviations across the study area (Figure 5b; see Appendix E also). Negative deviations often coincided with areas of dense human settlement, agricultural production (e.g., southwest Ontario), forestry (e.g., parts of southern Quebec), open pit mining (e.g., Sudbury, Ontario) and with transportation corridors (e.g., northern New Brunswick), among other land-uses, particularly in the Mixed Wood Plains, Boreal Plains and Atlantic Maritime ecozones. Urban expansion was clearly visible in negative deviations around the cities of Montreal, Toronto and Vancouver. Very high magnitude negative deviations occurred in some relatively small areas, such as the Alberta Tar Sands or the city of Sudbury, Ontario (Figure 5b), illustrating that the geographic area occupied by negative deviations did not necessarily vary directly as a function of their magnitude.

Ecosystem disturbances detected across Canada in other studies corresponded well with the negative deviations I detected. I found ecosystem disturbances similar to those detected by Latifovic and Pouliot (2005), particularly in the boreal forest zone, but fewer of their disturbance areas coincided with disturbances I identified as biologically relevant negative deviations. Instead, I found positive deviations in some areas where Latifovic and Pouliot (2005) saw ecosystem disturbances that should have decreased ecosystem productivity. Such disparities may have arisen from methodological differences, particularly my use of a 'theoretical' gNEP baseline. In another example, Bai et al. (2008) exceeded my estimates of the proportional area of negative deviations, suggesting that nearly 20% of Canada's land area has been "degraded", using rain-use efficiency-adjusted NDVI as a measure. This again highlighted a disparity related to differences in methodology and the types of remote sensing data used for change detection, e.g., worldwide rain-use efficiency-adjusted NDVI from the AVHRR sensor compared to my gNEP (NDVI) data from the SPOT-VGT sensor that was adjusted specifically for Canadian atmospheric conditions (Cihlar et al 2004).

My broad-scale results showed that in western Canada, low density human settlements and areas typically associated with forestry and agriculture were associated with biologically relevant positive deviations (Figure 5b). Despite a long history of forest harvesting throughout eastern Canada, coupled with many areas of post-harvest forest regeneration that should be deciduous species-dominated and therefore have higher gNEP values, I detected relatively few biologically relevant positive deviations associated with anthropogenic land-uses or human settlements in that part of the country.

Forest fires are the largest non-climatic driver of gNEP changes across Canada (Stocks et al. 2002; Weber & Stocks 1998) and thus presented a challenge in detecting human-induced changes in gNEP using remotely sensed data. I removed forest fires between 1998 and 2005 from my study area to prevent misinterpretation of the resulting negative deviations (at least during the year of fire) as human impacts on gNEP. However, I did not account for recovering forest fires that occurred prior to this period. Amiro et al. (2000) showed that burned areas may show increasing and variable net primary productivity patterns for more than 20 years post-fire. Not excluding areas burned before 1998 could have increased the area of gNEP surpluses I detected. This might explain some of the gNEP surpluses I revealed in remote regions presumably unaltered by direct human activity.

The portion of biologically relevant negative deviations I detected relative to positive deviations would have changed given different threshold values for biologically relevant relative deviations between 0 and ±100%. The thresholds for biologically relevant positive and negative deviations were not equal because known land-use changes corresponding to negative deviations were not captured using a negative threshold of -14.0%; therefore, a -8.0% threshold was used. Likewise, a threshold for biologically relevant positive deviations set at +8.0% captured very extensive areas across the country and was judged to be overly liberal. The final threshold values were carefully calibrated using very high resolution satellite imagery to ensure that areas of known human impacts on ecosystem productivity (e.g., major urban centres) were detectable.

Making sense of gNEP deviations based upon human land-uses

Comparisons of relative gNEP deviations by land cover and use type showed a tendency for intensive human land-uses to relate to negative deviations, though positive and negative deviations were observed for both human and natural land-uses/land covers (Figures 8a-d). Natural land cover types based on SPOT-VGT land-use data (Cihlar et al. 2001; Kerr & Cihlar 2003) at the Google Earth control points showed positive median deviations in three of eight cases (combined land covers representing ~34% of lands across the study area), while the negative median deviations for the remaining natural land covers were less negative than those for any of the human land-use types (Figure 8a.1). That pattern was well reflected in the comparison to mean deviations summarized for each SPOT VGT land cover type across the entire study area (Figure 8a.2), in which natural land covers had positive or relatively low negative mean deviations compared to most human land-uses, particularly intensive land-uses such as urban development and areas of grain production. I found that human land-uses had lower median deviations compared to natural land covers, and showed many more outlying negative deviations, when summarized generally across all control points (Figure 8b).

Looking more specifically at different sorts of human land-use (Figure 8c), I found that "urban/settlement/developed" and "agriculture" land-use types showed negative median deviations overall, while median gNEP deviations for all other land-use types were close to zero or positive. No land-use type showed deviations that were uniquely positive or negative, as there was substantial variance in each case around the median deviation value.

Outlying highly negative deviations for "mining" and "urban/developed" lands were indicative of the variability in and range of deviations observed for some land-use types, particularly those that were anthropogenic. While "protected natural areas" unexpectedly showed a number of negative deviations, despite having a median deviation of approximately zero, some of the 10 control points sampled for this land-use may have corresponded to land covers where gNEP was difficult to detect, i.e., sparsely-vegetated areas.

I found that trends in gNEP deviations over time were very similar across land-use types (Figure 8d). There was notable scatter around the median trends in deviations for each land-use type, though most median values were very close to zero. Only the changes in gNEP deviations at control points corresponding to "oil and gas exploration" and "forest removal" were significantly different from other land-uses during the 8-year study period. Points corresponding to "forest removal" showed increasingly positive deviations over time, whereas deviations associated with oil and gas exploration became increasingly negative throughout the study period.

My results are an additional confirmation that human land-uses can often be characterized by decreases in ecosystem productivity (Bai et al. 2008; Foley et al. 2007; Haberl et al. 2007; Morawitz et al. 2006; Potter et al. 2005; Stoms & Hargrove 2000). Unlike several of those studies, however, I found negative deviations associated with agriculture, as shown in the southern Boreal Plains ecozone and throughout the Mixedwood Plains (Figure 5b). Those negative deviations in agricultural areas may have reflected areas of drought stress (Bai et al. 2008; Ciais et al. 2005), poorly detected NDVI for crops with small leaf area indices (Myneni & Williams 1994), or insufficient growing season length (1 June to 31 August) to effectively estimate cropland productivity. Notwithstanding, differences in the remote sensing data (e.g., NPP derived from complex algorithms versus raw NDVI) used for change detection between studies may have also contributed to disparities between results.

I found that various types of temporary land-use change were associated with biologically relevant positive deviations, particularly within the Montane Cordillera, western Boreal Plains and Pacific Maritime (esp. Vancouver Island) ecozones (Figure 5b, Appendix D). Those land-uses included "forest removal", "mixed disturbance" and "oil and gas exploration" sites. Forest removal and mixed disturbance land-uses in eastern ecozones also showed positive deviations, but to a lesser degree. Oil and gas exploration sites were almost entirely located in western Canada.

Some human activities that could have feasibly resulted in negative gNEP deviations showed the opposite tendency. For example, "forest removal" and "oil and gas exploration" activities showed surpluses, though these land-uses can leave once productive ecosystems temporarily denuded or fragmented, which should lead to negative deviations. My method may have detected both forest harvesting and active forest regeneration in such areas[7] (Mildrexler et al. 2007; Morawitz et al. 2006; Neigh et al. 2008; Wylie et al. 2008). Regenerating forests are typically dominated by deciduous species that often have higher

[7] Note that active mines (e.g., the Alberta Tar Sands Project) are not included in the oil & gas exploration land cover category. Active mines fall under category 6 for "mines and mining infrastructure".

productivity than the mature/over-mature coniferous forests they may replace, therefore leading to positive deviations being detected. Alternatively, I may have detected 'natural' gNEP levels prior to disturbance given the temporal mismatch between the gNEP data (1998-2005) and the dates of land-use types I inferred from more recent high resolution *IKONOS* and *QuickBird*-based imagery in Google Earth. Overall, my results were similar to those of other studies showing that positive deviations are commonly associated with unmodified and post-disturbance land covers (Mildrexler et al. 2007; Stoms & Hargrove 2000; Wylie et al. 2008).

The results of my analyses of broad-scale gNEP deviations across the study area and median deviations between different land-use types must be considered in the context of my expected gNEP model's performance. Deviations falling outside the approximate 95% confidence interval in strictly protected areas (Figure 5a) showed a tendency for my model to over-predict very small, isolated parts of western Canada (possibly due to more highly variable topography) and spaces where vegetative cover was sparse or difficult to measure remotely (e.g., Athabasca Sand Dunes Provincial Park, SK). Similarly, the outliers showed that my model tended to under-predict very small, isolated forested areas in eastern, central and northern Canada, with no clear geographic pattern. In total, less than 5% of the total area of strictly protected areas fell outside the confidence interval and no one land cover type was predominantly associated with the 'outliers' (Figure 5c). Upon expanding my gNEP predictions to the entire study area, any over- and under-prediction of my model would have spread across a much larger area, leading to extraneous gNEP deviations and increasing the potential for Type I error. I mitigated and accounted for those risks in four ways: i) I used a study area that covered multiple geographic regions and captured Canada-wide gradients in gNEP, temperature and precipitation; ii) I used large sample sizes, stratified random sampling and more conservative non-parametric statistical tests to look at patterns in land-use and gNEP deviations across the study area; iii) where appropriate I examined average changes in gNEP deviations across large areas such as ecoregions; and, iv) I carefully calibrated thresholds for biologically relevant positive and negative deviations that showed the best performance in areas of known human impacts on gNEP, e.g., major cities. In summary, I used a combination of statistical methods and regional generalization/aggregation to avoid the bias of outlier areas where my expected gNEP did not perform optimally. It should also be noted that my expected gNEP model showed a consistency of 90% in its predictions over multiple iterations based on external validation, indicating a low likelihood of these outliers changing from one iteration of the method to the next.

Unexpected gNEP deviations shed light on short-term effects of climate change

While 'unexpected' deviations in remote regions may have reflected model performance, I showed a strong, significant association between weather anomalies and gNEP deviations, particularly for positive temperature anomalies. Figure 10 showed the distribution of positive temperature anomalies (>1.0° C over the 50-year average growing season temperature (Smith et al. 2009)) by ecoregion across the study area, highlighting the climatic changes in a number of northern regions as well as areas along all three marine coastlines. I found that both positive temperature and positive precipitation anomalies coincided more often with biologically relevant negative gNEP deviations. Negative temperature anomalies were relatively less associated with gNEP deviations, though positive precipitation anomalies occurred more often in association with gNEP deviations when temperature anomalies were negative. This latter tendency may have reflected the role of precipitation on gNEP in water-limited ecosystems.

Despite the observed role of precipitation anomalies interacting with temperature anomalies (Table 6), my results corresponded to those reported elsewhere regarding relationships between temperature anomalies and changes in gNEP. Olthof and Latifovic (2007) found extensive significant correlations between short-term gNEP (NDVI) anomalies and temperature anomalies in mostly forested areas across northern Canada, closely matching the northern ecoregions in which I detected gNEP deviations and temperature anomalies illustrated in Figure 10. Their study period closely matched mine, as well, being 1998 to 2004, and they used the same SPOT-VGT data for actual gNEP, despite their NDVI anomalies having been measured more conservatively than mine. Neigh et al. (2008) also showed a range of positive gNEP (NDVI) anomalies related to both land-use changes and climatic influences across the Mackenzie Delta region, northern Saskatchewan, southern Quebec and the Gaspé Peninsula, and Newfoundland and Labrador. While I found corresponding positive gNEP deviations in the Mackenzie Delta region, the Gaspé Peninsula and western Newfoundland and Labrador, my results for the other regions disagreed. I showed negative deviations in northern Saskatchewan, eastern Newfoundland and southern Quebec. In southern Quebec the negative deviations related to forest removal and agriculture, but deviations in the other regions did not reflect the positive effects of temperature fertilization on forest productivity shown by Neigh et al. (2007, 2008). My method may have also been sensitive to over-predictions associated with the Athabasca Sands and surrounding landscapes in parts of northern Saskatchewan (Figure 5a).

More complex responses of gNEP to environmental change, such as forest desiccation, disturbance or fragmentation, may have caused my results to differ from those presented elsewhere. It must be noted, however, that testing for such specific associations was beyond the scope of my research. Westerling et al. (2006) showed strong links between increasing temperatures, increasing water-stress/desiccation in ecosystems and, over time, increased forest fires. Forest desiccation typically results in lower levels of productivity (Running & Mills 2009), which my method may have detected as gradual negative deviations leading up to 'optimal' forest fire conditions in remote regions where direct human influence on gNEP was negligible. Increasing temperatures have been shown to be correlated to more frequent forest fires over the last 40 years in Canada (Gillett et al. 2004). Alternatively, natural forest disturbances (at a scale of $< 1\ km^2$) may have led to human-induced negative gNEP deviations being falsely detected. Goetz et al. (2005) and Bunn and Goetz (2006) report negative trends associated with fragmented patches throughout forested areas in Canada. That sort of sub-pixel influence on the gNEP for a given area that appeared to be pristine could have readily led to unexpected gNEP deviations that would not agree with other studies using different satellite data or other change detection methods. Whatever the cause, Pouliot et al. (2009) were careful to point out that unexpected ecosystem productivity deviations may result from climate change, local errors in satellite data or landscape disturbances.

Tracking rates of change in ecosystem productivity across Canada

My analysis of gNEP trends supported the hypothesis that deviations may signal short-term ecosystem responses to accelerating climate change in northern regions (Figures 6a & b). Pouliot et al. (2009) concluded that significant positive NDVI trends in northern Canada were driven primarily by changes in climate, while positive NDVI trends in southern Canada were driven primarily by land cover changes. I found biologically relevant trends in gNEP change throughout uninhabited parts of eastern Canada that agreed with Pouliot et al.'s (2009) and Slayback et al.'s (2003) climate-driven gNEP trends, but I also identified trends associated with temperature anomalies in some southern regions, typically in upland, broadleaf-dominated forests. My results suggested that the eastern boreal forest and eastern taiga regions became 'greener' over time as a result of accelerated climate change, while I found that some montane areas and the western boreal and central taiga regions became increasingly less productive over time, again possibly due to climate change. It must be cautioned, however, that not all increasing or decreasing trends outside of Canada's populated southern regions can be linked to climate change, as some trends may have reflected regenerating forests or persistent land cover alteration caused by human activities.

Analyzing trends in gNEP deviations provided another dimension to my change detection methods and implied more about the mid-term impacts of positive and negative gNEP deviations for a given area than a one-time "snapshot". There was some overlap between regions showing negative trends in deviations and very small areas where my model showed minor tendencies for over-prediction (and vice-versa). Although this might have influenced the overall magnitude of trends I detected, it did not appear to affect my results across the study area in a substantial way. As in several other analyses (Pouliot et al. 2009), I found an increasing gNEP trend in the Mackenzie Delta region, where climate has shown rapid changes (Olthof & Latifovic 2007). I also detected large-scale disturbances that could otherwise be missed by looking at static gNEP deviations alone (Figure 6a). For example, a contiguous region of decreasing gNEP trend in the northeast Montane Cordillera ecozone and the western Boreal Plains ecozone showed the same spatial distribution as an infestation of the defoliating Mountain Pine Beetle that began before my study period (Westfall 2005). Defoliation and salvage cutting to remove infested trees led to positive gNEP deviation relative to expected levels (possibly associated with foliar regeneration or gap-disturbance succession by broadleaf species), while the trend showed gNEP decreasing over time relative to expected levels. That apparent paradox could have been related to abnormally large deviations detected later in my study period, the effects of localized model over-prediction, or possibly due to weather variation and its short-term effects on gNEP.

Tracking the changing geographic area of gNEP deviations

I showed that human and other impacts on gNEP were not fixed in space over time and that their 'footprints' expanded and contracted geographically within individual ecoregions. I found that the area of gNEP deviations was expanding at various rates across the study area, with some geographic grouping based upon positive and negative gNEP deviations (Figures 9a & b). Expanding positive deviations may have indicated accelerated post-harvest forest regeneration dominated by deciduous species, or encroachment of shrubs and species with higher leaf area indices into sparsely forested and treeline areas (Neigh et al. 2008; Olthof & Latifovic 2007; Olthof et al. 2008). Likewise, expanding positive deviations could have signalled accelerated human and natural disturbances leading to forest regeneration (Neigh et al. 2008), increased production of high biomass crops (Kerr & Cihlar 2003) or increases in (or restoration of) intact green space at regional levels. Much like the decreasing gNEP trends observed in the British Columbia interior, several ecoregions corresponding to the mountain pine beetle outbreak showed expanding negative deviations. Other factors may have instead been driving the expansion of deficits, including weather variation (Olthof & Latifovic 2007), ongoing forest fires (Gillett et al. 2004), changing amounts of vegetation cover, or human land-use changes. Any influence of model performance on these trends would have been minimized given the regional aggregation of trends by ecoregion.

I detected a Canada-wide pattern of expanding and contracting areas of gNEP deviations that did not entirely resemble the pattern expected to result from positive temperature anomalies (Figures 9a, 9b, 10). Specifically, Olthof et al. (2008) suggested that northern shrub-dominated areas with higher gNEP should be expanding in response to increasing temperatures. While I found that the magnitudes of positive deviations were indeed changing in association with temperature anomalies in many southern ecoregions, I showed consistent shrinkage in the area of gNEP surpluses across all northern ecoregions where increasing temperatures are more prevalent (Figure 10). This could have been i) a methodological limitation due to the exclusion of non-treed areas from my analysis, likely including shrub-dominated areas of the tundra, or ii) it could have revealed the response of conifer-dominated northern forests to desiccation or drought stress (Ciais et al. 2005; Westerling et al. 2006) and/or decreased photosynthetic rates (Sage et al. 2008) resulting from increased temperatures over time. Sage et al. (2008) showed that productivity in black spruce-dominated ecosystems, such as those of Canada's boreal forest and taiga was particularly sensitive to increases in temperature. Ecoregions in northeast Canada may have instead showed the expected response to increased temperature due to a more gradual rate of anthropogenic climate warming compared to western- and central-northern ecoregions (IPCC 2007).

My results for the contraction of surpluses and expansion of deficits throughout the boreal forest zone were concerning with respect to potential climate change impacts. The boreal forest is a massive storehouse of carbon, containing more than 180 trillion tons of carbon in plant tissues and peat (Apps et al. 1993). gNEP is a measure of the productivity of plant tissues and so relates closely to carbon sequestration via photosynthesis. Any change in gNEP on a broad scale may have suggested a deceased ability to store carbon or a decrease in the vigour – or even coverage – of biomass where carbon is presently stored in tissues. Therefore, expansions of gNEP deficits could have signalled that the ability of the boreal forest to 'buffer' against climate change impacts has become compromised over time. The observation of expanding negative deviations was further exacerbated by biologically relevant negative deviations that were observed in the Taiga Plains, Boreal Shield and Hudson Plains ecozones during the study period. Those negative deviations again signalled potential decreases in the carbon sequestration ability of those black spruce-dominated ecosystems (Sage et al. 2008).

Caveats for my overall approach to change detection

Woodley et al. (2008) showed that 40% of Canada's 217 ecoregions lack representation in the existing protected areas network, however I showed that IUCN category I-III protected areas proportionally represent Canada's land cover types (Figures 5e & f). Under-representation of Canada's full ecosystem diversity in my model could have resulted in positive or negative deviations being detected where such 'unrepresented' ecosystems occur, leading to mislabelled human-induced deviations. I showed that over- and under-prediction by my expected gNEP model was not substantially biased toward a particular land cover type and therefore should not be systematic across the study area. The importance of capturing as many vegetation types as possible from the study area and ensuring that they are all well predicted by the model should not, however, be overlooked in similar studies undertaken elsewhere.

Considering the above, I removed the Prairies ecozone from my study area to reduce the potential for over-estimates in expected gNEP and, consequently, the appearance of inaccurate negative gNEP deviations. Grassland and rangeland-dominated protected areas in the Prairies ecozone added <1,000 km^2 to the 190,000 km^2 total area used to train the expected gNEP model. Expected gNEP within the Prairies differed from Canada-wide patterns that were based largely on forested landscapes because vegetation density is naturally low in the mixed-grass ecosystems dominating the Prairies. Indeed, ecosystem productivity studies focusing on grasslands-dominated regions have often trained expected gNEP, or "potential natural vegetation", models using observations of vegetation from these ecosystems only (Garbulsky & Paruelo 2004; Paruelo & Lauenroth 1998). Previous Canadian research further underscores the importance of accounting for regional relationships between climate variables and vegetation dynamics when monitoring changes at the ecosystem level (Davidson & Wang 2004; Latifovic & Pouliot 2007).

There is always uncertainty inherent in the use of remotely sensed data, be it from classification errors in the particular dataset being used, or aggregation of heterogeneous information from many small areas into a single, larger areal unit. My analysis included several potential sources of uncertainty, all of which could have contributed to decreased accuracy in my results due to propagation of errors. In particular, my fitting of a regression model using medium resolution (1 km^2) remote sensing data introduces a great deal of statistical 'noise' in the modelling process, making a good model 'fit' more difficult to achieve. Notwithstanding, I attempted to acknowledge and mitigate each of these uncertainties to the best possible extent. It is important to effectively mitigate and acknowledge as many sources of uncertainty as possible in change detection studies based on remotely sensed data.

Using NDVI (gNEP) to measure ecosystem productivity

The satellite-based proxy I used for gNEP, integrated growing season NDVI, is subject to certain limitations as a tool for monitoring ecosystem productivity trends and assessing environmental change (Kerr & Ostrovsky 2003; Pettorelli et al. 2005). NDVI varies closely with NPP, and like NPP responds to changes in temperature and precipitation (Xiao & Moody 2004), but this relationship is also sensitive to very low and very high vegetation densities where the correlation becomes weaker (Phillips et al. 2008). Where weather anomalies and gNEP deviations (Figures 5b and 10) were not strongly related in southern regions this could have explained biologically relevant positive deviations. Such positive deviations often occurred in upland, well-drained areas where growing conditions may have favoured deciduous, broadleaved tree species with inherently higher gNEP values. Thus, positive deviations may have been artificially high because low actual gNEP values were contrasted against high expected gNEP for the same areas based on the influence of Hijmans et al.'s (2005) long-term temperature and precipitation variables. Similarly, there may have been an under-prediction problem related to the expected gNEP model, although deciduous forest cover was not affected by under-prediction to a substantial degree more than other land covers. Nevertheless, I saw strong relationships between positive temperature anomalies and both positive and negative deviations across much of the study area, which lended more support for the dominant influence of temperature anomalies in generating localized gNEP surpluses in upland, broadleaved forests.

It would be remiss not to acknowledge possible sensor abnormalities, signal detection errors or atmospheric contamination in my remotely sensed NDVI data. Though I was confident in the accuracy of the remotely sensed input data, these sources of error could have led to mislabelling and misinterpretation errors in my analysis. All Canada-wide SPOT VGT-derived NDVI products are, however, calibrated and corrected specifically for Canadian land cover types and atmospheric conditions, eliminating as many sources of signal interference and other errors as possible (Latifovic et al. 2005b) and possibly permitting more reliable results than those obtained from other data sources.

Limitations of this research with regard to climate change

While this analysis corroborated evidence for climate change effects presented by other authors, my methods were not specifically designed to detect evidence of climate change. I did not control for inter-annual variation in temperature and precipitation in my predictions of expected gNEP, which would have been necessary to confidently detect a climate change signal. That approach could have reduced unexpected gNEP deviations related to fluctuations in factors such as land surface temperature, seasonality, rainfall variability and mean annual temperature (Neigh et al. 2007, 2008). Despite more appropriate methods, I did find significant relationships between the gNEP deviations and short-term weather anomalies, which may have indicated some effect of climate change.

The nature of those weather anomalies was beyond the scope of my study; however, the term “climate” typically refers to intervals of 30 years or more, and because those short-term weather anomalies differed from a 50-year average of expected climate conditions, it is reasonable to conclude that my anomalies matched the widely held view that ecosystems around the world are responding to accelerated climate change as an environmental stressor (IPCC 2007; MA 2005).

Next steps for this research

Next steps for this research should include a longer-term analysis of both human impacts and the influence of weather/climate anomalies on ecosystem productivity across Canada (including the Prairies ecozone), as well as analysis of the relationships between different types of human activities and the magnitude of gNEP deviations observed. My study period was long enough to detect apparent directional trends in gNEP deviations, and to see a relationship between deviations and positive short-term temperature anomalies, but a longer study period would add more statistical power to the trend analyses. Similarly, more specific hypothesis testing related to weather anomalies and gNEP deviations could determine at which magnitude weather anomalies become unequivocally biologically relevant. Longer-term, Canada-wide gNEP data are available for such a study (Latifovic & Pouliot 2005). Using a longer period to determine weather anomalies relative to 50-year norms would also permit more powerful trend analysis, in addition to reducing the potential for a positive trend resulting from short-term ‘noise’ in the weather data.

Similarly, trends in deviations related to land-use would be more unequivocal given additional control points and equal representation of each land-use category to allow for parametric comparisons. As I showed, it is unlikely that the spatial distribution of deviations, especially human-induced gNEP deficits, would differ greatly in comparison to what I detected using my expected gNEP model. A model including different long-term climate terms may, however, have yielded different relationships between gNEP deviations and short-term weather anomalies, depending on how well long-term temperature and precipitation norms were captured by the combination of terms in such a different expected gNEP model. Finally, future research taking into account additional information on the drivers of human impacts on gNEP deviations would be better suited to control for spatial autocorrelation across all analyses. This would be the case because suitable predicting variables could be added to spatial autoregressive and/or spatially lagged models to determine more accurate, spatially independent values of the response variable, i.e., the variable that would be used for further analysis.

Conclusions

This research offered a new approach to monitoring the impacts of human activities on the potential productivity of regions across Canada, and could be applied anywhere that the necessary input data are available. I have expanded on the role of strictly protected areas as 'natural museums' (Vamosi & Vamosi 2008) and have showed how scientists, land managers and decision makers can gain new perspective on the intensity and extent of human and natural disturbances on ecosystems by using protected areas as ecological benchmarks for broader change detection. While I initially set out to detect more or less 'direct' human impacts on levels of expected gNEP across Canada, I may have detected the short-term effects of climate change. Despite some evidence of minor prediction error by my model, I detected a myriad of both direct (i.e., land-use change) and indirect (i.e., anthropogenic climate change) human impacts on ecosystem productivity that manifested differently depending on land-use in a given area and the location of that area.

This research concluded that:

1. Human land-use change was principally associated with ecosystem productivity deviations in southern, inhabited regions of Canada (1998-2005), while increases in temperature relative to the 50-year average related strongly to deviations in remote regions and along the east and west coasts of the country.

2. There was a great deal of variation in gNEP deviations associated with different land-uses, with several obvious associations between positive or negative deviations and particular land-use types. Urban/settled areas and agriculture were most consistently associated with biologically relevant negative deviations. Forest removal, regenerating forests, and oil and gas exploration were most consistently associated with biologically relevant surpluses.

3. Increasing and decreasing trends in ecosystem productivity deviations did not relate strongly to land-use types. Based on my analysis, lands characterized by forest removal showed increasingly positive deviations over time, while oil and gas exploration lands became increasingly negative. gNEP deviations associated with

protected natural areas require additional sampling before a conclusion can be drawn for this land-use category. For analysis of gNEP deviations in relation to land-use, a longer study period and additional sampling points may have better explained the lack of differences I observed.

4. The magnitude of positive and negative deviations in a given area fluctuated over time, by approximately 1.6% per year in each direction. Between 1998 and 2005 approximately 25% of Canada's land area showed decreasing trends in "greenness" (i.e., ecosystem productivity); roughly 13% of the country showed negative deviations becoming more severe relative to gNEP levels expected in the absence of human activities. Conversely, roughly another 25% of the country showed increasing trends in "greenness" for the same period; roughly 18% of the country showed increasingly higher positive deviations over time. The eastern boreal forest zone and much of eastern Canada showed increasingly higher levels of greenness, except where human land-uses occurred, while much of western and northwest Canada may have been approaching levels of expected gNEP over time, except where natural disturbances and climate impacts altered this pattern.

5. Overall, areas of higher than expected gNEP expanded geographically over time faster than areas of lower than expected gNEP, but not exclusively across northern ecoregions where climate change has been shown to drive such patterns. Negative feedbacks of climate change may have been implicated here. Throughout southern Canada, in northern Quebec and throughout the Rocky Mountains, the total area of positive gNEP deviations was significantly expanding within ecoregions at about the same rate that areas of negative deviations were significantly contracting: roughly 6% of each ecoregion's area per year. In central northern Canada, the areas of negative deviations were expanding by roughly 2% of each ecoregion's area per year, equivalent to the rate at which surpluses were contracting. This expansion of deficits within the carbon-rich Boreal forest is a potential climate change concern.

6. During the short period encompassed by my study, I showed a significant dependency of gNEP deviations on weather anomalies, with a strong association between the two measures. However, the relationship must be further explored to determine if this was a truly biologically relevant dependency or not.

Table 1 – List of Bioclimatic variables (Hijmans et al. 2005) used to fit the expected gNEP model, including basic summary statistics and bivariate correlations between each variable and gNEP. The bioclimatic variables have been rescaled by factors of 10 from their raw form in the Hijmans et al. dataset unless otherwise specified. Arithmetic mean values are listed. Values in the correlations column correspond to Pearson's coefficients of correlation between the raw forms of each variable and average 8-year gNEP.

Bioclimatic variable (Hijmans et al. 2005)	**Mean (units, if applicable)**	**Range**	**Correlation to gNEP (r)**
Annual mean temperature	-1.10 (C)	-16.2 to 9.9	0.5565
Mean diurnal range	10.58 (C)	4.1 to 15.1	0.1105
Isothermality	24.69	15.0 to 43.0	0.0996
Temperature seasonality	11.31 (std dev)	33.1 to 15.8	-0.0705
Temperature annual range	43.49 (C)	13.9 to 55.5	-0.0492
Mean temp. of wettest quarter	9.13 (C)	-12.5 to 21.6	0.1185
Mean temp. of driest quarter	-9.29 (C)	-32.1 to 18.5	0.2774
Mean temp. of warmest quarter (T_{summer})	12.78 (C)	2.2 to 21.6	0.6435
Mean temp. of coldest quarter	-16.12 (C)	-32.1 to 5.3	0.2957
Total annual precipitation	652.14 (mm)	146.0 to 3605.0	0.2534
Precipitation seasonality	38.82 (coeff. of variation)	10.0 to 78.0	-0.1145
Precipitation of the wettest quarter	245.43 (mm)	78.0 to 1389.0	0.2280
Precipitation of the driest quarter	97.22 (mm)	12.0 to 423.0	0.2818
Precipitation of the warmest quarter (P_{summer})	203.06 (mm)	74.0 to 537.0	0.3425
Precipitation of the coldest quarter	145.42 (mm)	14.0 to 1248.0	0.1930
Interaction8 – P_{summer} & ($T_{summer} \cdot 10$)	2631.93 (C·mm)	202.4 to 7356.9	0.5885
Isothermality-squared9	633.72	225.0 to 1849.0	0.0676

[8] Not part of the original WorldClim variable set. This variable is the product of T_{summer} and P_{summer}.
[9] Not part of the original WorldClim variable set. This variable represents the squared value of isothermality.

Table 2 – List of 14 lag distances used to determine the 'neighbourhood of influence' between data points within the weights matrix in the conditional autoregressive model for expected gNEP. Intervals refer to the specific lag distances being pair together to define a 'neighbourhood'. The lag distances were determined – using Spatial Analysis in Macroecology software version 3 (Rangel et al. 2006) – based on equal numbers of pairs of data points sampled from the training data for the expected gNEP model. Minimum distances correspond to the distance at which each neighbourhood of influence begins and maximum distances correspond to where each neighbourhood ends. The distances are compared to those calculated in the weight matrix of the conditional autoregressive model based on the function $w_{ij} = 1 / d_{ij}^{\alpha}$, where d_{ij} is the distance between two data points. Points at distances less than the maximum lag distance at which spatial autocorrelation is present are considered to be spatially autocorrelated to one another.

Lag Distance Interval	Minimum distance (km)	Maximum distance (km)
1 – 2	0	240.87
2 – 3	240.87	556.42
3 – 4	556.42	718.43
4 – 5	718.43	841.80
5 – 6	841.80	964.57
6 – 7	964.57	1,119.74
7 – 8	1,119.74	1,317.78
8 – 9	1,317.78	1,526.53
9 – 10	1,526.53	2,003.10
10 – 11	2,003.10	2,294.19
11 – 12	2,294.19	2,698.80
12 – 13	2,698.80	3,508.87
13 – 14	3,508.87	5,322.85

Table 3 – Listing of ordinary least squares regression and Type I Sums of Squares ANOVA table diagnostics for the initial expected gNEP model trained on strictly protected areas. a) Ordinary least squares regression diagnostics. Definitions for each variable in the table are provided in the results section and units in the table above. Beta coefficients have the same units as the variable to which they apply. The multiple R-squared value is synonymous with the coefficient of determination for the regression model. b) The Type I Sums of Squares ANOVA table for the regression model. Sums of squares results represent the sequential amount of variance in observed gNEP (within protected areas) explained by each additional term added to the model after controlling for the effect of the preceding variable on observed gNEP. Definitions for each variable in the table are provided in the results sections and units in the table above.

a)

Ordinary Least Squares Regression Diagnostics					
Variable	**Beta Coefficient**	**Std Error**	**t-value**	**p-value for t**	
(Intercept)	0.4956	0.0446	11.1217	~0	
Isot	0.3076	0.0036	85.7265	~0	
Isot-squared	-0.0045	0.0001	-65.4626	~0	
P_{Summer}	-0.0180	0.0001	-282.5054	~0	
$P_{Summer} \cdot T_{Summer}$	0.0015	~0.0	415.1573	~0	
Residual standard error			0.7272	**Degrees of freedom**	192970
Multiple R-squared	0.56		**F-Stat**	62310, p~0	

b)

Analysis of Variance Table for Regression Model					
Terms added sequentially	**Degrees of freedom**	**Sums of squares**	**Mean square error**	**F-value**	**p-value**
Isot	1	2,317.9	2,317.9	4,382.7	~0
Isot-squared	1	23,393.0	23,393.0	44,232.6	~0
P_{Summer}	1	14,949.0	14,949.0	28,266.2	~0
$P_{Summer} \cdot T_{Summer}$	1	91,152.6	91,152.6	172,355.6	~0
Residuals	192970	102,054.8	0.53		

Table 4 – Listing of ordinary least squares regression 'global' model for expected gNEP using training data from strictly protected areas. Definitions for each variable in the table are provided in the results section and units in the table above. Beta coefficients have the same units as the variable to which they apply. The multiple R-squared value is synonymous with the coefficient of determination for the regression model.

Ordinary Least Squares Regression Diagnostics					
Variable	**Beta Coefficient**	**Std Error**	**t-value**	**p-value for t**	
(Intercept)	0.0130	0.0573	0.2262	0.8211	
Elev	0.0011	0.00001	84.9974	~0	
Elev-squared	-0.000001	~0	-97.2887	~0	
Isot	0.2439	0.0043	57.1366	~0	
Isot-squared	-0.0035	0.0001	-44.4155	~0	
Dirng	-0.0016	0.0002	-9.9847	~0	
T_{Summer}	0.0093	0.0003	35.0230	~0	
P_{Summer}	-0.0102	0.0002	-57.9215	~0	
$P_{Summer} \cdot T_{Summer}$	0.0001	0.000001	74.9529	~0	
Residual standard error			0.7083	**Degrees of freedom**	192966
Multiple R-squared	0.59		**F-Stat**	34142.3, p~0	

Table 5a – Description of land cover for simple comparisons of relative gNEP deviations on anthropogenic versus natural lands (n=3). Each Google Earth control point (n=1044) was assigned to a category based upon the description of land-use around the point (Appendix B). Points in the "unknown" category were excluded from the final analysis.

Description of Land-use	**Category number for Kruskal-Wallis one-way ANOVA**
Natural (e.g., intact, geographically remote forest)	1
Anthropogenic (e.g., clearcut, open pit mine, urban)	2
Unknown (e.g., indistinguishable as 1 or 2 above)	3

Table 5b – Description of land cover for detailed comparisons of relative gNEP deviations across various land cover types (n=10). Each Google Earth control point (n=1044) was assigned to a category based upon the description of land-use around the point (Appendix B). Points in the "unknown" category were excluded from the final analysis.

Description of Land Cover Type (based upon interpretation of Google Earth control point descriptions)	**Category number for KW one-way ANOVA & non-parametric multiple comparisons**
Urban/settlement/developed	1
Forestry (extensive and intensive methods)	2
Regenerating forest	3
Mixed disturbance (e.g., forestry with agriculture)	4
Agriculture (all crop and livestock production)	5
Mining activity & infrastructure	6
Natural (e.g., intact, remote forest)	7
Protected natural area	8
Oil & gas exploration activity	9
Unknown (e.g., indistinguishable land-use/cover)	10

Table 6 – Contingency table showing frequencies of co-incidences of gNEP deviations and combinations of temperature and precipitation anomalies by ecoregion from 1998-2005 (n=3224). *Symbols correspond to positive temperature anomalies (+T), negative temperature anomalies (-T), positive precipitation anomalies (+P), negative precipitation anomalies (-P), missing observations (Nil) and omitted observations (--). Temperature and precipitation anomalies were determined by comparing the growing season (June to August) average of each by ecoregion every year from 1998-2005 to the 50-year average growing season temperature and precipitation for the same ecoregion. Values that exceeded the 50-year average for the ecoregion were counted as positive anomalies while values lower than the 50-year average were counted as negative anomalies. Combinations of precipitation and temperature anomalies by ecoregion were counted only because of the interaction of those terms in the baseline gNEP model (equation 2). gNEP surpluses and deficits were also counted by ecoregion; temperature and precipitation data used to calculate the anomalies were gathered only from within the boundaries of the gNEP deviations with which they coincided.*

(Table 2 – see caption above)

			Combinations of Temperature/Precipitation Anomalies					Totals
			Nil	**-T/-P**	**-T/+P**	**+T/+P**	**+T/-P**	
Direction of relative gNEP deviations (surplus or deficit)	**Negative gNEP deviation**	→ *Count*	**0**	**104**	**336**	**657**	**447**	**1544**
		→ *% of gNEP deviations*	0%	6.7%	21.8%	42.6%	29.0%	100%
		→ *% of anomalies*	0%	63.8%	58.8%	58.5%	50%	47.9%
		→ *% of total*	0%	3.2%	10.4%	20.4%	13.9%	47.9%
	No data – Neg. deviation	→ *Count*	**56**	**0**	**6**	**1**	**1**	**64**
		→ *% of gNEP deviations*	87.5%	0%	9.4%	1.6%	1.6%	100%
		→ *% of anomalies*	11.9%	0%	1.1%	0.1%	0.1%	2.0%
		→ *% of total*	1.7%	0%	0.2%	0%	0%	2.0%
	No data – Pos. Deviation	→ *Count*	**368**	**1**	**6**	**2**	**7**	**384**
		→ *% of gNEP deviations*	95.8%	0.3%	1.6%	0.5%	1.8%	100%
		→ *% of anomalies*	78%	0.6%	1.1%	0.2%	0.8%	11.9%
		→ *% of total*	11.4%	0%	0.2%	0.1%	0.2%	11.9%
	Positive gNEP Deviation	→ *Count*	**48**	**58**	**223**	**464**	**439**	**1232**
		→ *% of gNEP deviations*	3.9%	4.7%	18.1%	37.7%	35.6%	100%
		→ *% of anomalies*	10.2%	35.6%	39.1%	41.3%	49.1%	38.2%
		→ *% of total*	1.5%	1.8%	6.9%	14.4%	13.6%	38.2%
Totals		→ *Count*	**472**	**163**	**571**	**1124**	**894**	**3224**
		→ *% of gNEP deviations*	14.6%	5.1%	17.7%	34.9%	27.7%	100%
		→ *% of anomalies*	100%	100%	100%	100%	100%	100%
		→ *% of total*	14.6%	5.1%	17.7%	34.9%	37.7%	100%

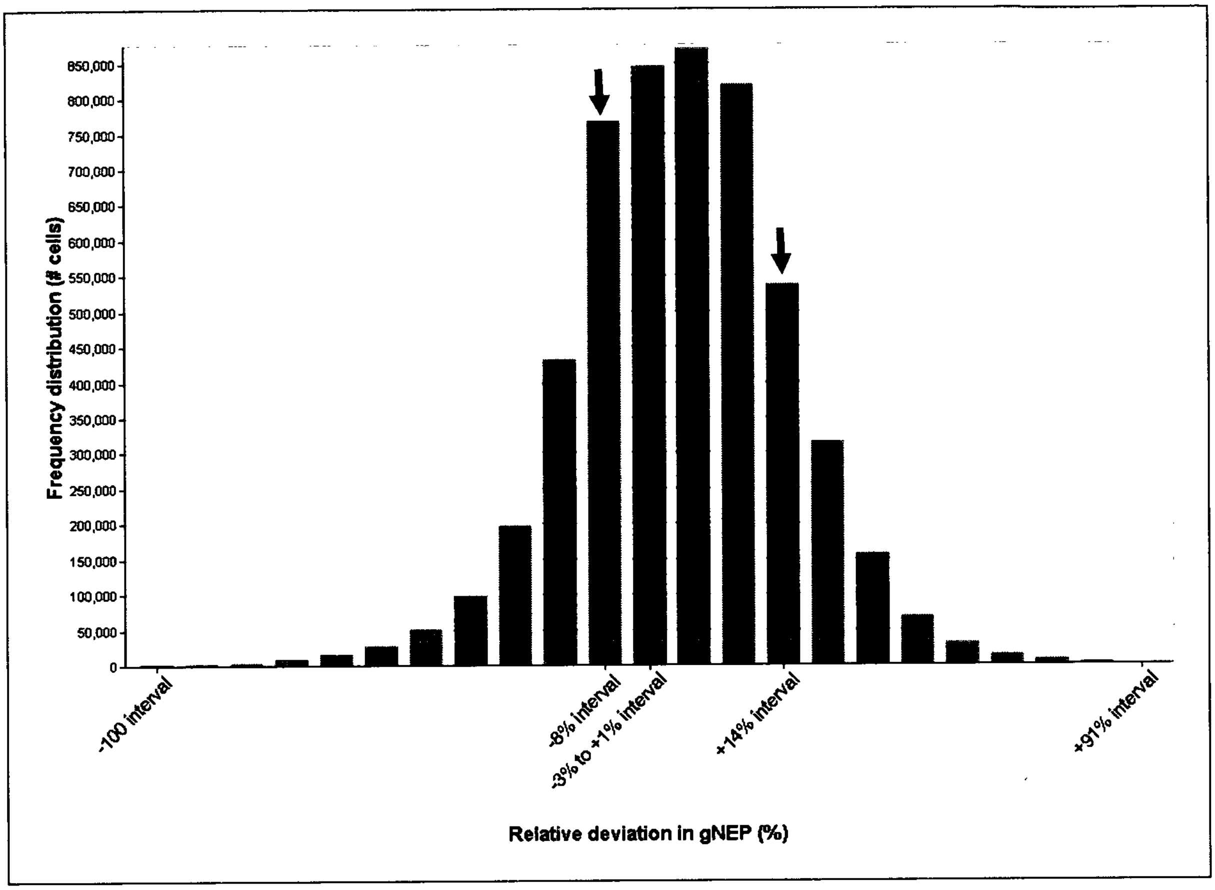

Figure 1 - Histogram of relative deviations in gNEP illustrating placement of thresholds for biologically relevant deviations (n>3,200,000). Mean relative deviations for the 8-year period 1998 to 2005 are shown (corresponding to map in Figure 5b), ranging from -100% to 91% in magnitude. Arrows indicate histogram bars containing threshold values for biologically relevant gNEP deficits (-8%) and surpluses (14%).

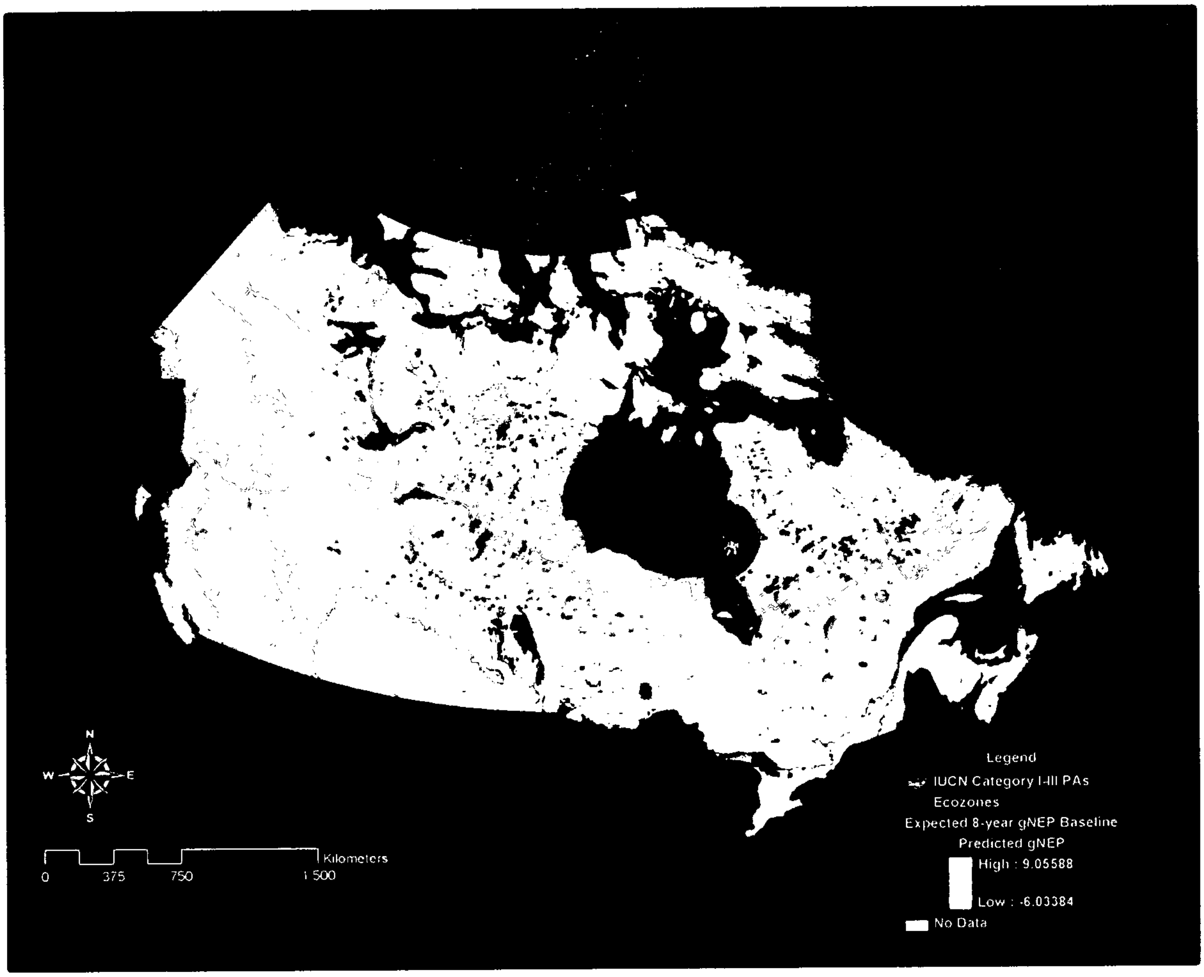

Figure 2a - Average expected (predicted) 8-year gNEP for the period 1998-2005 generated using Equation 3. gNEP values are unitless. High and low gNEP values are shown at 1 km^2 resolution for all areas excluding the Prairies ecozone and regions of Canada's far north archipelago beyond the orbital path of the SPOT-VGT satellite. The map colour palette is stretched based on n=2 standard deviations around the Canada-wide mean expected gNEP (mean expected gNEP = 5.30) for easier interpretation.

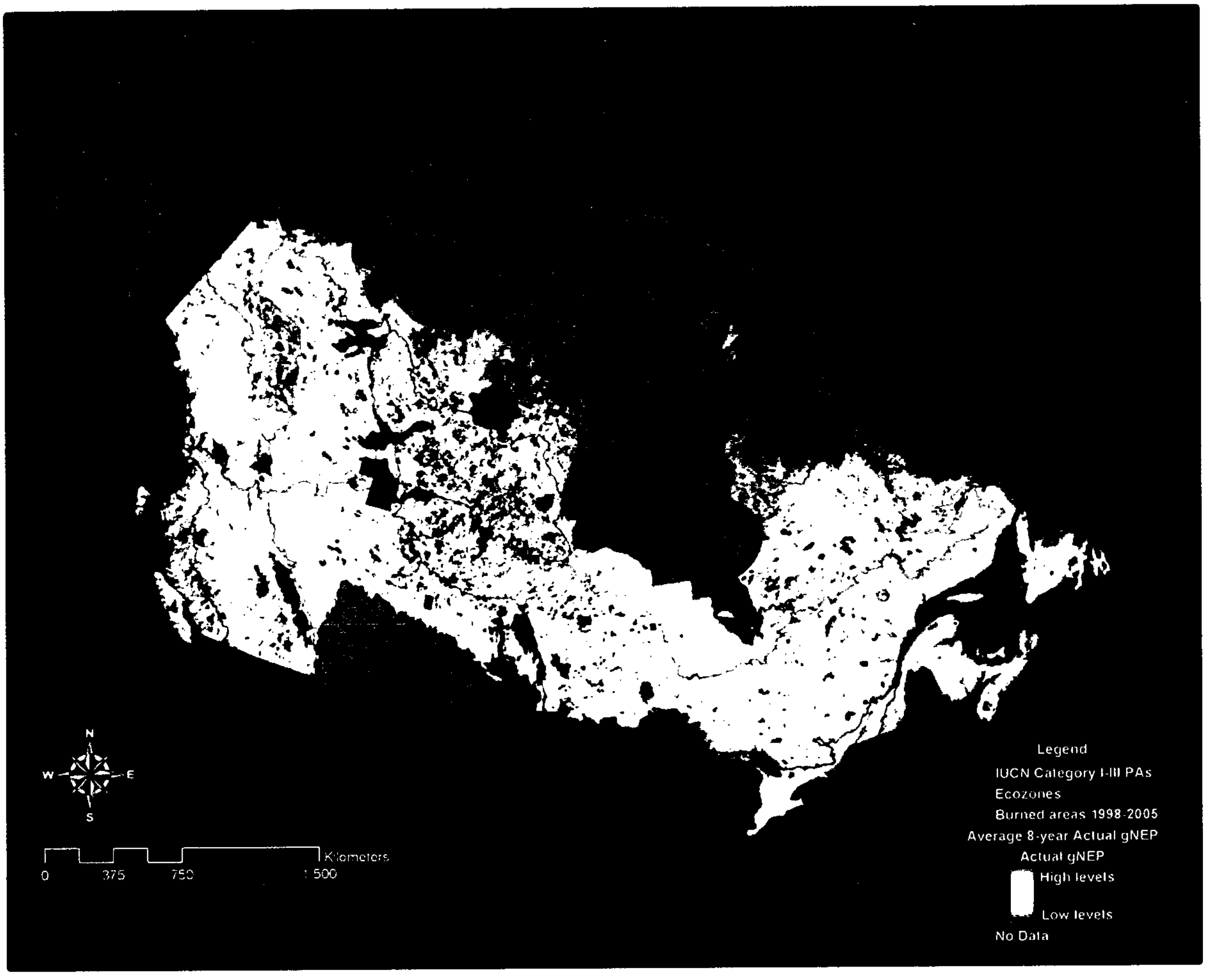

Figure 2b - Average actual (observed) 8-year gNEP for the period 1998-2005 based on SPOT-VGT satellite data. Derived by averaging integrated 10-day growing season NDVI composites (June to August) for the same 8-year period. gNEP values are unitless. High and low gNEP values are shown at 1 km^2 resolution for all areas excluding the Prairies ecozone, non-vegetated land surfaces (>1 km^2) and regions of Canada's far north archipelago beyond the orbital path of the SPOT-VGT satellite. The map colour palette is stretched based on n=2 standard deviations around the Canada-wide mean actual gNEP (mean actual gNEP = 5.13) for easier interpretation.

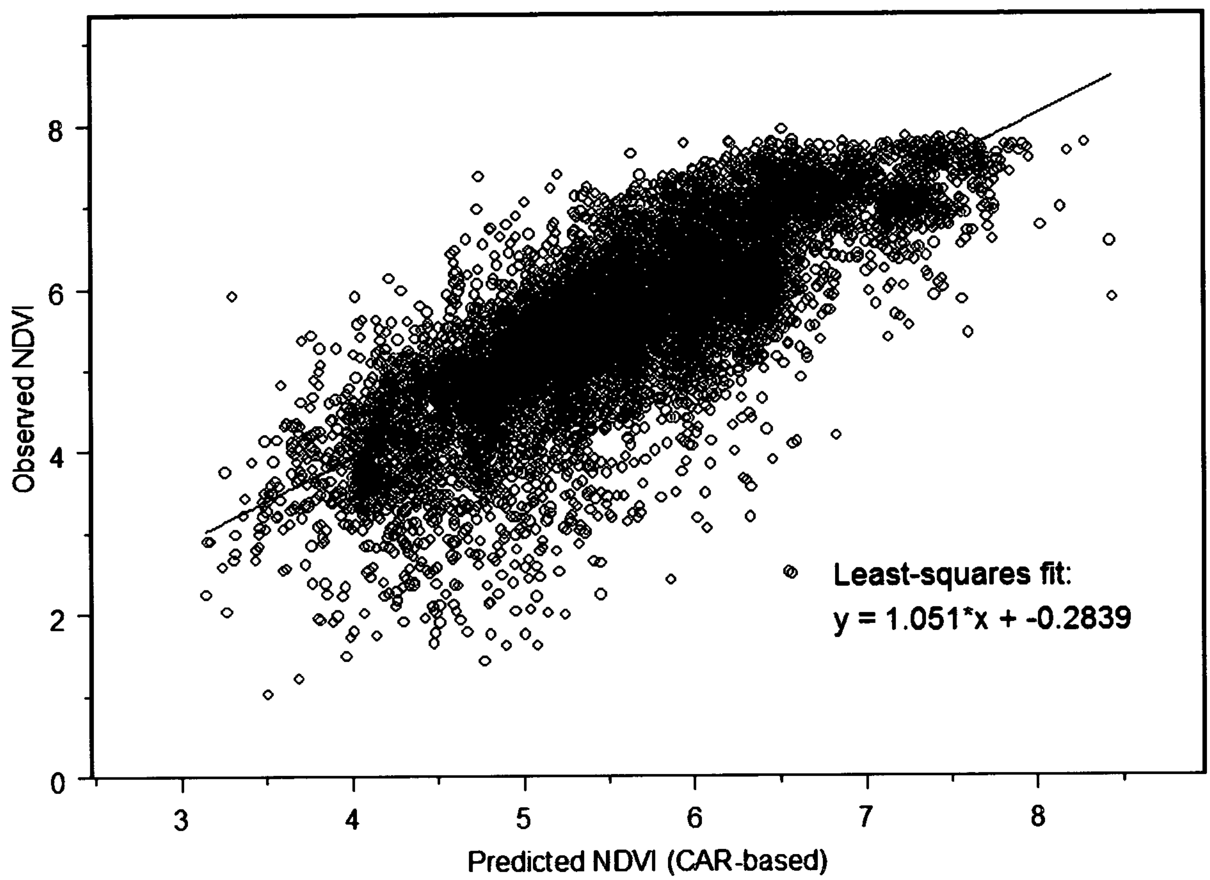

Figure 3a - Fit of conditional autoregression-based predicted gNEP versus observed gNEP values within IUCN category I-III protected areas across Canada (n>10,000). Mean gNEP values for the 8-year period 1998 to 2005 are shown for both observed and predicted gNEP (unitless). Each value represents the gNEP of a 1 km^2 grid cell within a protected area from the training dataset. Predicted values were generated using equation 2 after the effects of positive spatial autocorrelation were removed from the model through an iterative conditional autoregressive process (see methods). A least squares-based smoothing line is shown for reference.

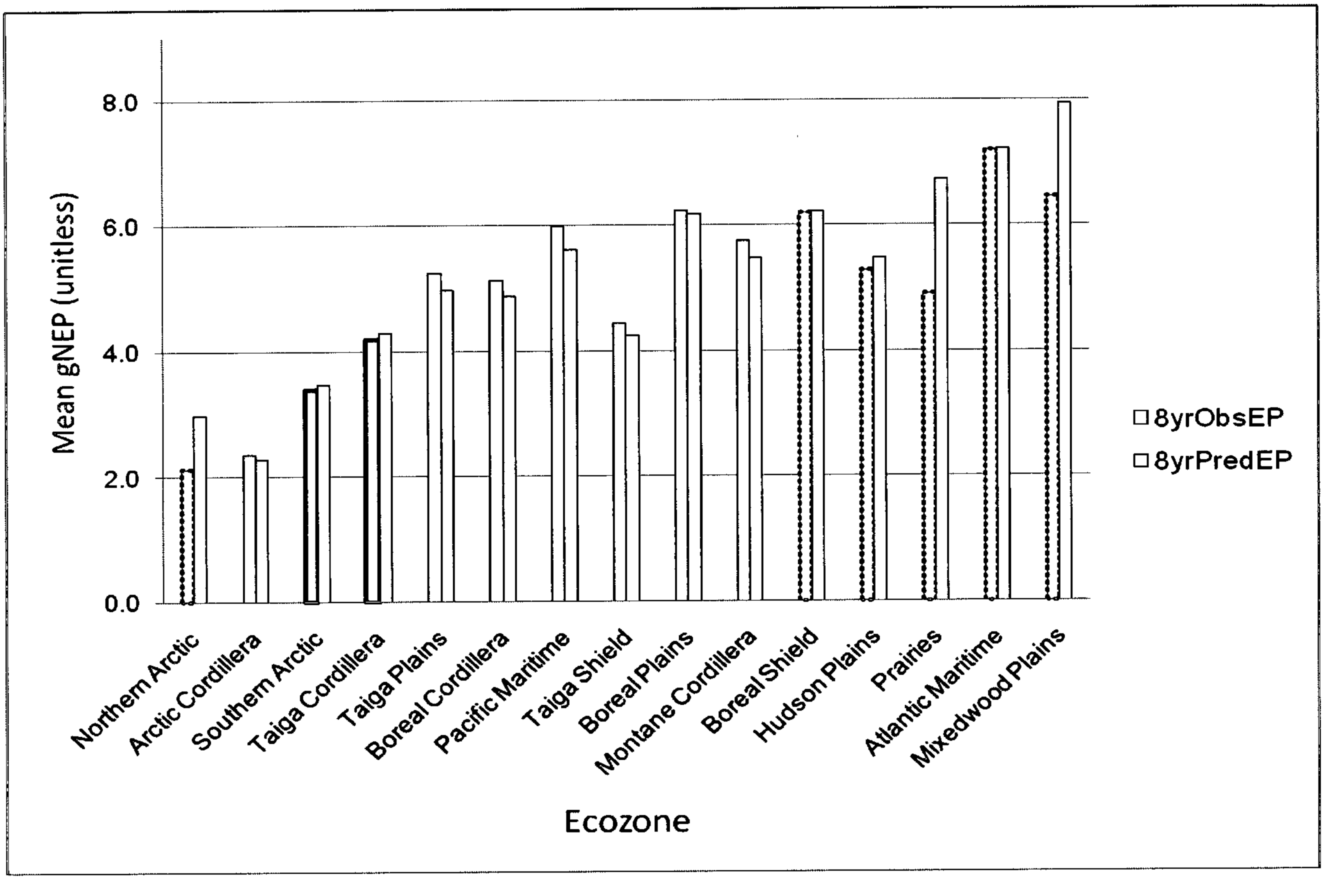

Figure 3b - Comparison of mean observed and predicted gNEP by ecozone across Canada, 1998-2005 (n>3,200,000). Predicted gNEP (green) was generated at 1 km2 resolution on a Canada-wide scale using equation 2 and was subsequently averaged across 15 ecozones for presentation here. gNEP values are unitless. Mean observed gNEP values shown in red with dashed borders represent ecozones experiencing gNEP deficits; ecozones with mean observed values shown in grey are experiencing gNEP surpluses. Predicted and observed gNEP values are based upon treed lands only for northern ecozones. Values for the Prairies ecozone are shown for reference only and were excluded from the analysis.

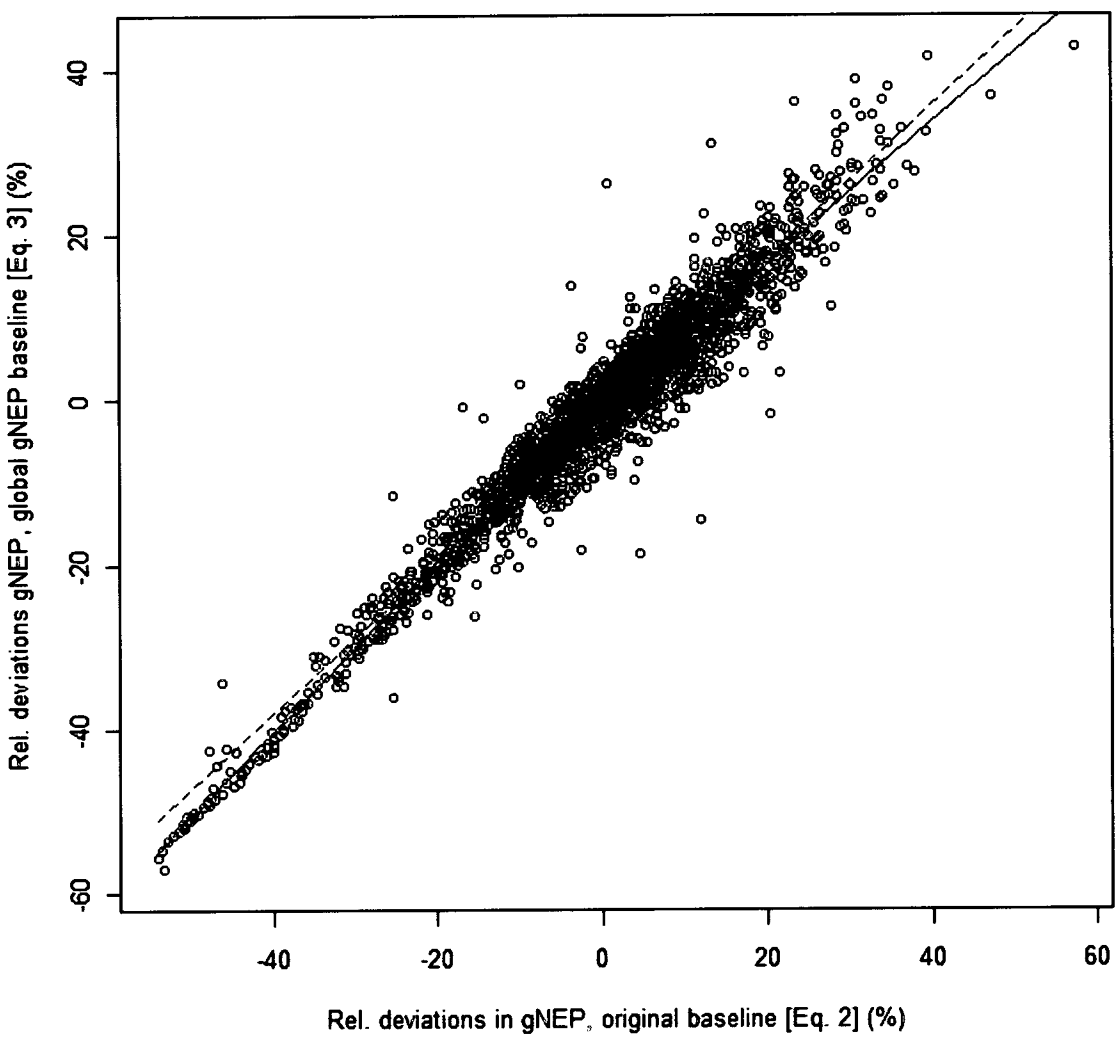

Figure 4 – Fit of relative deviations in gNEP at random points derived based upon i) the original baseline gNEP model (equation 3) and ii) the 'global' baseline gNEP model (equation 4) (n=2500). Sampling locations were randomly distributed across Canada and sampled after calculated the relative difference between observed gNEP and the expected gNEP calculated with equations 3 & 4, respectively (Spearman's $\rho=0.952$, no hypothesis tested). A least squares-based smoothing line is shown for reference.

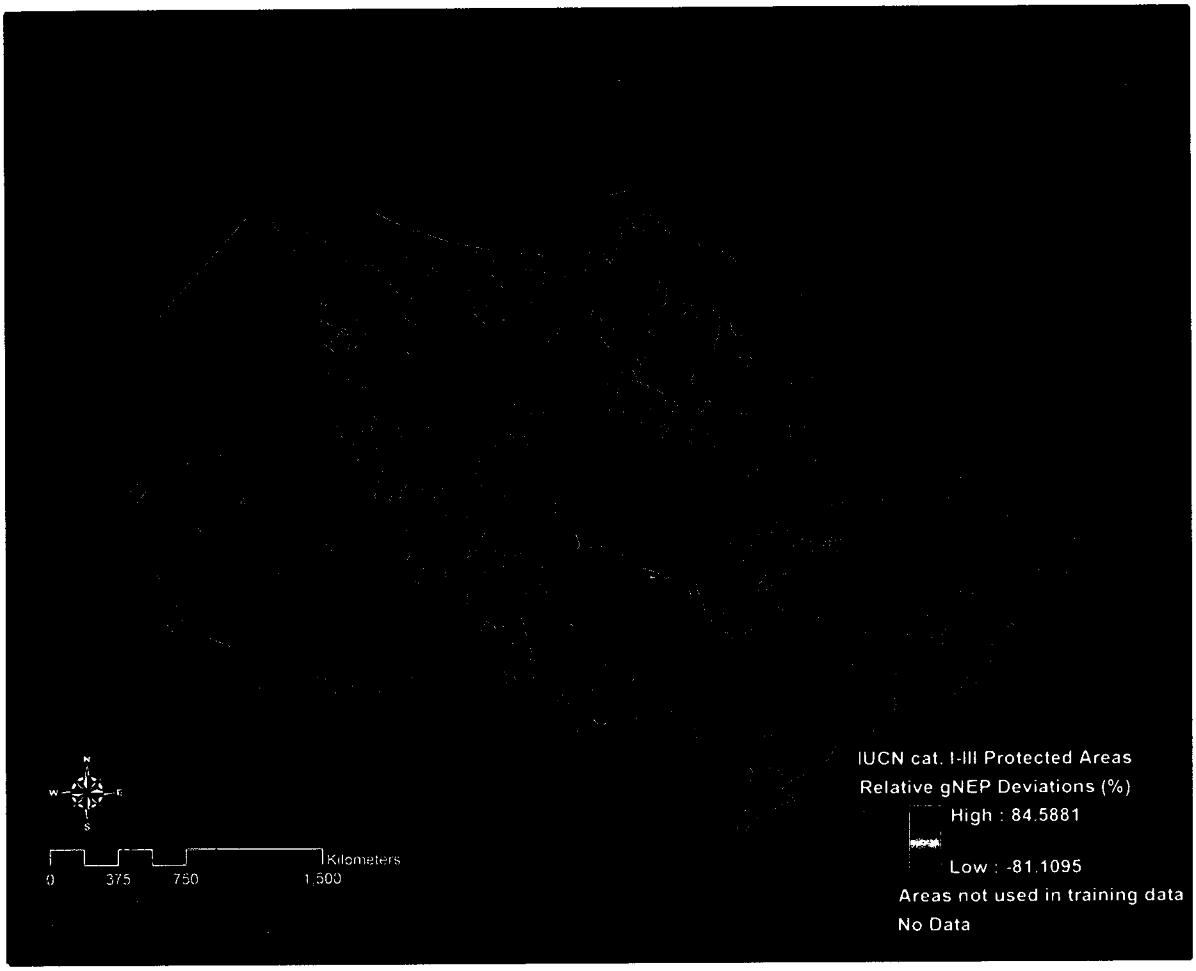

Figure 5a – gNEP deviations within IUCN category I-III protected areas based on the difference between observed gNEP and conditional autoregression-based predicted gNEP in protected areas, 1998-2005. Relative deviations are shown as percentages relative to expected gNEP. Positive and negative gNEP deviations are shown at 1 km^2 resolution within all strictly protected areas. Canada's far north archipelago falls beyond the orbital path of the SPOT-VGT satellite and is therefore excluded. The map colour palette is stretched based on n=2 standard deviations around the mean relative deviation for ease of interpretation. Dark grey areas behind gNEP deviations represent portions of IUCN cat. I-III protected areas that were excluded from the analysis because of land cover type.

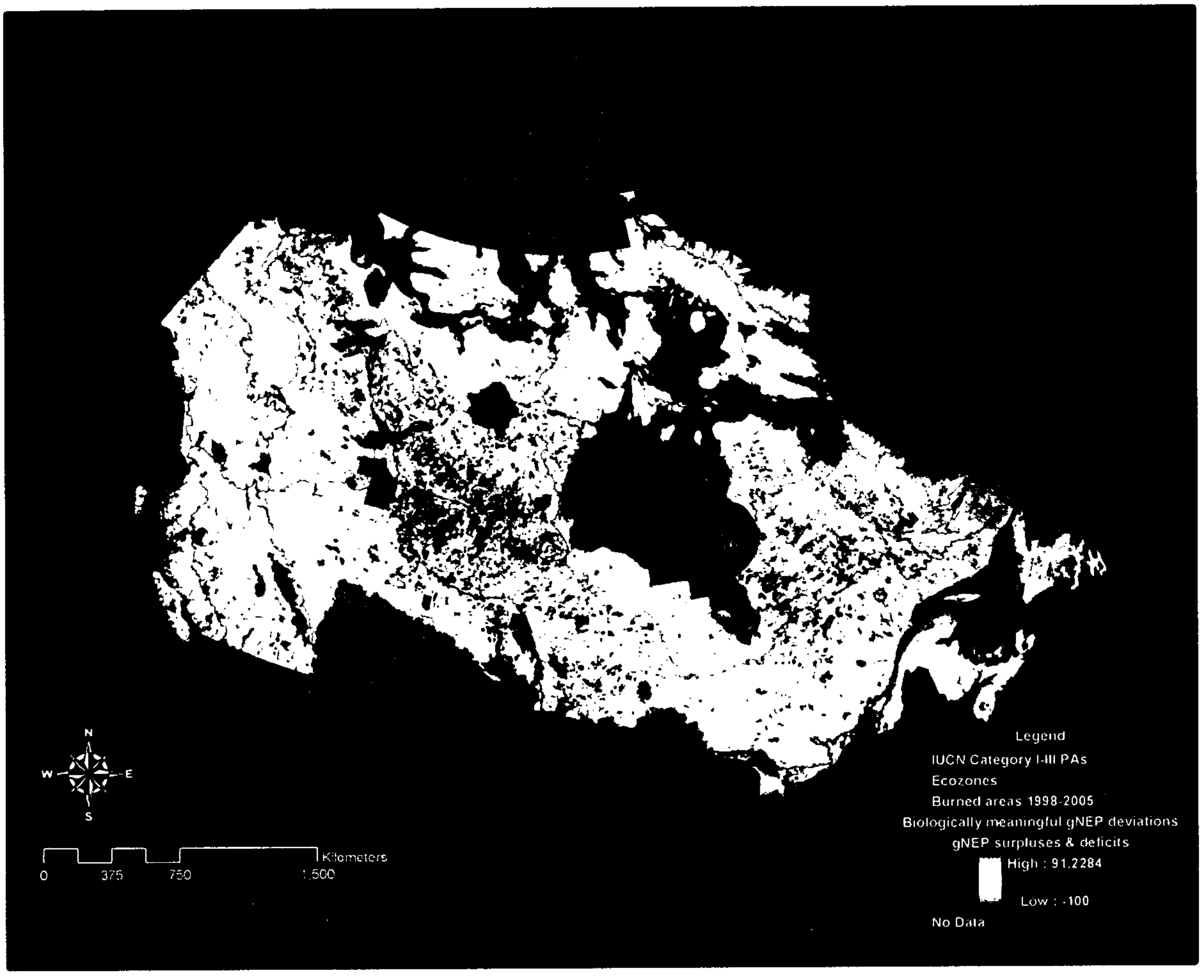

Figure 5b - Canada-wide biologically relevant 8-year average relative gNEP deviations (positive and negative), 1998-2005. Relative deviations are shown as percentages relative to expected gNEP. Thresholds for biologically relevant positive and negative gNEP deviations are set at approximately 1.0 and 0.5 the standard deviation around the mean of the residuals of equation 4, translating to relative differences of 14.0% and -8.0%, respectively (mean rel. dev. gNEP = -0.06). gNEP deviations that fall below the biologically relevant thresholds are shown in yellow. gNEP deviations are shown at 1 km^2 resolution for all areas excluding the Prairies ecozone and regions of Canada's far north archipelago beyond the orbital path of the SPOT-VGT satellite. The map colour palette is stretched based on n=2 standard deviations around the mean relative deviation for ease of interpretation.

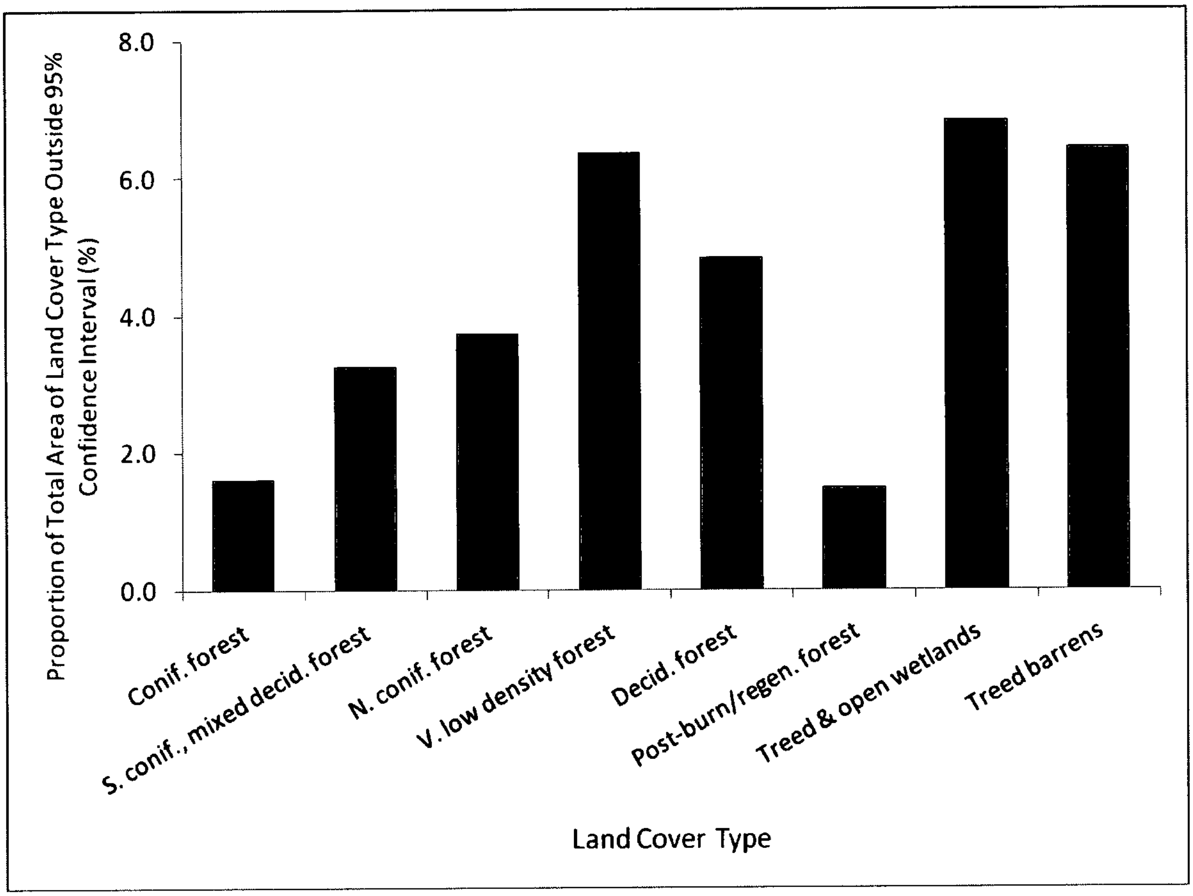

Figure 5c – Proportional area of each land cover class used in expected gNEP model training areas falling outside approximate 95% confidence interval (n>9,000). The area falling outside the approximate 95% confidence interval was determined based on figure 5a. The SPOT-VGT satellite-based land cover type was extracted for each grid cell falling beyond the confidence interval and the total area of grid cells representing each cover types was summarized as shown above. The approximate 95% confidence interval for gNEP deviations within strictly protected areas was calculated based on $2 \cdot SD \pm$ mean gNEP deviation. Areas sampled within strictly protected areas to train the expected gNEP model were limited to the land cover types listed on the x-axis. The proportional area of each land cover type was calculated using the total area of that land cover type across all strictly protected areas.

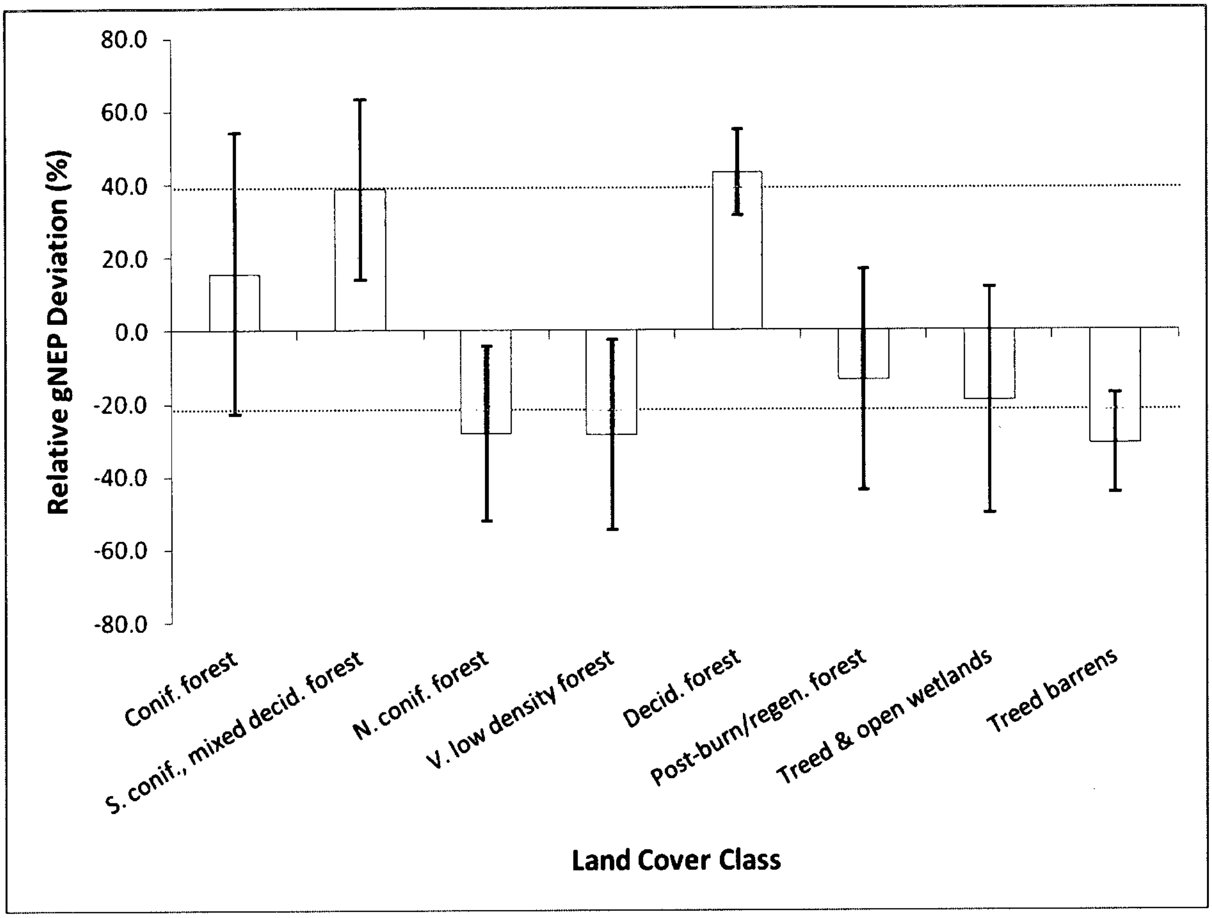

Figure 5d – Average relative gNEP deviations associated with each land cover type found in expected gNEP model training areas (n>192,000). gNEP deviations shown in figure 5a were summarized based upon the SPOT-VGT satellite-based land cover types found in strictly protected areas. Average gNEP deviations were summarized for each land cover type as shown above. Error bars represent the standard deviation for gNEP deviations associated with each land cover type. Mean gNEP deviations falling beyond the -21.4% and +39.2% thresholds, shown as dashed red lines, are outside the approximate 95% confidence interval.

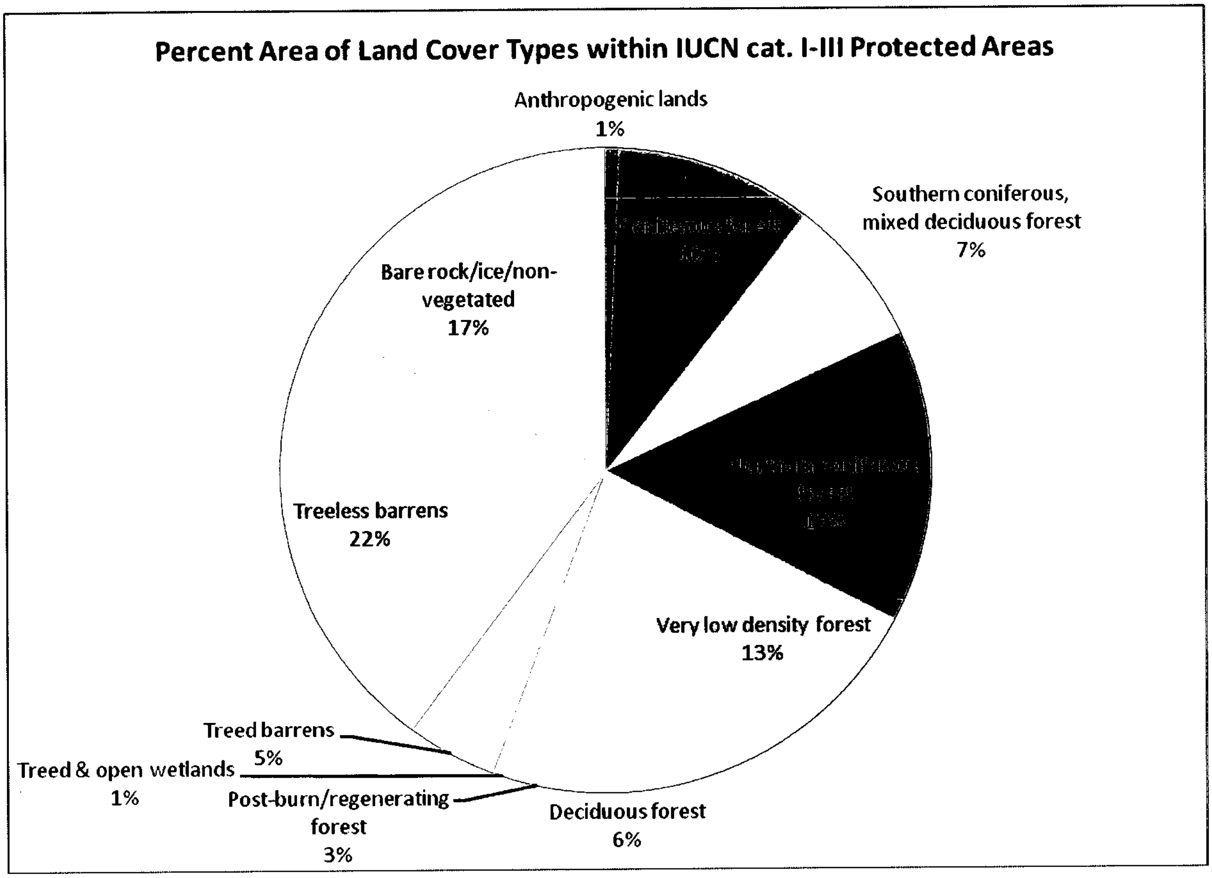

Figure 5e – Proportional area of all SPOT-VGT land cover types within IUCN category I-III protected areas (n>192,000). The total area of each SPOT-VGT land cover type was calculated within the boundaries of Canada's strictly protected area and summarized as shown above. "Anthropogenic lands" refers to all agricultural and urban lands categorized by Cihlar et al. 2001 and Kerr & Cihlar 2003.

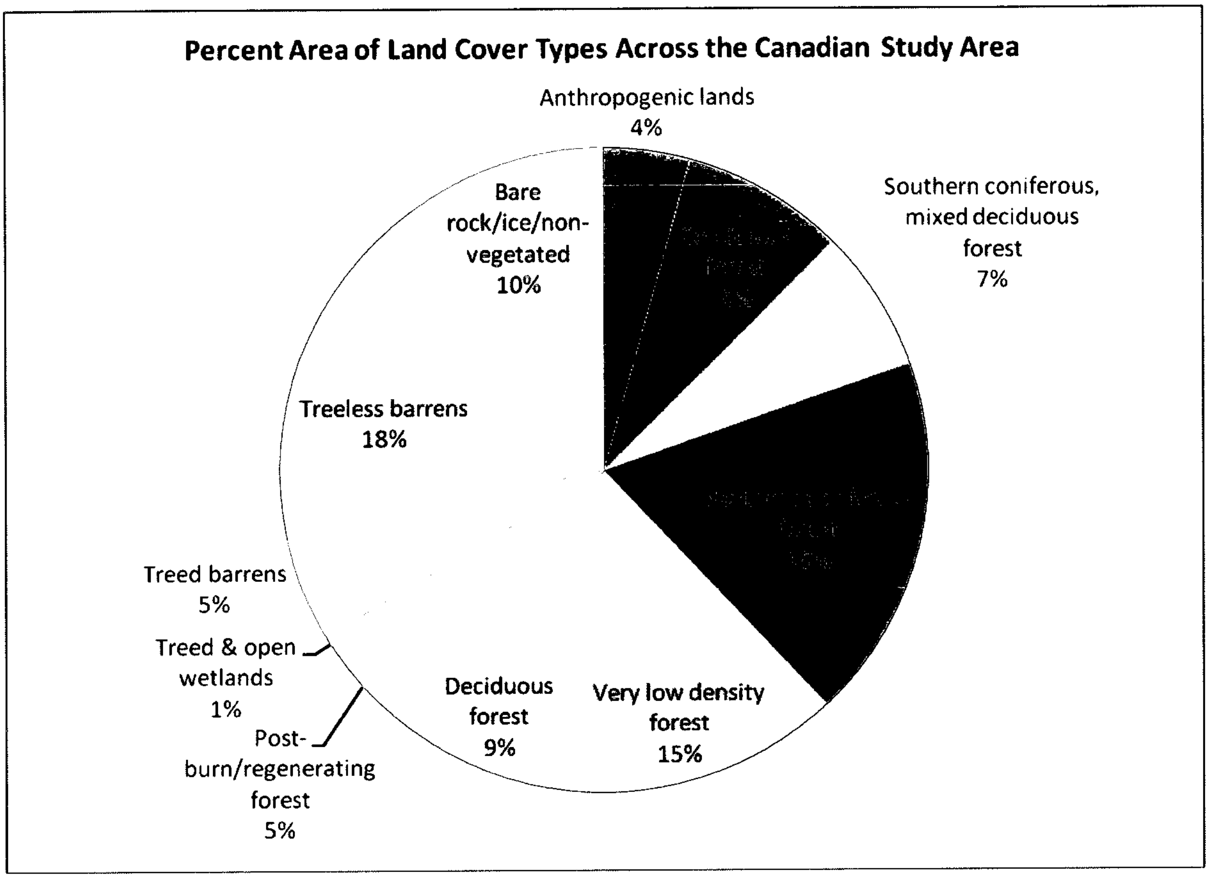

Figure 5f – Proportional area of all SPOT-VGT land cover type across the Canadian study area. The total area of each SPOT-VGT land cover type was calculated across the Canadian study area and summarized as shown above. "Anthropogenic lands" refers to all agricultural and urban lands categorized by Cihlar et al. 2001 and Kerr & Cihlar 2003.

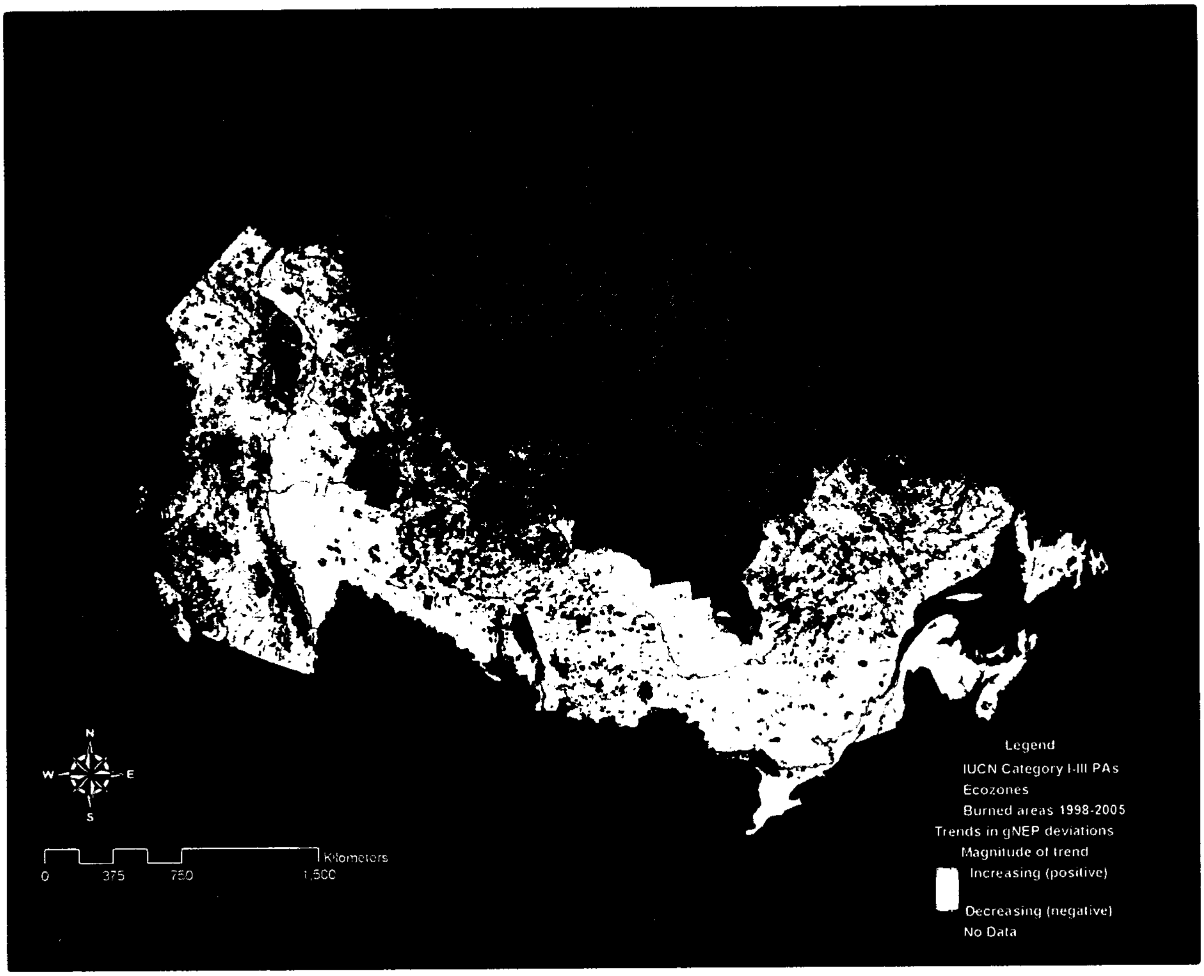

Figure 6a - Canada-wide increasing and decreasing trends in gNEP surpluses and deficits between 1998-2005. Trends were calculated as the average difference between annual relative deviations in gNEP over the 8-year study period. Trends are reported as percentage change per year. Trends vary from a maximum rate of increase of 13.0%·yr^{-1} to a maximum decreasing rate of -13.0%·yr^{-1}, with a mean trend of 0.30%·yr^{-1}. Trends in gNEP surpluses and deficits are shown at 1 km^2 resolution for all areas except the Prairies ecozone and regions of Canada's far north archipelago beyond the orbital path of the SPOT-VGT satellite. The map colour palette is stretched based on n=2 standard deviations around the mean relative deviation for ease of interpretation.

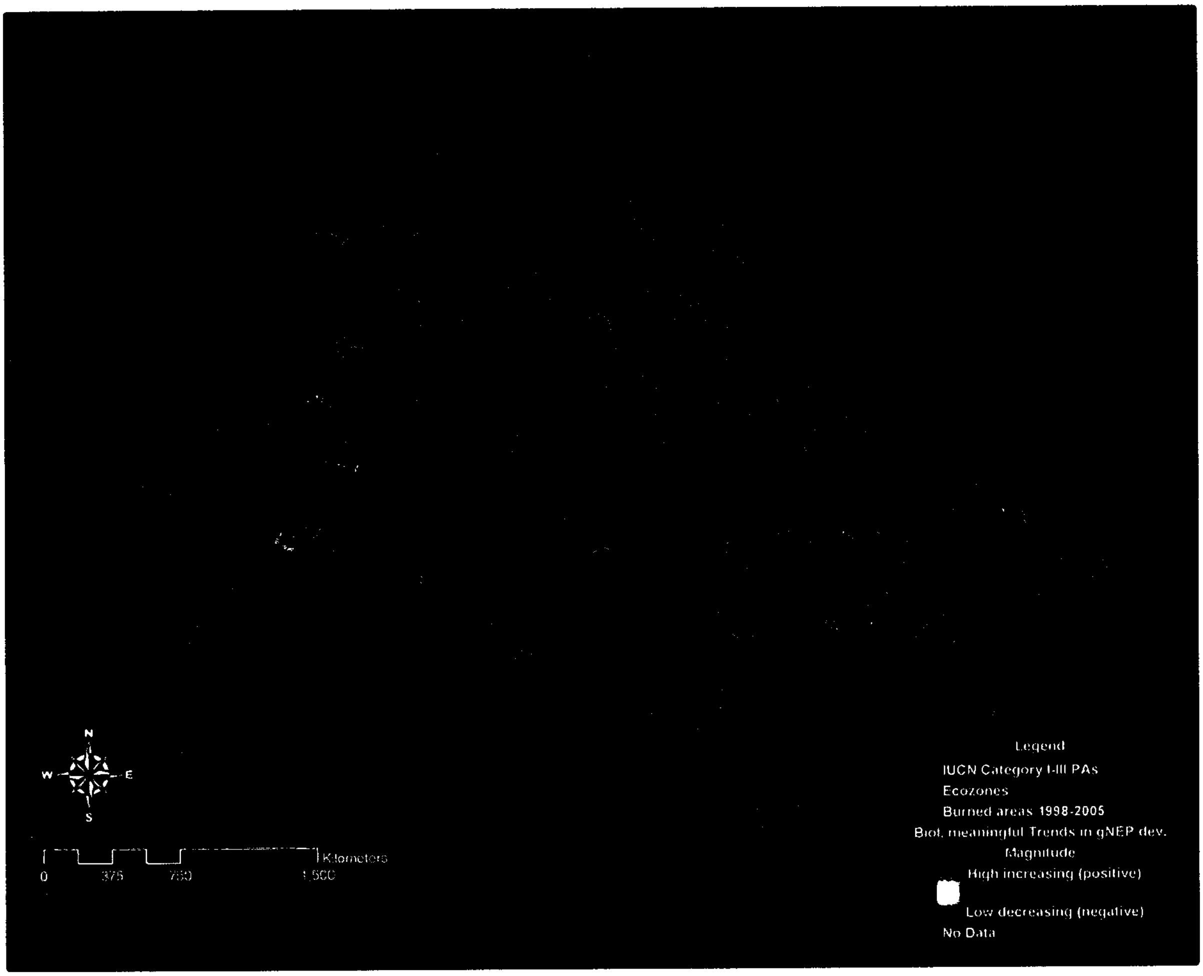

Figure 6b - Canada-wide biologically relevant trends in gNEP surpluses and deficits. See figure 6a for details on the derivation of trends. Thresholds for biologically relevant trends were set at mean ± one standard deviation for trends in gNEP surpluses and gNEP deficits, respectively. These were $0.21\%\cdot yr^{-1} \pm 1.21$ for surpluses and $0.34\%\cdot yr^{-1} \pm 1.26$ for deficits. Trends falling below the threshold values are shown as "No Data". Trends in gNEP surpluses and deficits are shown at 1 km^2 resolution for all areas except the Prairies ecozone and regions of Canada's far north archipelago beyond the orbital path of the SPOT-VGT satellite. The map colour palette is stretched based on n=2 standard deviations around the mean relative deviation for ease of interpretation.

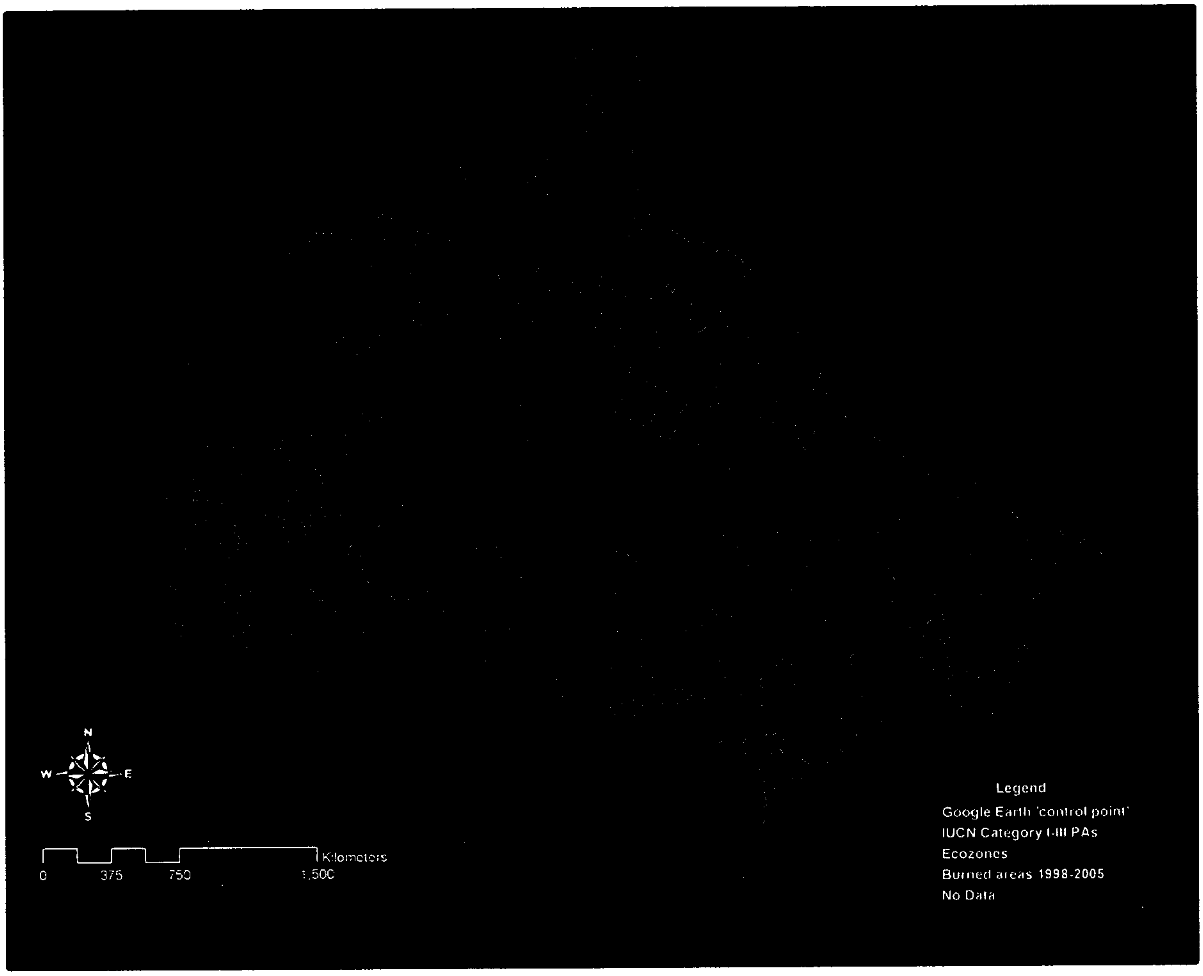

Figure 7 - Google Earth-derived high resolution control points (n=1044). Google Earth place-markers were imported into ArcMap software (ESRI, Redlands, CA) and converted from KML to SHP format using a Python script developed by Parent et al. (2008). Points are geo-referenced at the sub-pixel level (< 1 km^2) and are displayed at the visible scale for ease of interpretation. All points are described according to i) direct observation of the high-resolution satellite imagery in Google Earth; ii) SPOT-VGT derived land cover (Kerr & Cihlar 2003; Cihlar et al. 2001); and, iii) manual land-use categorization (n=10) based on Google Earth observations.

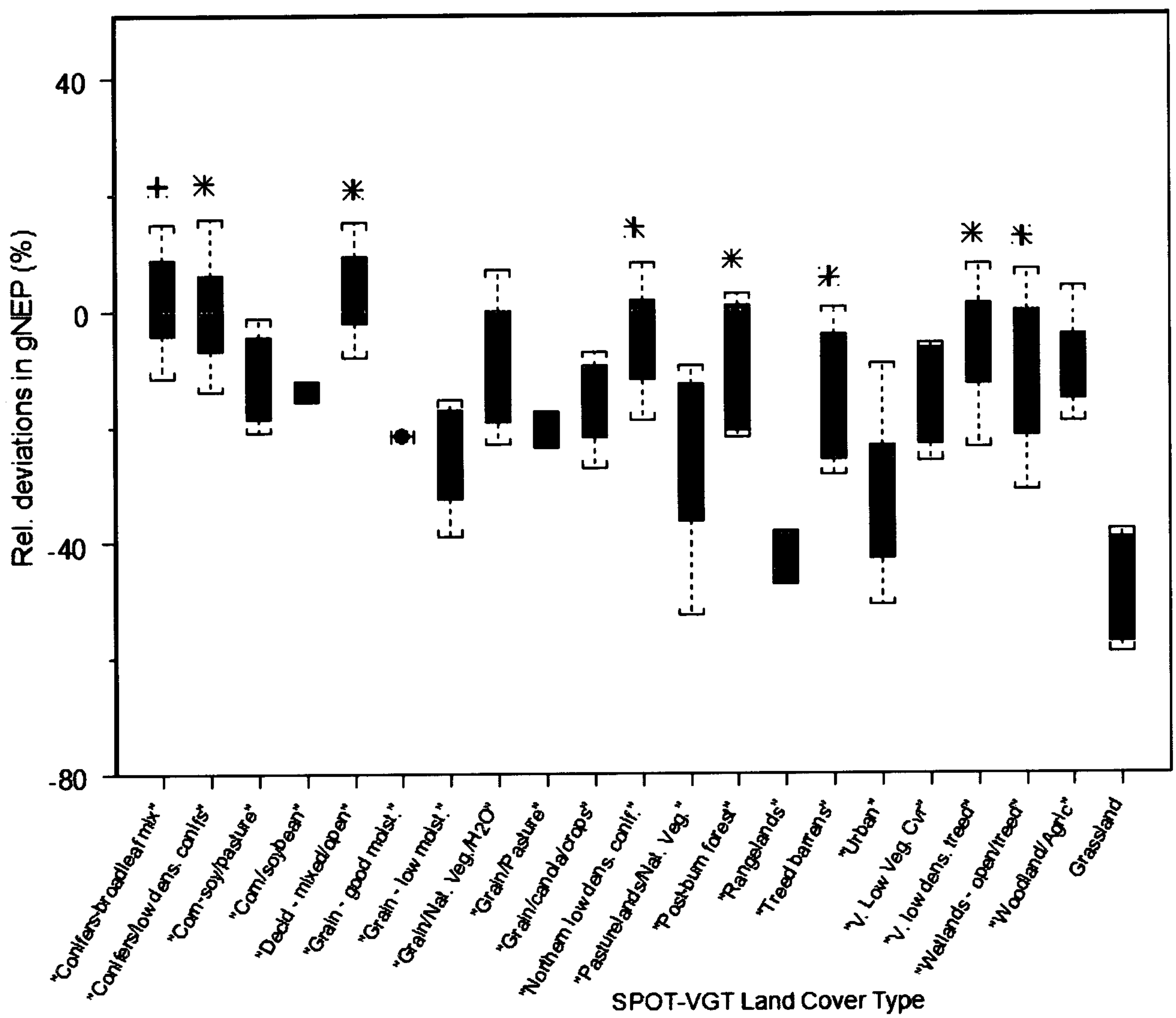

Figure 8a.1 – Comparison of relative gNEP deviations between SPOT VGT-based land cover classes at Google Earth control points (n=1016). Land cover information (based on Cihlar et al. 2001 and Kerr & Cihlar 2003) and relative gNEP deviation information was extracted (without spatial interpolation) at each control point. Relative gNEP deviations for 'natural' land cover types are highlighted with asterices, unlike the 'anthropogenic' land cover types. Whiskers delimit the 10th and 90th percentiles of gNEP deviation values for each land cover type. Dark blue circles show the median gNEP deviation value for each land cover type and the tops and bottoms of the cyan boxes delimit the 25th and 75th percentiles within each distribution, respectively. A reference line is shown in grey at y=0. The "post-burn forests" land cover type is included in the figure but was excluded from the analysis since this land cover type was filtered out because of its association with forest fires (see methods).

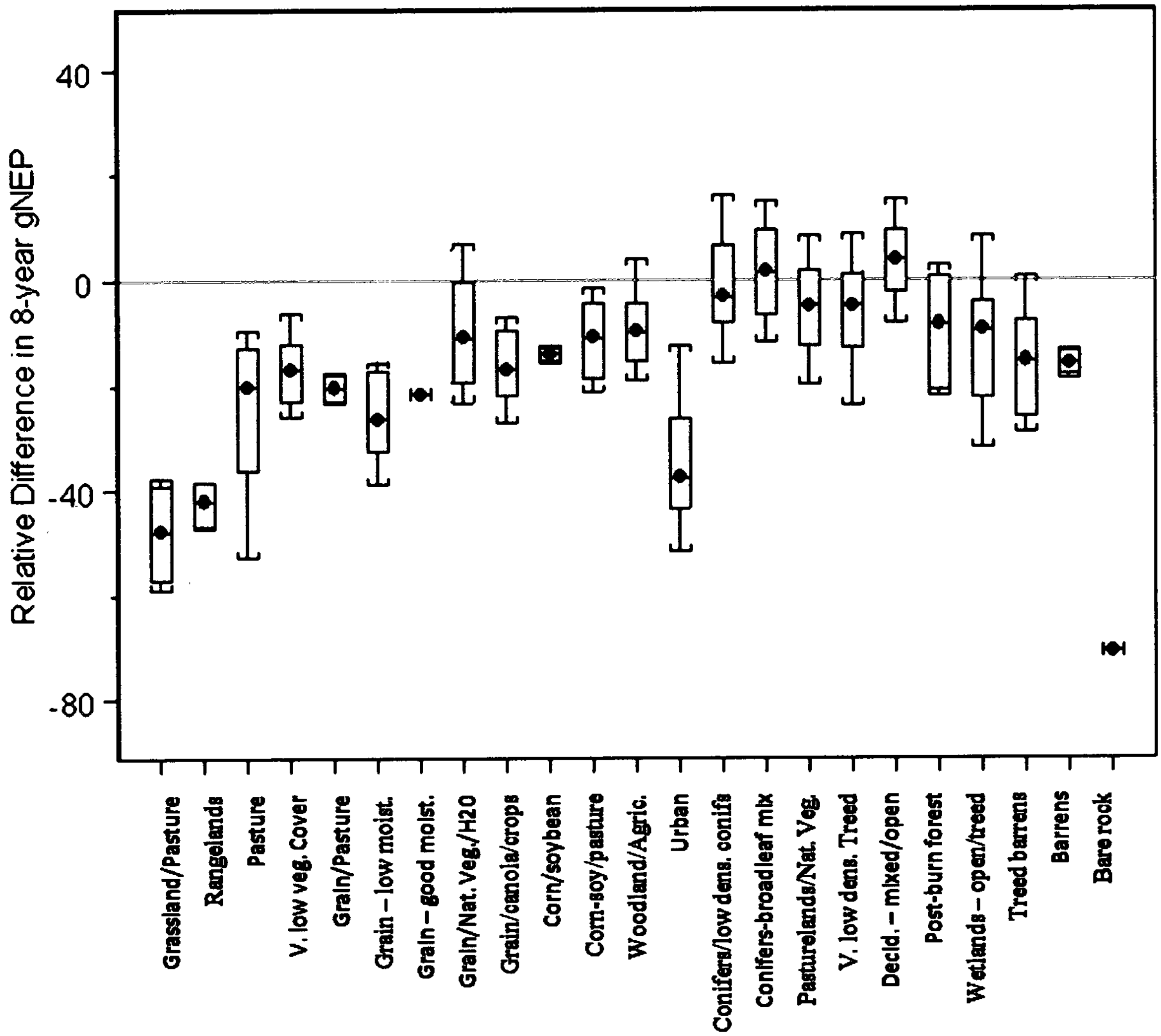

Figure 8a.2 – Comparison of relative gNEP deviations between SPOT VGT-based land cover classes for the study area (n>5,000,000). Relative gNEP deviation data was extracted individually by each land cover class (based on Cihlar et al. 2001 and Kerr & Cihlar 2003). Relative gNEP deviations for 'natural' land cover types are highlighted with asterices, unlike the 'anthropogenic' land cover types. Whiskers delimit the 10th and 90th percentiles of gNEP deviation values for each land cover type. Red circles show the median gNEP deviation value for each land cover type and the tops and bottoms of the cyan boxes delimit the 25th and 75th percentiles within each distribution, respectively. A reference line is shown in grey at y=0. The "post-burn forest" and "bare rock" land cover types are included in the figure but were excluded from the analysis since this land cover type was filtered out because of its association with forest fires (see methods).

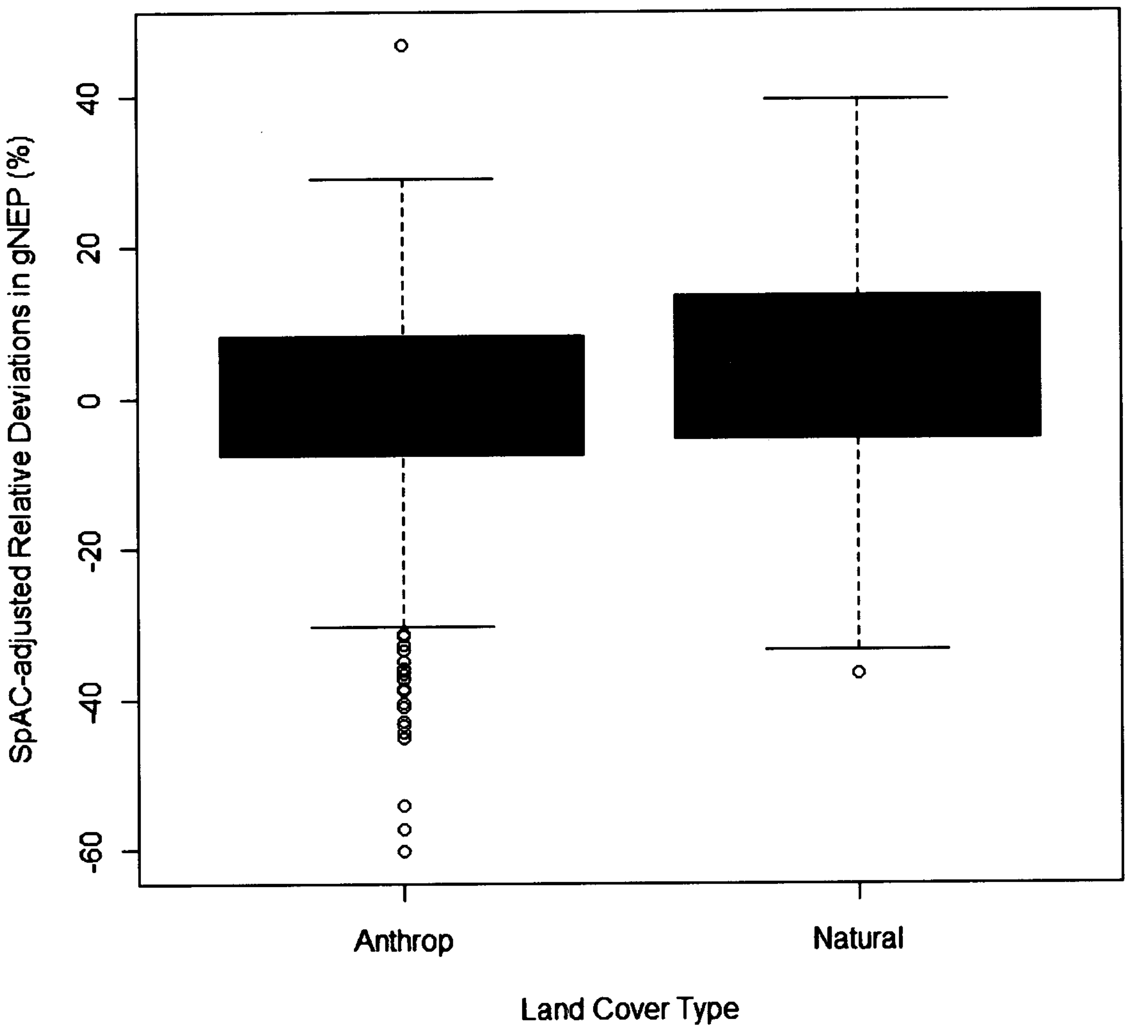

Figure 8b – Comparison of relative gNEP deviations at Google Earth control points for "natural" and "anthropogenic" land cover types (n=867). Relative gNEP deviations plotted here have been adjusted for positive autocorrelation using a spatially lagged pure autoregressive model (Rangel et al. 2006) and are in fact the residuals of that model. Median values are shown by the solid black line transecting each box. The top and bottom of each box delimits 1.5 times the interquartile range (Q3 – Q1) around the median value for each land cover type. Whiskers delimit th 10th and 90th percentiles; individual outliers are shown beyond whiskers. A total of 183 control points were removed as "unknown" land cover types prior to analysis.

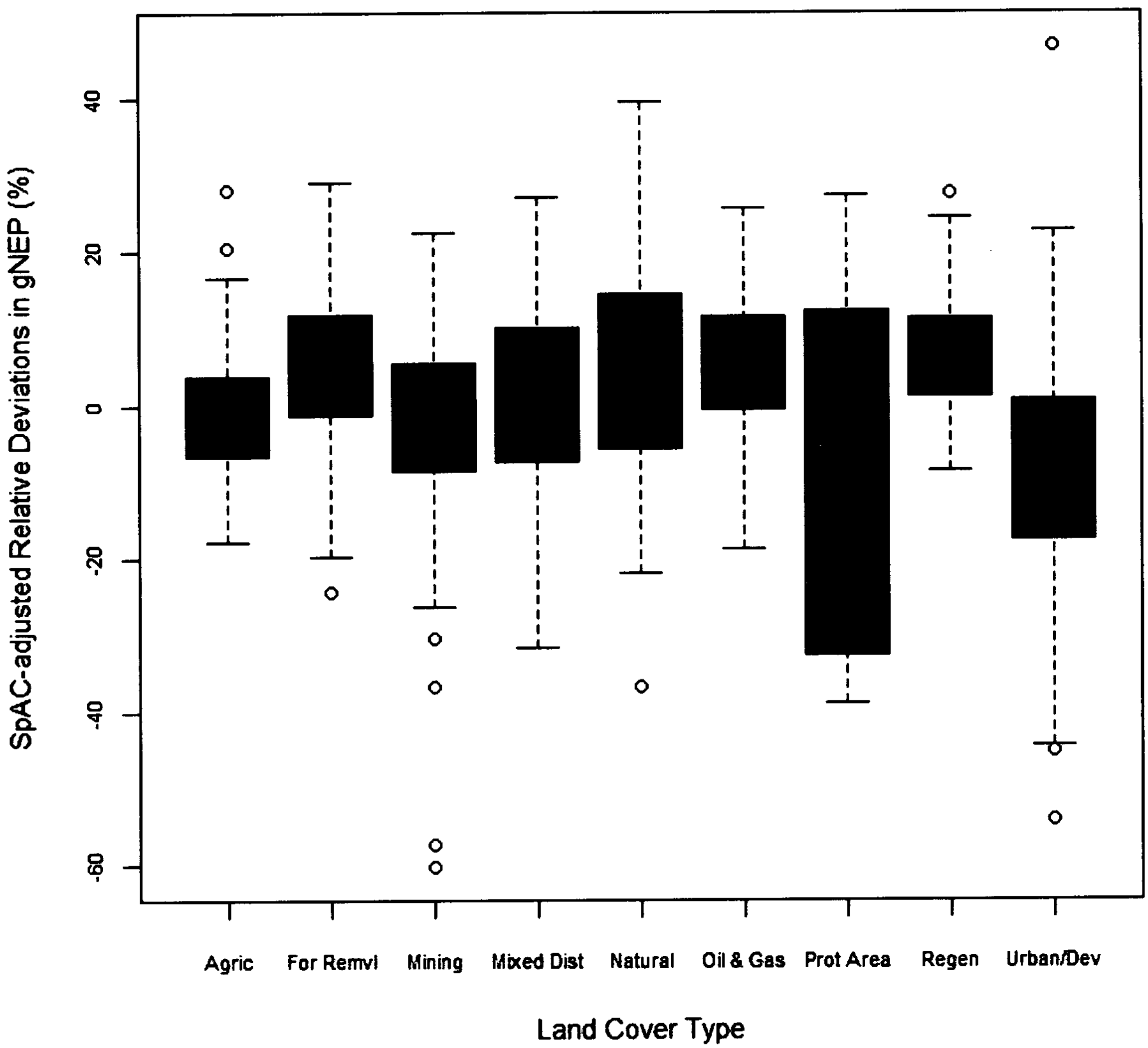

Figure 8c – Comparison of relative gNEP deviations at Google Earth control points for a 10-category land cover classification (n=867). Category abbreviations are: "Agric"=agriculture; "For Remvl"=forest removal; "Mining"=mining & mining infrastructure; "Mixed Dist"=mixed disturbance; "Natural"=natural; "Oil & Gas"=oil and gas exploration; "Prot Area"=protected area; "Regen"=regenerating forest; and, "Urban/Dev"=urban/settlement /developed. "Unknown" land cover types were excluded from the analysis (n=183). Relative gNEP deviations plotted here have been adjusted for positive spatial autocorrelation, or "SpAC", using a spatially lagged pure autoregressive model (Rangel et al. 2006) and are in fact the residuals of that model. Median values are shown by the solid black line transecting each box. The top and bottom of each box delimits 1.5 times the interquartile range (Q3 – Q1) around the median value for each land cover type. Whiskers delimit the 10th and 90th percentiles; individual outliers are shown beyond whiskers.

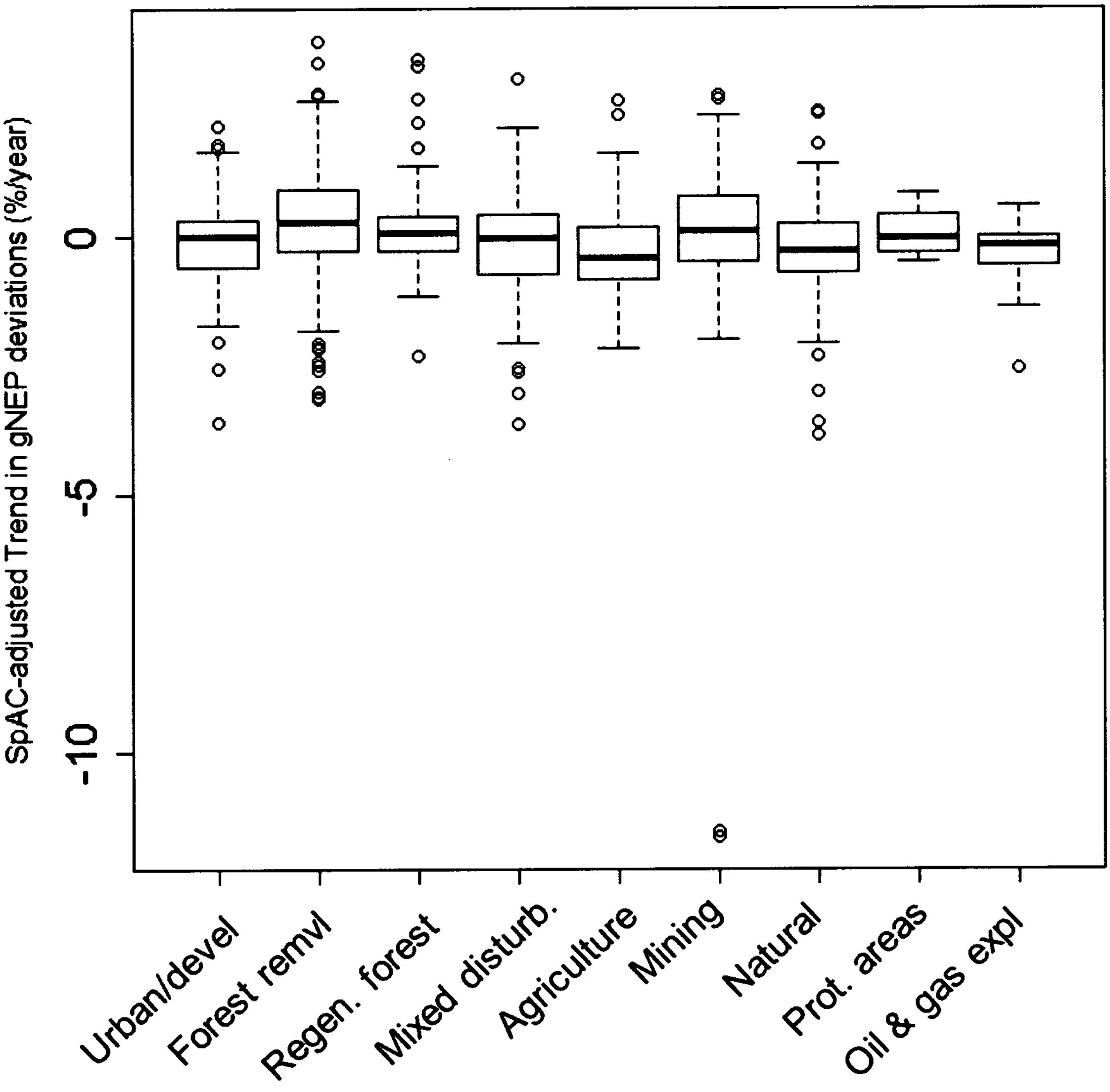

Figure 8d – Comparison of trends in relative gNEP deviations at Google Earth control points for a 10-category land cover classification (n=867). Land cover categories (x-axis) match those listed in figure 8c but have been re-orderd. "Unknown" land cover types were excluded from the analysis (n=183). Trends in relative gNEP deviations plotted here have been adjusted to control for the effects of positive spatial autocorrelation, or "SpAC", using a spatially lagged pure autoregressive model (Rangel et al. 2006). Median values are shown by the solid black line transecting each box. The top and bottom of each box delimits 1.5 times the interquartile range (Q3 – Q1) around the median value for each land cover type. Whiskers delimit the 10th and 90th percentiles; individual outliers are shown beyond whiskers.

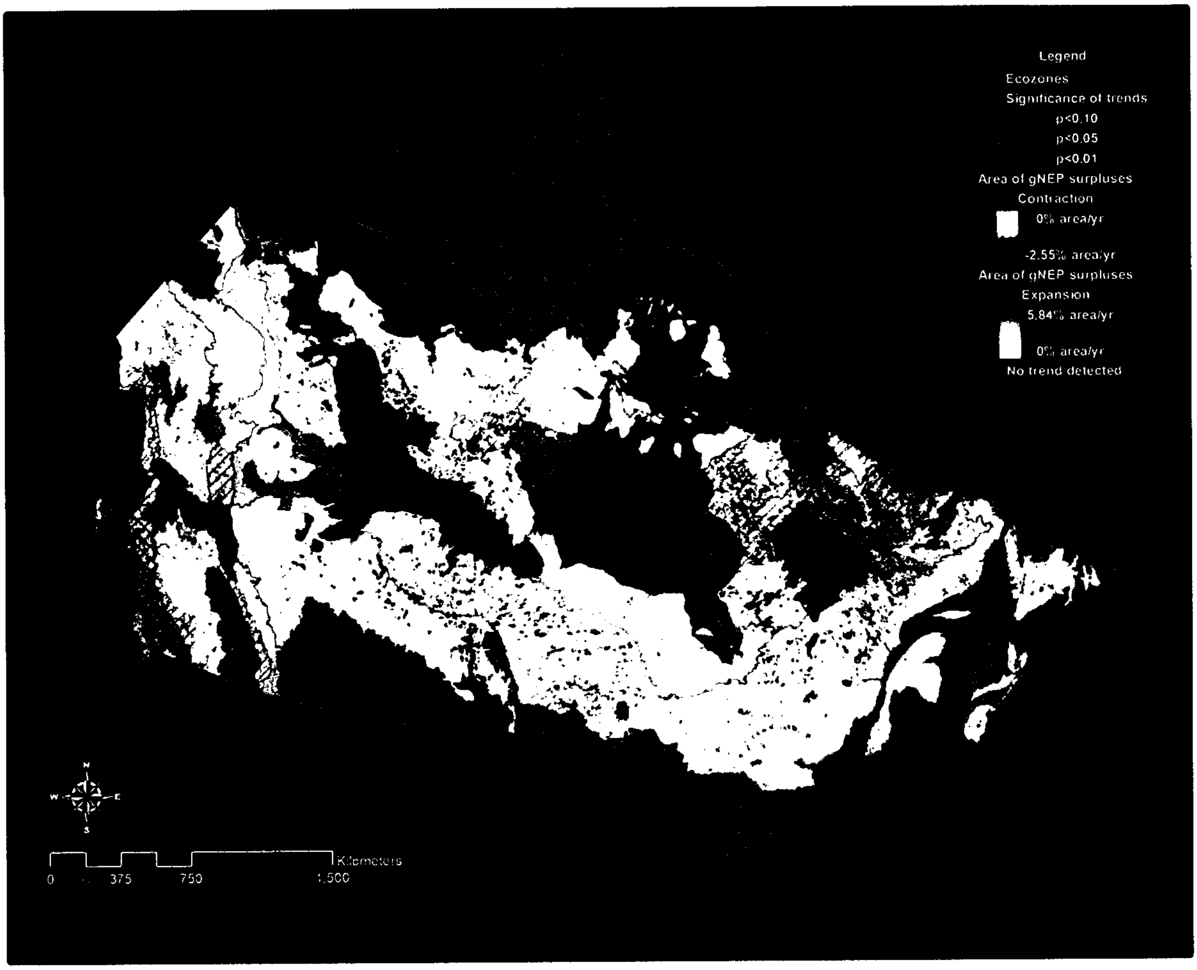

Figure 9a - Rates of change in the geographic extent of gNEP surpluses per ecoregion between 1998 and 2005 (n=165). Rates for each ecoregion were determined based upon the change in the total area of gNEP surpluses throughout the study period. Expanding surpluses are shown in green to represent increasing ‘greenness’, while contracting surpluses are shown in red to signify decreasing greenness. The maximum rate of expansion in surpluses was 5.84% ecoregion area·yr^{-1}, with a maximum rate of contraction in surpluses of -2.55% ecoregion area·yr^{-1}. Rates of change and their significance were calculated using trend-free pre-whitened Mann-Kendall trend tests (S). Significant rates ($p<0.10$) are shown as ecoregions with cross-hatching. Ecoregions for which no rate could be calculated are shown as “No Data”. Despite being summarized at the ecoregion scale data are still displayed at 1 km^2 resolution, excluding the Prairies ecozone and Canada’s far north archipelago.

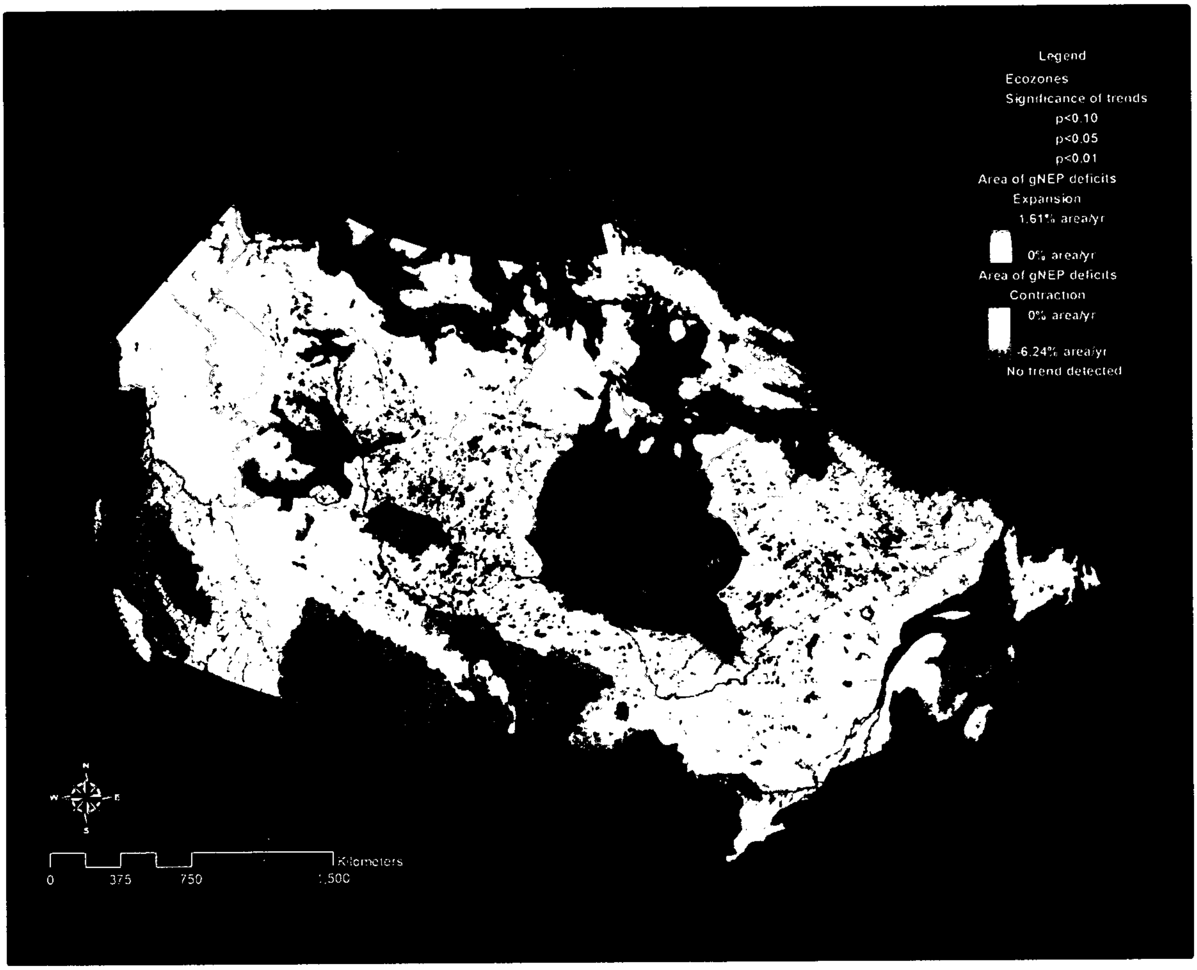

Figure 9b - Rates of change in the geographic extent of gNEP deficits per ecoregion between 1998 and 2005 (n=195). Rates for each ecoregion were determined based upon the change in the total area of gNEP deficits throughout the study period. Expanding deficits are shown in red to represent decreasing 'greenness', while contracting deficits are shown in green to signify increasing greenness. The maximum rate of expansion in deficits was 1.61% ecoregion area·yr^{-1}, with a maximum rate of contraction in deficits of -6.25% ecoregion area·yr^{-1}. Rates of change and their significance were again calculated using trend-free pre-whitened Mann-Kendall trend tests (S). Significant rates ($p<0.10$) are shown as ecoregions with cross-hatching. Ecoregions for which no rate could be calculated are shown as "No Data". Despite being summarized at the ecoregion scale data are still displayed at 1 km^2 resolution, excluding the Prairies ecozone and Canada's far north archipelago.

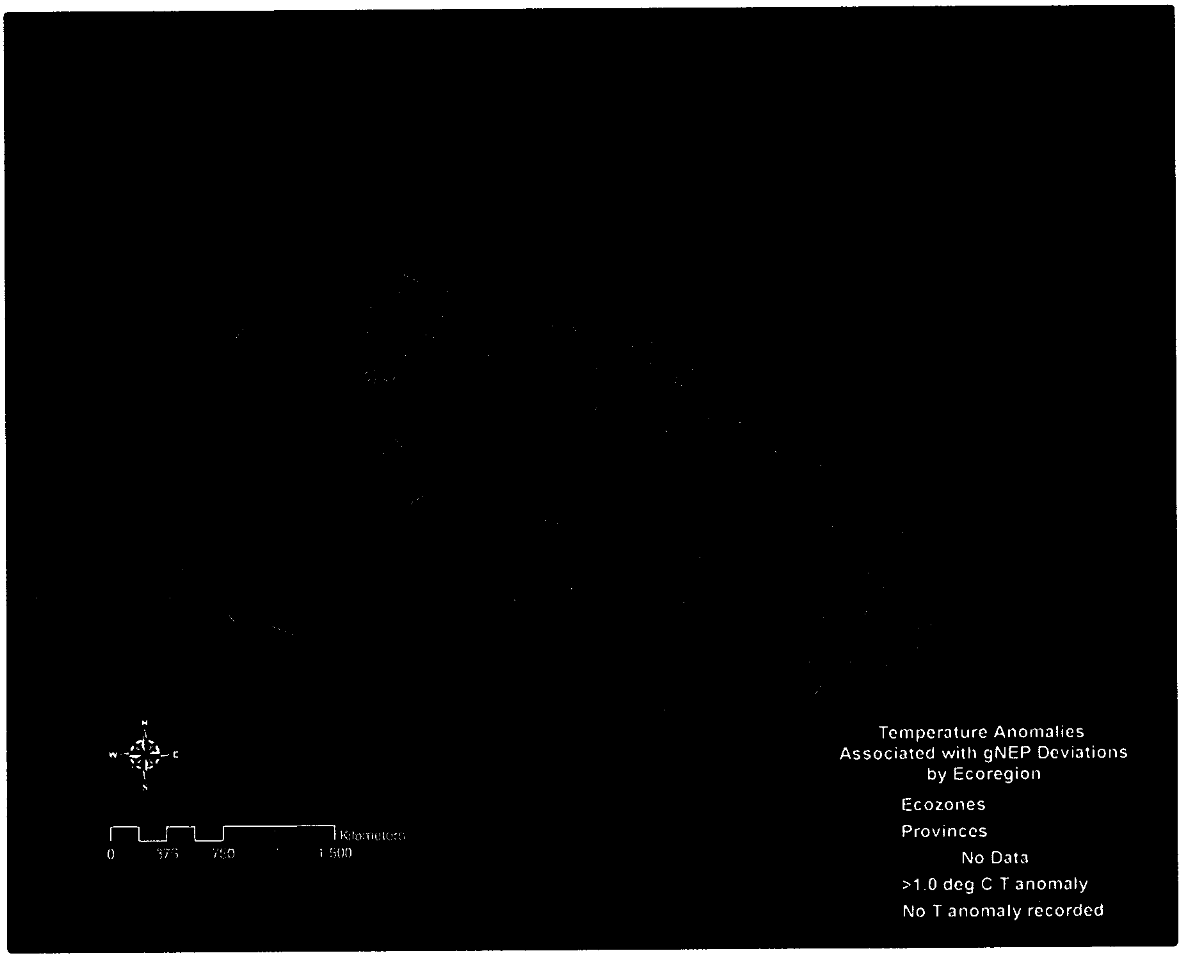

Figure 10 - Positive summer temperature anomalies 1998-2005 associated with gNEP deviations by ecoregion (n=92). Anomalies in average summer temperature of greater than 1.0° C each year were calculated relative to the 50-year average of summer temperature (June to August) for areas encompassed by gNEP surpluses and gNEP deficits, respectively, in each ecoregion. Areas where average summer temperature anomalies occurred within areas where gNEP deviations (in either direction) were recorded are shown in green. The individual maps for anomalies associated with gNEP surpluses (n=76) and gNEP deficits (n=45) were combined into a single map for ease of interpretation; some ecoregions showed associations with both surpluses and deviations. Ecoregions in which no anomaly greater than 1.0° C was recorded are shown as "No Data". Despite being summarized at the ecoregion scale data are still displayed at 1 km^2 resolution, excluding the Prairies ecozone and Canada's far north archipelago.

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APPENDIX A – Detailed explanation of SPOT VGT satellite data

The SPOT VGT (S10) NDVI product

SPOT VEGETATION is a multispectral sensor that captures reflectances of sunlight from the planet's surface in the red and near infrared bands, which are necessary to calculate NDVI. The sensor is flown aboard the Système pour l'observation de la terre (SPOT) satellites and has collected data data over 10-day periods continuously since 1998. The Canada Centre for Remote Sensing processes VEGETATION data over Canada to eliminate the effects of atmospheric haze, cloud contamination (Cihlar 1996), and other potential sources of error such as variation in viewing angle geometry (Chen & Cihlar 2000). The resulting data products are provided for 10-day periods across the growing season (April to October) of each year between 1998 and 2005 (ftp.ccrs.nrcan.gs.ca), enabling the construction of integrated growing season observations of NDVI, which strongly resembles growing season NEP.

SPOT VGT-based NDVI data are based on a finer spectral range than moderate resolution NDVI data (1 to $8km^2$) available via the advanced very high resolution radiometer-derived (AVHRR) sensors (Latifovic et al. 2005b), carried aboard various National Oceanic & Atmospheric Administration (NOAA) Pathfinder satellites since 1981. Despite their relatively short temporal coverage the SPOT VGT NDVI data can more effectively monitor vegetation conditions with only minor differences compared to the longer-term AVHRR NDVI data (Morisette et al. 2004; Swinnen et al. 2007). In contrast to SPOT VGT's vegetation-specific spectral range, the AVHRR sensors are calibrated specifically to detect surface temperature and cloud cover (NOAA 2008, http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html).

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APPENDIX B – CAR-based expected gNEP model parameters summaries

Summary of baseline gNEP model parameters derived using conditional autoregression, as described in Methods. Symbols are as follows: isothermality (Isot), summer precipitation (P_{summ}) and the interaction of summer precipitation and temperature ($P_{summ} \cdot T_{summ}$). The interaction term has been divided by 10.

Model subsample	Coefficient Values				
	Intercept	**Isot**	**Isot^2**	**P_{summ}**	**$P_{summ} \cdot T_{summ}$ (/10)**
1st sub	0.1990	0.3140	-0.0046	-0.0163	0.0015
2nd sub	1.1760	0.2360	-0.0031	-0.0168	0.0015
3rd sub	0.9380	0.2650	-0.0036	-0.0181	0.0015
4th sub	0.8310	0.2680	-0.0038	-0.0158	0.0014
5th sub	0.7810	0.2750	-0.0038	-0.0179	0.0015
6th sub	0.5890	0.2920	-0.0042	-0.0168	0.0001
7th sub	0.0989	0.3400	-0.0051	-0.0175	0.0015
8th sub	0.1445	0.3240	-0.0049	-0.0174	0.0016
Mean 8yr gNEP	**0.6590**	**0.2843**	**-0.0040**	**-0.0170**	**0.0013**

APPENDIX C – Land cover descriptions for Google Earth control points

Point no.	Google Earth Control Point Description	Relative gNEP deviation recorded (%)
1	Lots of forestry and agric, Lake of the Woods ON	-7.7
2	More checkerboard clearcut patches S of Dryden ON	-12.9
3	Outskirts - Cypress Hills I.P. Park	-23.3
4	Cypress Hills Interprovincial Park - West Block	0.5
5	Non-descript Rangeland	-45.8
6	South of Cypress Hills I.P. Park	-42.6
7	Protected area on woodland-agricultural matrix	-11.2
8	V. low veg. cover site on Niagara Peninsula	-26.5
9	SW Ont negative deviation coldspot (partial PAs method)	-12.2
10	SW Ont coastal negative deviation coldspot (partial PAs method)	-13.2
11	Caledon-area negative deviation coldspot (partial PAs method)	-8.0
12	Guelph negative deviation hotspot (partial PAs method)	-32.6
13	N Central ON negative deviation (full PAs method)	Data absent
14	Landscape of clearcuts near Ignace, ON	-7.4
15	Negative deviation near Sioux Lookout, ON	-8.0
16	La Sarre, Quebec	-24.9
17	St. Bruno de Guiges, Quebec	-13.0
18	Temiscaming, Quebec	-4.5
19	E of central Lake Winnipeg	-27.3
20	Marble mine W of Carleton Place	-3.4
21	Greenspot W of Mink Lake, Hastings Co ONT	11.8
22	Forest patch btw Carleton Place & Arnprior	-12.2
23	Mine E of Arnprior	-12.9
24	Mine E of Almonte/Missippi Mill	-15.9
25	The Elk Ranch, Kanata, ON	-21.7
26	Greenspace? E of Carleton Place	-4.7
27	Intense forestry N of La Sarre, Qc	-12.4
28	Mer Bleu Conservation Area	-17.1
29	Mine 1 E of Edelweiss Ski Hill	-10.3
30	Bog? W of St. Michel-des-Saints	-10.2
31	Forestry ops N of Lac Devenyns	-6.9
32	Lumberyard NE of Mauricie NP	-10.7
33	Greenspot? NE of Lac Devenyn forestry	11.8
34	Anomalous? EP deficit W of Riviere Nottaway	-8.6
35	Selbaie Mine	Data absent
36	Forestry ops W of Selbaie Mine	-4.4

37	Geological surf anomaly S of Nottaway R. Head	-28.4
38	Mine NW of Selbaie Mine	Data absent
39	False positives near On/Qc border	-7.1
40	False positives N of Mosonee, ON	-16.3
41	Neg deviation N of Little Long Rapids, ON	-22.3
42	Large forestry ops NE of Kapuskasing	-12.0
43	Mine and forestry SW of Kapuskasing	-9.6
44	Hardwood greenspot on St. Joseph Island, ON	8.5
45	Green upland N of The Sault (windmills)	13.1
46	Mine N of The Sault	1.0
47	Multiple forestry techniques SE of Chapleau, ON	-19.7
48	Two huge clearcut scars E of Chapleau, ON	-19.1
49	Wawa, mines and hydro dam	-5.8
50	Dubreuilville, ON	2.3
51	2nd large forestry op SW of Kapuskasing	-7.6
52	Huge clearcut near Fire River, ON	1.8
53	Clearcuts SW of Hearst	-5.3
54	Neg deviations SW of Exton/Nakina, ON	-17.4
55	Neg deviations 2 near Exton/Nakina, ON	-9.5
56	False positive wetland NW of Hearst	-37.1
57	Large clearcut W of Hearst	3.2
58	Bare earth clearcut near Pagwa River	-4.9
59	False neg deviation on MB/ON border	-22.0
60	Cuts S of Dryden, ON	-7.2
61	Fort Frances/Emo, ON	-18.6
62	Regenerating cuts W of Lake Nipigon	5.5
63	Anomalous neg deviation W of Winnipegosis	-15.9
64	Greenspace and agr on Winnipegosis	1.1
65	Green upland W of Pine River and Ethelbert	9.2
66	Cuts & green upland N of Swan River, MB	10.0
67	Green upland N of town called Hudson Bay SK	4.3
68	Green upland E of Prince Albert SK	8.4
69	Meadow Lake SK & environs agr	-21.6
70	Fire scar, geol anomaly? N of Meadow Lake	-10.2
71	Forestry? Peat mines? far NE of Meadow Lake SK	-21.6
72	Forestry? Peat mines? far NE of Meadow Lake SK	-7.5
73	Forestry? Peat mines? far NE of Meadow Lake SK	-7.0
74	Barren, low tree dens E of AB border, Oil Sands	-33.9
75	Faro, YT	1.3
76	Pelly Crossing, YT	3.0

77	Old gold mines SE of Dawson City YT	Data absent
78	Gold mines along river S of Dawson City YT	5.3
79	Gold mines outside Dawson YT	1.3
80	Dawson YT & environs	-3.9
81	Dawson City YT	-7.6
82	Whitehorse YT	-10.1
83	Mines? Agr? near Takhini Hotspring YT	-8.8
84	Takhini Salt Flat YT	-25.8
85	Stony Creek Camp mine YT	Data absent
86	Champagne YT	-16.2
87	Haines Junction YT	3.1
88	Bear Creek mine YT	-2.5
89	Silver City mine YT	-5.3
90	Burwash Landing YT	-15.0
91	Beaver Creek YT	-0.9
92	Ekati diamond mine NWT	Data absent
93	Diavik diamond mine NWT	-22.9
94	Lupin mine NU	Data absent
95	Churchill MB	Data absent
96	Inuvik NWT	40.3
97	Tuktoyaktuk NWT	Data absent
98	Clearcut & burn in Gaspe QC	Data absent
99	Clearcut in Haute Gaspesie	13.5
100	Murdochville QC & copper mine	8.8
101	Huge clearcut in Gaspe	8.6
102	Landscape of clearcuts in Matapedia QC	6.0
103	Agr near Causapscal QC	-4.4
104	Forestry & agr near Sayabec QC	1.4
105	Agr & For around Mont-Joli QC	0.7
106	Old clearcuts in Chic-Chocs?	15.6
107	Saint-Quentin NB	Data absent
108	Various For. practices, northern NB	4.4
109	Christmas Mtns clearcuts, NB	-0.3
110	For. & agr outside Doaktown, NB	-10.3
111	Forestry ops N of Glassville, NB	-1.7
112	Hartland NB	-22.0
113	Decid. uplands N of Glassville NB	2.9
114	Forestry, mines & urban near Minto/Newcastle NB	Data absent
115	Oromocto, NB	-19.1
116	Agr btw Hartland & Woodstock NB	-17.1

117	Fredericton NB	Data absent
118	Clearcuts & other SW of Gagetown, NB	-9.7
119	St. Stephen NB	-20.5
120	Sussex NB & area	-18.2
121	Tantramar marsh & agric	-12.8
122	Agric along Shubenacadie River	Data absent
123	Extensive agric N of Kensington PEI	-18.6
124	Forested areas in Prince Co, PEI	2.9
125	Charlottetown PEI	Data absent
126	Large agr fields near Souris, PEI	-12.1
127	Decid. or regen. uplands on Cote Nord QC?	29.8
128	Mine or other in northern QC	-15.8
129	Mine or other again in northern QC	Data absent
130	Mine near La Grande, northern QC	10.6
131	Clearcuts SW corner of Sept Rivieres QC	1.6
132	Huge clearcuts NW of Baie-Comeau QC	1.5
133	Clearcut landscapes around Carcajou Rapids, N QC	-27.8
134	Agr landscapes around Normandin QC	-12.3
135	Extensive cc'd landscapes E of Abitibi QC	-12.3
136	Barrens near Avalon Penin., NL	-23.5
137	Mines & exploration in Central Nfld	-13.1
138	Deer Lake, Nfld	-17.0
139	Cornerbrook & area	-9.1
140	Upper Salmon Hydro, S central Nfld	-18.5
141	Old forestry ops, SW of Gander	-0.5
142	Agr et al around Saint Fintan's Nfld	11.3
143	Former forestry ops N of St. Andrew's Nfld	29.0
144	Kruger cuts W of Gros Morne NP	10.1
145	Barrens 2 - Mealy Mtns	Data absent
146	S. coniferous upland greenspot AB	33.3
147	Marystown, Nfld	Data absent
148	s. conif uplands greenspot near Tar Sands	22.2
149	Fort Liaird NWT	3.7
150	s. conif. upland greenspot NWT	34.8
151	Barrens 1 - Mealy Mtns	17.5
152	Forestry ops N of John D'or airport AB	21.0
153	Yellowknife, NWT & area	Data absent
154	Forestry op remnants? W of Yellowknife	1.1
155	Fort Providence NWT	Data absent
156	Hay River NWT	1.4

157	Huge mining op E of Hay River NWT	-19.8
158	Wha Ti, NWT	-7.3
159	Barrens on W shore of Lac La Martre	Data absent
160	Relative greenspot W of Great Slave Lake	1.2
161	Forestry ops E of Grand Cache AB	-0.5
162	More forestry ops S of Grand Prairie AB	18.1
163	Weird northern QC anomaly on burn scar	-26.7
164	Kuujjuarapik, QC	2.3
165	Potential greenspot btw Antigonish & Pictou	4.6
166	Antigonish greenspot - WA	2.8
167	Riparian agric landscapes N of Reynolds, MB	-16.8
168	Exposed shield & mixed forests, Falcon Lake MB	-11.9
169	Agr along river, Pine Falls MB	-5.6
170	Calgary area	-52.4
171	Agr to N, E, S in Rocky Mtn House AB	-20.2
172	Extens. agr landscapes btw Edm & Red Deer	2.3
173	Agr areas surrounding Edson, AB	-20.0
174	Forestry ops along AB Foothills	1.6
175	Elkview mine E of Sparwood BC	0.0
176	Valley of agr N of Sparwood BC	-1.4
177	Agr & old forestry along W BC valley	1.1
178	Canal Flats BC	-27.4
179	Invermere BC	-32.0
180	Agr btw Canal Flats & Invermere BC	-23.6
181	Fort Ware BC - forestry along valley	0.4
182	Rainbow Lake, far N AB	-0.4
183	Extensive forestry ops, far N AB	8.5
184	Zama City AB + environs	13.1
185	High level AB	-21.2
186	Seismic lines W of Zama City AB	1.7
187	Extensive agric around High level AB	-14.5
188	Forestry ops outside Loon River AB	10.7
189	Agric in Manning AB	-11.4
190	Forestry + agric around Eureka River, AB	-5.7
191	Fort St. John BC + environs	-7.3
192	Cuts outside Hudson's Hope BC	4.2
193	Agric in Bonanza AB + Dawson Creek BC	-13.9
194	Barren cut scar NW of Fort St. John BC	-0.7
195	Seismic? old cut scars? N of Fort St. John BC	3.5
196	Agric near Bentton Valley BC	5.7

197	Hazelton BC + extensive forestry ops	13.8
198	Fort St. James BC	10.3
199	Forestry ops N of Fort St. James BC	7.6
200	Forestry ops E of Fort St. James BC	4.3
201	Quensnel BC - interior forestry	-14.3
202	Kamloops/Chilcotin BC	-49.0
203	Prince George + environs	-14.3
204	Riparian agric + forestry - Topley BC	10.0
205	Vanderhoof BC + environs	-6.2
206	Squamish BC	-5.1
207	Smithers BC + surrounding forestry ops	1.3
208	Kispiox BC - forestry in valley	-0.7
209	Fort Nelson BC + forestry ops around	-12.0
210	Forestry ops around La Biche BC	26.6
211	Tread barren N of Baya Lake on Cassiar Hwy	-11.0
212	Cheztainya Lake environs forestry ops	6.4
213	Deforested valley N of Hazelton BC	Data absent
214	Lillooet BC - grassland steppe	Data absent
215	Seton BC	-3.1
216	Cutaway strips along Anderson Lake BC	5.5
217	Devine BC	7.8
218	Whistler BC + environs	9.5
219	Penticton/Summerland BC + environs	Data absent
220	Ross River YT	-9.2
221	Circle agr valleys E of Chapaka BC	-41.2
222	Agric + forestry btw Oliver and Osoyoos BC	-30.3
223	Huge open pit mines in s. BC interior	-32.0
224	Agric + forestry along lower Similkamten River BC	-24.4
225	Agric in Sidley BC	-8.3
226	Massive forestry ops N of Manning Park BC	Data absent
227	Hope BC	Data absent
228	Mayo YT	-9.3
229	Port Alberni BC + surrounding forestry	-4.8
230	Extensive forestry btw Port Hardy + Port McNeill BC	9.7
231	Extensive forestry ops near Holberg BC	10.4
232	Forestry ops near Nimpkish BC	13.5
233	Nanaimo BC	Data absent
234	Campbell River BC + forestry	-27.9
235	Ucluelet BC	Data absent
236	Huge clearcuts W of Campbell River BC	24.7

237	Forestry on S edge of Pac Rim NP	15.5
238	Decid forests on Five Finger rapids, YT	-6.1
239	Watson Lake YT + environs	2.5
240	Mine N of Mayo YT	14.7
241	Golden BC & forestry w agr ops	-20.4
242	Mt Wright Mine W side, QC-Lab	Data absent
243	Mt Wright Mine E side, QC-Lab	-4.4
244	Mt Wright Mine S side, QC-Lab	-8.6
245	Iron mine N of Labrador City	Data absent
246	Labrador City, NL	Data absent
247	Cleared landscape outside Labrador City	9.2
248	Various cuts SW of Labrador City	Data absent
249	Wabush Mine site 1	Data absent
250	Caniapiscau, QC-Lab	13.6
251	Huge Wabush Mine site 2	-22.5
252	Wabush, NL	-4.5
253	Former Lac Jeannine Mine, QC	Data absent
254	Various QC Mtns barren uplands	13.9
255	Exposed riparian rock along QC river	-5.6
256	Clearcuts around Lac Walker QC	-5.9
257	Clearcuts around Lac Rond QC	-8.2
258	Clearcut landscapes N of Lac Walker QC	4.7
259	Clearcut landscapes around Lac Arthur QC	12.4
260	Huge clearcut landscape in Manicouagan	-7.1
261	Barren upland N of Baie Comeau?	0.4
262	Fire scar on Haute Cote Nord?	-12.2
263	Churchill Falls, NL	16.3
264	Mine S of Happy Valley	-40.8
265	Forestry N of Muskrat Falls NL	10.3
266	Happy Valley-Goose Bay	-33.4
267	Pits or mines N of Happy Valley	-8.5
268	NW River town, NL	Data absent
269	Barren mtn beside Long Pond NL	-3.7
270	Huge undevel'd prairie upland N of Beaver Flats, SK	-32.7
271	Riding Mountain NP	11.3
272	Moose Mtn greenspot, SK	9.5
273	Relative greenspot S of Round Lake, SK	-7.0
274	Relative green upland W of Spring Valley, SK	-19.2
275	Grasslands NP	-53.0
276	Undevel'd prairie upland NW of Grasslands NP	-38.2

277	Recent fire scar, northern MB	-4.9
278	Thompson, MB	-32.1
279	Thompson Inco open pit mine	Data absent
280	Other open pit mine? Thompson, MB	Data absent
281	Geol exploration, Grass River MB	-6.5
282	Huge geol. expl. site near Grass River MB	-2.2
283	Ilford, MB	1.4
284	Shamattawa MB mining ops?	-1.3
285	Kasabonika ON mining ops?	Data absent
286	Kingfisher Lake ON - mining town?	Data absent
287	Muskrat Dam ON	-12.0
288	Small open pit ops on lake E of Muskrat Dam ON	Data absent
289	Weagamow Lake ON	Data absent
290	Forestry landscapes NE of Sioux Lookout	-13.7
291	Various clearcut landscapes SE of Sioux Lookout	-5.8
292	One of many clearcuts near Mojikit Lake ON	-9.7
293	Red Lake / Balmertown ON	-7.1
294	Huge clearcuts N of Red Lake ON	-21.7
295	Extens. forestry ops N of Nakina ON	-8.4
296	Agr in Val Marie SK	-23.5
297	Agr amidst uplands NE of Climax SK	-31.7
298	BC Interior sands/steppe?	Data absent
299	BC Interior steppe forestry?	-17.9
300	Huge mine NW of Vanderhoof BC	-59.3
301	Mining ops SW of Cluff Lake SK	-19.9
302	Mining or forestry along Cluff Lake valley	-24.8
303	Snake-line of ops extending fr Cluff Lake?	-20.9
304	Carswell (Gorilla Lake) SK uranium mine ops	Data absent
305	More indust ops near Cluff Lake	3.7
306	Seismic ops S of Gorilla Lake SK	-4.1
307	Evidence of human activity - Carswell Lake	Data absent
308	Northern SK towns + forestry	-12.3
309	Fond du Lac SK	Data absent
310	Mine 1 Points North SK	-20.5
311	Mine 2 Points North SK	5.6
312	Various spider-lines of seismic?	-6.4
313	Key L mine - northern SK	Data absent
314	Key L mine forestry? exploration?	-25.5
315	Old Key L forestry and exploration?	-29.5
316	Old Key L mine exploration	-26.2

317	Jazinksy Lake SK exploration	-15.2
318	Old forestry for mine exploration in N SK?	-26.5
319	Old small forestry ops in N SK?	-5.9
320	Extensive forestry S of Pinehouse SK	Data absent
321	Lots of seismic lines - AB/SK border	11.5
322	Lots of forestry - AB/SK border	0.4
323	Lots of mixed forestry + seismic lines - AB/SK border	2.3
324	Extensive forestry S of Fort MacKay	19.7
325	Extensive forestry near Calling Lake AB	12.4
326	Cleared forestry ops S of Fort Mac	6.1
327	Fort MacKay oilsands mine 1	-70.7
328	Fort Mac Syncrude mine + forestry around	-39.5
329	Firebag River scrapes	-23.9
330	Big forestry scar near AB/SK border?	-18.1
331	Barrens or forestry? SK	Data absent
332	Forestry ops in N SK?	-36.7
333	N SK linear clearing - patch 1	-26.6
334	N SK linear clearing - patch 2	Data absent
335	N SK linear clearing - patch 3	-19.6
336	More N SK linear clearing?	Data absent
337	More N SK cleared patches w roads?	Data absent
338	Cluff Lake SK	-20.7
339	Old forestry ops in N SK?	-33.9
340	Roads = old forestry in N SK?	-15.6
341	Old, huge forestry site in N SK?	Data absent
342	Uranium City, SK	-1.9
343	Cluff Lake mine 2	-13.7
344	Decomm'd mine site in N SK?	-20.9
345	Forestry along N SK road to nowhere	-18.6
346	Disorg'd forestry patches in N SK	-8.9
347	Decomm'd mine or forestry site?	-4.4
348	Signs of former human activity?	-32.6
349	Lots of seismic, forestry and maybe mining - N BC	11.5
350	Large cuts in N BC	9.9
351	Patchwork drilling ops in N BC	-2.3
352	Recent & regnerating clearcuts near Sioux Lookout	-1.5
353	Selective forestry techniques scars??	4.7
354	Kapuskasing, ON	-23.8
355	Timmins ON	-42.3
356	Forestry W of Timmins	4.2

357	Large mine in Kamiskotia ON	-24.7
358	Large strip forestry NW of Kamiskotia ON	-0.2
359	Huge pit mine outside Timmins	Data absent
360	Mine 2 outside Timmins	-31.5
361	Mine 3 outside Timmins	-15.8
362	Mine 4 outside Timmins	-23.1
363	Engelhart ON	-5.7
364	Mining in Bracebridge ON	-5.9
365	Small mine S of Gravenhurst ON	-8.5
366	Mine in New Uhthoff ON	-27.3
367	Orillia ON	-33.8
368	Extens foothills forestry and post-harvest regen AB	-6.3
369	Barrie ON	-45.7
370	London ON	-40.9
371	Windsor ON	-55.3
372	Wallaceburg ON	-37.5
373	Sarnia ON	-40.9
374	Stratford ON	-37.2
375	Kitchener-Waterloo ON	-42.9
376	Hanover ON	-23.5
377	Listowel ON	-22.6
378	Fergus ON	-25.4
379	Shelburne ON	-15.8
380	Agric lands outside Sturgeon Falls ON	-10.8
381	Forestry & mining in Northwestern ON	-12.9
382	Mining ops NW of Mojikit Lake ON	-23.6
383	Radius of forestry N of Nipigon Lake	-2.9
384	Greenspot? around Fort Hope ON	4.2
385	Strange forestry patterns NE of La Sarre	6.1
386	DOMTAR mill & Lebel-sur-Quevillon to the NW	-11.3
387	More forestry W of La Sarre	-15.6
388	Senneterre QC & surrounding agriculture	-17.3
389	Val D'Or	-30.5
390	La Motte QC & agric to S and E	-20.5
391	Malartic QC	-24.6
392	Mine outside Malartic QC	-5.0
393	Mine 1 W of Malartic QC	-19.3
394	Mine 2 W of Malartic QC	-13.9
395	Rouyn-Noranda QC	-48.8
396	Noranda QC mine	-20.5

397	Evain & surrounding agriculture	-4.9
398	Mine outside Clericy QC	-7.0
399	Amos QC & surrounding agric	-14.5
400	Very big clearcuts N of Amos QC	4.0
401	Large mine far N of Amos QC	-12.3
402	Forestry all along the valley, far N of Amos QC	-4.1
403	Mines at each side of point - Matagami QC	-13.1
404	Matagamic QC	-6.2
405	Recent clearcuts all over the place E of Matagami QC	2.4
406	Mine and Chapais QC	-8.2
407	Clearcuts along Mistassini Lake	-15.0
408	Developments around La Grande?	16.7
409	La Grande Riviere airport and land conversion?	-4.7
410	Chisasibi QC	Data absent
411	False positive - barrens in N ON	-9.9
412	Barren mountaintops on the Queen Charlottes	-12.7
413	Huge old and recent cuts - Queen Charlottes	-0.2
414	Louise Island BC - forestry	-0.1
415	Snow-capped mountain-tops on Queen Charlottes	-11.5
416	Old and recent forestry - Lyell Island BC	Data absent
417	Old forestry and road scars - Lyell Island BC	-2.2
418	Bogs on South Moresby Island BC?	-11.0
419	Old forestry or natural veg patterns - Queen Charlottes	-3.7
420	Old forestry and road scars 2 - Lyell Island BC	Data absent
421	Serpentine forestry and road scars - Lyell Island BC	0.4
422	Large patches of clearcutting scattered for 100km's	Data absent
423	Post-harvest forest regen with patchy recent clearcuts	-4.9
424	Post-harvest forest regen 2	-4.1
425	More post-harvest forest regen examples	Data absent
426	Even more post-harvest regen with new cuts around	-7.2
427	More post-harvest regen again	-10.7
428	Big clearcuts snake their way up a valley	-12.3
429	More clearcuts along valley	-15.3
430	Old and recent cuts fork out along valleys	-6.6
431	Post-harvest regen on Louise Island	Data absent
432	Valley floor clearcut - Louise Island BC	-11.8
433	Mountainside cuts? - Louise Island BC	-12.7
434	Island draped in post-harvest regen - Queen Charlottes	Data absent
435	End of regen cuts along spine of island mtns	Data absent
436	Post-harvest regen with large new cuts around	Data absent

437	East Narrows tidal flats	Data absent
438	Post-harvest regen throughout watershed	5.4
439	Serpentine post-harvest regen and new cuts	-7.1
440	Old and recent forestry at Gray Bay BC	-7.9
441	Huge ring of post-harvest regen w new cuts	6.0
442	Watershed full of regen clearcuts	-5.1
443	Serpentine post-harvest regen w new cuts 2	5.3
444	Graham Island mountain in post-harvest regen	-3.7
445	Ring of cuts around the mountain	-12.0
446	Post-harvest regen along shores of inlet	Data absent
447	Patchey recent cuts along both shores of inlet	-23.8
448	Extensive chain-link pattern of clearcuts	-6.5
449	Post-harvest regen	-6.1
450	Chain-link-style cuts	-4.5
451	Montane barrens or very old forestry??	-12.5
452	Many cuts in form chain up a road/valley	Data absent
453	Lots of post-harvest regen all around Juskatla BC	-4.6
454	Chains of fishbone-patterned cuts	-9.4
455	Post-harvest regen along mtn-side on Louise Island	Data absent
456	Lots of post-harvest regen along valley	-3.6
457	Volcanoe outside Jedway BC?	Data absent
458	Post-harvest regen along moutainside	4.7
459	Horsehshoe shaped ecoregion - AB	-4.3
460	Bottom arm of horseshoe-shaped ecoregion - AB	-13.2
461	Northern ON low wetland amidst barrens	11.1
462	Fort Severn ON	Data absent
463	Quarry or pit outside Fort Severn, ON	-4.5
464	Small, finger-like wetlands between forested high ground, Northern ON	-6.7
465	York Factory, Northern MB	Data absent
466	Pockets of forested high-ground, outside York Factory	15.6
467	Limestone settlement, Northern MB	Data absent
468	Fox Lake mine, Northern MB	-11.7
469	Long Spruce Dam and ops, Nelson River, MB	Data absent
470	Pit mine and old forestry ops, Boots Creek, MB	-1.2
471	Open pit 2, Boots Creek, MB	3.2
472	Hydro generation station on Nelson River, Gillam MB	3.2
473	Townsite for Gillam, MB	-13.1
474	Open pits and ops around Gillam Dam, MB	Data absent
475	Intersection of hydro corridors, Gillam and Long Spruce Dams	11.1
476	Riverside quarry? Nelson River	Data absent

477	Circular forestry and exploration site?	-6.2
478	Hydro corridors along Nelson River, MB	2.2
479	Mine ops near Conawapa, MB?	-28.9
480	Limestone pit 1 outside Kettle Rapids, MB	8.5
481	Limestone pit 2 outside Kettle Rapids, MB	4.1
482	Split Lake settlement and mine, MB	Data absent
483	York Landing settlement, MB	1.1
484	Human activity off hydro corridor, N or Ilford, MB	7.6
485	Wetland area outside Gillam, MB	2.9
486	Open pit and exploration routes, Northern MB	3.5
487	Townsite for Kelsey, MB	-27.4
488	Kelsey airstrip and dam ops	-4.3
489	Hydro corridors and road intersection	4.8
490	Townsite and airstrip, Pitwonei, MB	8.7
491	Patchwork clearcut ops outside Grass River, MB	-9.8
492	More patchwork clearcut ops outside Grass River	-5.9
493	Old mine or quarry site, SW of Thompson MB	0.4
494	Patchwork forestry scars, SW of Thompson MB	6.8
495	3 big forestry scars, SW of Thompson MB	-1.7
496	Patchwork forestry scars, E of Pitew Falls, MB	-0.6
497	Big cuts (2 more nearby to E) W of Pitew Falls, MB	Data absent
498	Cross Lake townsite, MB	Data absent
499	Big clearcut ? S of Cross Lake MB	2.2
500	Patchwork of clearcuts outside Cross Lake MB	-3.4
501	Myriad of small patch cuts NW of Cross Lake MB	1.2
502	Townsite for Leaf Rapids MB	-12.9
503	Forestry ops outside Leaf Rapids MB	-5.1
504	Huge mine op E of Leaf Rapids, MB	-25.5
505	Huge pit mine?? Lynn Lake, MB	-30.7
506	Townsite for Lynn Lake, MB	Data absent
507	Mining ops N of Lynn Lake, MB	-2.3
508	Neskantaga, ON quarry	4.4
509	Townsite for Neskantaga, ON	Data absent
510	Neskantaga, ON airstrip	Data absent
511	Huge forestry scars in NW ON	-11.6
512	Upland barrens near Fort Hope, ON	-4.5
513	Regenerating clearcuts N of Kapuskasing, ON	2.7
514	Extensive post-harvest regenerating cuts, N of Kapuskasing	1.1
515	Very extensive post-harvest regen, S of Hearst	9.3
516	Very extensive post-harvest regen S of Hearst 2	9.1

517	Very extensive post-harvest regen S of Hearst 3	7.9
518	Very extensive post-harvest regen S of Hearst 4	11.7
519	Massive post-harvest regen patch S of Hearst 5	8.9
520	Post-harvest regen SW of Hearst	8.9
521	Large patchwork clearcuts N of Kapuskasing, ON	1.9
522	Selective forestry surrounded by clearcuts near Hearst	-3.1
523	Patchwork ofselective cuts and post-harvest regen near Hearst	6.5
524	Oromocto, NB	-19.1
525	Large patchwork clearcuts and regen near Exton/Nakina ON	8.6
526	Clearcut in Haute Gaspesie	13.5
527	Clearcut & burn in Gaspe QC	Data absent
528	Very extensive post-harvest regen far W of Hearst	7.8
529	Kashechewan ON	Data absent
530	Site 932 for AMSE-R flood detection on Albany River ON	Data absent
531	Patchwork clearcuts surrounded by post-harvest regen, ON	-0.1
532	Fort Albany, ON	-4.3
533	Huge clearcut in Gaspe	8.6
534	Small industrial ops outside Fort Albany ON	-7.6
535	More extens. low dens forest uplands, Northern ON	-13.4
536	More extens. low dens treed uplands, Northern ON	-10.6
537	Finger-like quarry outside Kashechewan ON	Data absent
538	Hydro corridors or roads along James Bay ON	9.4
539	Extens. riparian wetlands/fens, Northern ON	Data absent
540	West boundary of estuarine lowlands around Attawapiskat ON	1.7
541	Murdochville QC & copper mine	8.8
542	Wetlands amidst low dens forest uplands, MB/ON border	0.3
543	Attawapiskat ON	-7.0
544	Dense riparian forests along Albany River ON	Data absent
545	Thunder Bay ON	-46.0
546	Low dens forest uplands w lakes - Akimiski Island, James Bay	-7.0
547	Patchwork of post-harvest regen NW of Thunder Bay	-1.3
548	Wetland amidst high-ground barrens near Moosonee ON	-3.8
549	Extensive patchwork of clearcuts NW of Thunder Bay	-5.5
550	Unharvested areas NW of Thunder Bay??	-3.4
551	Patchwork clearcuts and post-harvest regen, N of Thunder Bay	7.1
552	Patchwork of cuts and post-harvest cuts SE of Sioux Lookout	-6.2
553	Patchwork of clearcuts far NW of Thunder Bay	-15.7
554	Post-harvest regeneration NW of Thunder Bay	-1.0
555	Montcalm agric region N of Montreal	-26.8
556	Montreal	-60.6

557	Big clearcut patches SE of Sioux Lookout	-18.1
558	Ottawa	-45.8
559	Saint-Jovite QC	-14.2
560	Post-harvest regen S of Sioux Lookout	1.9
561	Drummondville QC	-41.6
562	Joliette QC surrounded by agriculture	-38.4
563	Trois-Rivieres	Data absent
564	Sherbrooke	-40.2
565	Patchwork of clearcuts NW of Thunder Bay	-6.3
566	Wide riparian zones along Northern ON river	7.0
567	Ormstown QC surrounded by agriculture	-24.7
568	Kingston ON	-47.0
569	Toronto	-37.4
570	Decomm'd tin mine ops near Keji NP, NS	-0.2
571	Townsite for Neskantaga, ON	Data absent
572	Brantford ON	-38.9
573	Woodstock ON	-39.1
574	Townsite for Neskantaga, ON	Data absent
575	Bridgewater NS	-11.8
576	Black Bull Kaolinite clay mine near Keji NP, NS	11.7
577	St Catherines ON	-29.9
578	Granby	-28.8
579	Cornwall ON	Data absent
580	Coaticook, QC surrounded by agriculture	-17.2
581	Quebec City	-55.2
582	Patchwork clearcuts S of Sioux Lookout	-10.7
583	Neskantaga, ON quarry	4.4
584	Neskantaga, ON airstrip	Data absent
585	Post-harvest regen SW of Hearst	8.9
586	Huge forestry scars in NW ON	-11.6
587	Very extensive post-harvest regen, S of Hearst	9.3
588	Large patchwork clearcuts N of Kapuskasing, ON	1.9
589	Very extensive post-harvest regen S of Hearst 2	9.1
590	Very extensive post-harvest regen S of Hearst 3	7.9
591	Very extensive post-harvest regen S of Hearst 4	11.7
592	Patchwork clearcuts surrounded by post-harvest regen, ON	-0.1
593	Extensive post-harvest regenerating cuts, N of Kapuskasing	1.1
594	Upland barrens near Fort Hope, ON	-4.5
595	Very extensive post-harvest regen far W of Hearst	7.8
596	Regenerating clearcuts N of Kapuskasing, ON	2.7

597	Large patchwork clearcuts and regen near Exton/Nakina ON	8.6
598	Patchwork ofselective cuts and post-harvest regen near Hearst	6.5
599	Oil and gas ops, Prairie Parkland AB	4.4
600	Extens agric landscapes around Big Head SK	-7.5
601	Massive post-harvest regen patch S of Hearst 5	8.9
602	Grand Centre AB	-10.6
603	More oil and gas exploration, NW of Grand Centre AB	-4.8
604	Extens forestry and oil and gas, W of Cold Lake AB	-3.6
605	Extens matrix of oil and gas exploration, N of Cold Lake AB	-16.2
606	Extens forestry patchwork NE of Lac La Biche AB	3.0
607	CFB Cold Lake (AB) air force base	-18.6
608	Lac La Biche AB	Data absent
609	Pristine forest w seismic lines running throughout, AB	21.0
610	Extens. low dens treed uplands amidst small lakes, Northern ON	-9.0
611	Selective forestry surrounded by clearcuts near Hearst	-3.1
612	Extens agric landscapes E of Loon Lake SK	-18.4
613	Bonnyville AB	-17.1
614	Old post-harvest regen E of Lac La Biche AB	23.1
615	More patchwork clearcuts throughout Prairie Parkland AB	10.1
616	Intact decid forest w extens seismic lines throughout AB	19.4
617	Lots of post-harvest regen E of Lac La Biche AB	18.4
618	Wandering River AB and surrounding agric landscapes	-8.8
619	North Battleford SK	-26.3
620	Extens agric landscapes around Bonnyville AB	-9.3
621	Extens forestry and regen N of Goodsoil SK	14.4
622	Patchwork clearcuts and post-harvest regen N of North Battleford SK	9.3
623	Extens patchwork of clearcuts NE of Cold Lake SK	8.3
624	Extens agric landscapes btw/around Peerless and Goodsoil, SK	-11.0
625	Extens serpentine patchwork of clearcuts, northern AB	-2.1
626	Scattered oil and gas expl near AB/SK border	5.2
627	Old forestry and mines near SK/AB border	6.4
628	Extens agric, oil and gas development, S of Elk Point AB	-16.6
629	Patchwork clearcuts, oil and gas expl SE of Bonnyville AB	6.1
630	Extens patchs of agric, forestry, oil and gas expl, AB	-6.2
631	Elk Point AB	-15.5
632	Extens agric, oil and gas expl S of Paradise Hill SK	-21.1
633	Patchwork of clearcuts N of Onion Lake AB	-3.7
634	Lashburn SK w extens agric, oil and gas expl	-22.1
635	Large clearcut outside Canwood SK	-21.9
636	Prince Albert SK	-34.5

637	Old post-harvest regen in SK, east of Onion Lake AB	5.4
638	Extens agric landscapes around Choiceland SK	-12.0
639	Extens agric landscapes around Nipawin SK	-19.4
640	Large mine op NE of Nipawin SK	3.5
641	Agric turns to forestry far N of Prince Albert SK	-1.9
642	Mine op surrounded by tilled agric hummocks NW of Watrous SK	-36.4
643	Big open pit mine on AB/SK border	-4.1
644	Saskatoon SK	-39.9
645	Potash mine (?) E of Saskatoon	-49.1
646	Post-harvest regen areas near Candle Lake SK	15.0
647	Dalmeny SK and extens surrounding agric landscapes	-21.7
648	Potash mine 2 E of Saskatoon	-31.1
649	Regina SK	-50.7
650	Big potash mine SE of Saskatoon	-54.2
651	Odd forest-agro patchwork N of Regina	2.4
652	Small potash mines (?) N of Martensville SK	-22.1
653	Huge mine 1 outside Estevan SK	-54.0
654	Huge mine 2 outside Estevan SK	-57.1
655	Huge mine 3 outside Estevan SK	-47.4
656	Huge mine 1 outside Bienfait SK	Data absent
657	Huge mine 2 outside Bienfait SK	-35.0
658	Estevan SK	-57.2
659	Moose Jaw SK	-41.5
660	Potash mine near SK/MB border	-36.3
661	Drumheller AB	-53.3
662	Lethbridge AB	-41.0
663	Gardiner Dam earthen dam build-up	Data absent
664	Forestry and oil and gas exploration, W of Cold Lake AB	-6.7
665	Big mine N of Yarbo SK	Data absent
666	Brandon MB	-52.4
667	Esterhazy SK	-15.9
668	Winnipeg MB	-55.4
669	Portage La Prairie MB and surrounding extens agric	-32.7
670	Winkler MB	-38.4
671	St Malo MB	-17.4
672	New Glasgow NS	-14.3
673	Circular agric production N of Taber AB	-21.9
674	Huge quarry at Canso Causeway, NS	-7.1
675	Large coal mine W of Stellarton NS	-15.3
676	Leamington ON	-45.3

677	Extens old forestry around Millbrook NS	-5.5
678	Sandilands MB surrounded by forest	-8.1
679	Truro NS	-18.1
680	Barren or bare tallous in northern ON	1.0
681	Sackville NS	-13.6
682	Upland barrens (?) in northern QC	5.5
683	Treed wetland (?) in northern ON	16.2
684	Stellarton NS	-11.8
685	Industrial ops at Obimiscow QC	4.6
686	Development on Bedford Commons, NS	-19.2
687	Quarry (?) outside Portobello NS	-12.5
688	Low dens northern coniferous forest in northern QC	0.8
689	Halifax regional landfill, NS	-13.9
690	Quarry outside Bedford NS	-9.1
691	Grand Pre NS	-22.2
692	Forested lowland in north central QC	-8.5
693	Windsor NS	-20.8
694	Gypsum mine outside Windsor NS	-29.5
695	Gypsum mine 2 outside Windsor NS	-22.0
696	Hall's Harbour NS	Data absent
697	CFB Greenwood air force base	-29.9
698	Extens patchwork of cuts outside Digby NS	-0.1
699	Extens clearcuts near Walton NS	-12.0
700	Point Tupper mill or power station NS	Data absent
701	Aggregate quarry outside Glenora NS	-12.3
702	Antigonish NS	-17.7
703	Digby NS	Data absent
704	Aggregate quarry outside Askilton NS	-8.3
705	Extens post-harvest regen, Cape Breton	6.4
706	More post-harvest regen, Cape Breton	13.3
707	Even more post-harvest regen, Cape Breton	9.5
708	Forests and agric matrix in Eastern PEI	-10.1
709	Refinery at Point Tupper NS	Data absent
710	Shaw open sand pits, Coldbrook NS	-21.5
711	Post-harvest regen N of Shelburne NE	12.4
712	Lots of agric mixed with forest patches, S of Tignish PEI	-15.1
713	Large contiguous forest patch S of Montague PEI	1.0
714	Some untouched hills in Cobequid mountains NS	3.2
715	Within Chignecto Game Sanctuary NS	-0.5
716	Bogs in southwest NS	20.9

717	Old forestry outside boundaries of Cape Chignecto PP, NS	Data absent
718	Dam on Granite Lake, NL	-8.6
719	Springhill NS	-11.1
720	Old forestry site, western NL	16.7
721	Post-harvest regen W of Route 12, central NS	-2.6
722	Brooks AB	-37.1
723	Alberta Badlands park area	-61.4
724	Medicine Hat AB	-37.5
725	Non-descript rangeland amidst circular agric production in AB	-47.9
726	Milk River AB	-37.9
727	Summerside PEI	Data absent
728	Hoodoo formations - Writing-on-Stone Prov Park AB	-55.2
729	Meandering Badlands streambed surrounded by agric, southern AB	-42.5
730	More extens circular agric production in southern AB	-15.8
731	Pincher Creek AB	-27.8
732	Waterton Lake golf course	-10.2
733	Raymond AB	-27.4
734	Edge of foothills, Longview AB	-11.6
735	Extens patchwork of forestry in foothills N of Calgary	-14.6
736	Okotoks AB	-33.2
737	Big patchwork of cuts within foothills far N of Calgary	4.9
738	Post-harvest regen on edge of foothills AB	8.1
739	Hamiota MB and extens surrounding agric landscapes	-17.2
740	Extens patchwork of cuts and post-harvest regen, far N of Calgary	13.7
741	Cochrane AB	-29.2
742	Hinton AB	-23.3
743	Signs of oil and gas exploration N of Moutain House AB	-1.9
744	Drayton Valley AB	-18.7
745	Landscape of many cuts and regen near Nordegg AB	8.9
746	Extens post-harvest regen outside Hinton AB	10.4
747	Extens post-harvest regen E of Hinton AB	9.6
748	Foothills rangeland N of Waterton Lakes NP	-15.1
749	St Albert AB	-35.5
750	Fort Assiniboine AB	-6.0
751	Fort Saskatchewan AB	-26.6
752	Edmonton AB	-40.0
753	Extens cuts N of Hinton AB	-10.2
754	Camrose AB	-30.2
755	Wetaskiwin AB	-18.9
756	Red Deer AB	-42.1

757	Small-scale oil and gas exploration on SK/AB border	-35.7
758	Foothill quarries (?) in AB	-19.9
759	Landscape of oil and gas, cuts, regen, Peace River region AB	21.1
760	Leduc AB	-28.7
761	Oil and gas expl grid on landscape outside Swan Hill AB	4.5
762	Lots of cuts and regen in foothills S of Hinton AB	7.8
763	Large mountainside clearcuts on Queen Charlottes	Data absent
764	Oil and gas expl and cuts w regen outside Swan Hill AB	9.8
765	Spruce Grove AB	-25.2
766	Extens landscape of cuts on edge of AB foothills	2.9
767	Burnside Industrial Park, NS	-39.8
768	Halifax Peninsula, NS	-36.0
769	Clearcuts beyond Hammonds Plains developments, NS	-14.6
770	More clearcuts in hills S of Windsor NS	-10.2
771	Clearcuts and post-harvest regen in central W NS	-7.8
772	Some cuts and post-harvest regen in Yarmouth County NS	12.2
773	Yarmouth NS	-2.1
774	Small bog network outside Shelburne NS	10.5
775	Clearcut patches S of Bridgetown NS	-1.3
776	Saint John NB	-64.3
777	Extens post-harvest regen S of Hampton NB	0.9
778	Moncton NB	-38.5
779	Extens riparian agric along Memramcook River (?) NB	-14.5
780	Shediac NB	Data absent
781	Extens forestry and post-harvest regen outside Moncton NB	-6.6
782	Open pit mine S of Bathurst NB	-33.5
783	Bathurst NB	Data absent
784	Extens agric landscapes around Fort Fairfield NB	Data absent
785	Grand Falls NB and extens agric surrounding	-17.4
786	Extens forestry and post-harvest regen outside Grand Falls NB	-5.4
787	Patchwork of cuts and post-harvest regen in SW of NB	2.1
788	Trois Pistoles QC	-6.8
789	Patchwork of cuts and regen in mtns over Kamouraska Region QC	1.9
790	Townsite for Thetford Mines QC	-27.6
791	Open pit mine 1 - Thetford Mines QC	-25.0
792	Open pit mine 2 - Thetford Mines QC	-12.7
793	Open pits 3 and 4 (?) - Thetford Mines QC	-38.2
794	Victoriaville QC	-36.4
795	Chicoutimi QC	-35.9
796	Jonquiere QC	-37.6

797	Extens agric S of Alba	-13.3
798	Extens agric landscapes around Lac St Jean QC	-0.7
799	Massive clearcut landscape NE of Lac St Jean QC	0.1
800	Continuation of massive clearcut landscape NE of Lac St Jean QC	-9.1
801	Easterly continuation of massive clearcut landscape NE of Lac St Jean QC	0.8
802	Another massive clearcut landscape N of Lac St Jean QC	5.9
803	Extens clearcut landscape N of Chicoutimi QC	-0.9
804	Patchwork of large clearcuts - Anticosti Island QC	-3.2
805	Patchwork of small clearcuts on Anticosti Island QC	9.7
806	Low and med density upland forests	10.3
807	High density forests along river canyons, Labrador	12.4
808	Very low density upland forest in northern QC	17.0
809	Huge exposed sand patch 1 S of Great Slave Lake	Data absent
810	Huge exposed sand patch 2 S of Great Slave Lake	-25.0
811	Patchwork forestry NW of High Level AB	10.7
812	Extens spread of small-scale oil and gas expl, northern AB	10.8
813	Extens large cuts and post-harvest regen in Northern Rockies	18.4
814	Pristine (?) forest along Northern Rockies river valley	23.3
815	Extens patchwork of clearcuts SW of Topley BC	10.7
816	Extens patchwork of clearcuts SW of Vanderhoof BC	-2.7
817	Extens patchwork of clearcuts S of Prince George BC	-15.8
818	Extens patchwork of low evel clearcuts - central BC Rockies	14.3
819	Extens patchwork of low elev clearcuts - central BC Rockies	11.0
820	Extens patchwork of low elev clearcuts 2 - central BC Rockies	Data absent
821	Salmon Arm BC	Data absent
822	Extens patchwork of low elev clearcuts outside Salmon Arm BC	-2.7
823	Extens patchwork of clearcuts in Northern Okanagan region	8.8
824	Kelowna BC	-43.7
825	Vernon BC	-48.8
826	Clearcut moutaintop and side-slopes in Thompson-Nicola region of BC	17.5
827	Extens patchworks of clearcuts in Thompson-Nicola region of BC	-5.2
828	Extens patchwork landscape of clearcuts NE of Seton BC	-20.7
829	Extens patchwork landscape of clearcuts N of Seton BC	-3.0
830	Low density high elev forests on Hunter Island BC	Data absent
831	Lots of clearcuts and post-harvest regen on W Thurlow Island BC	7.0
832	Extens clearcuts and post-harvest regen outside Campbell River BC	18.4
833	Extens post-harvest regen S of Campbell River BC	19.4
834	Large cuts and regen S of Port Alberni BC	6.8
835	Parksville BC	Data absent
836	Courtenay BC	-16.2

837	Agric landscapes N of Courtenay/Comox BC	6.7
838	Patchwork of low elev clearcuts and regen, Vancouver Island	Data absent
839	Vancouver BC	-53.3
840	Abbotsford BC	-19.5
841	White Rock BC	-16.9
842	Chilliwack BC	-25.4
843	Patchwork of clearcuts and post-harvest regen N of Lake Superior	1.0
844	Sudbury and mine sites	-29.4
845	Agric landscapes around Noelville ON	-4.4
846	Patchy deciduous uplands S of North Bay region	7.4
847	North Bay ON	-38.8
848	Peterborough ON	-26.8
849	Belleville ON	-37.1
850	Extens clearcut and regen landscapes, upper Gatineau River	-4.2
851	Extens patchwork of clearcuts, upper Gatineau River	-10.2
852	Extens landscape of clearcuts and regen, upper Gatineau River valley	-11.5
853	Large checkerboard clearcut patches SE of Dryden ON	-7.5
854	Large patchwork of clearcuts W of Thunder Bay ON	-9.6
855	Huge post-harvest regen patch on US border S of Thunder Bay ON	8.4
856	More patchwork clearcuts SE of Dryden ON	-16.3
857	Extens patches of clearcuts along US border, northwest ON	1.8
858	Clearcut along Arrow Lake ON	Data absent
859	Patchy agric, forestry and settlement outside Thunder Bay	-0.4
860	Agricultural areas on outskirts of Thunder Bay ON	-1.8
861	Upland treed barren (?) along Albany River ON	-7.2
862	Albany River Provincial Park ON	-5.3
863	Elliot Lake ON	-9.6
864	Surficial till N of Blind River ON	-1.0
865	More surficial till N of Blind River ON	3.0
866	Even more surficial till N of Blind River ON	6.5
867	Extens landscape of low dens forest N of North Shore ON	-0.4
868	Ski hill outside Elliot Lake ON	1.1
869	Open pit mine S of Elliot Lake ON	6.2
870	Patchwork of post-harvest regen near North Shore ON	-0.2
871	Thessalon ON	-11.1
872	Lakeside agric outside Thessalon ON	0.1
873	Patchwork agric outside Thessalon ON	-2.3
874	Agricultural production around Parkinson ON	-0.4
875	Agric or forestry outside Dunns Valley ON	1.3
876	Agric around Dunns Valley ON	1.4

877	Sault St Marie ON	-37.5
878	Riverside agric landscapes E of The Sault	-5.9
879	Open pit mine outside Bruce Mines ON	-5.0
880	Bruce Mines ON	Data absent
881	Agric around Plummer Township ON	-3.4
882	Agric landscapes on St Joseph Island ON	-3.5
883	Post-harvest regen S of Dunns Valley ON	7.9
884	Dykeland agric (?) in Goulais River ON	-2.1
885	Upland decid forests on W shore of Lake Superior ON	23.5
886	Agric around Leeburn ON	4.1
887	2 mines near Plummer Additional ON	1.9
888	Exposed till hillsides near Plummer Township ON	2.3
889	Exposed till hillside S of Rock Lake ON	3.8
890	Big open pit mine in Plummer Additional ON	0.9
891	Numerous exposed till hillsides, Plummer Additional ON	-0.4
892	Small mine op at Rock Lake ON	6.5
893	Old forestry and agric landscapes in Country Home ON	3.0
894	Exposed till hillsides N of Rydal Bank ON	-1.5
895	Old open pit mine E of Rydal Bank ON	5.9
896	Agricultural landscapes N of Bruce Station ON	-3.6
897	More exposed till outside Rydal Bank ON	3.6
898	More post-harvest regen N of Wharncliffe ON	7.5
899	Post-harvest regen outside Wharncliffe ON	4.0
900	Scattered post-harvest regen N of Wharncliffe ON	7.8
901	Post-harvest regen outside Batchawana ON	Data absent
902	High biomass agric(?) N of Thessalon ON	-0.6
903	Exposed till S of Wharncliffe ON	1.3
904	Agric landscapes btw Spanish and Espanola ON	0.4
905	Upland post-harvest regen(?) N of Goulais River ON	18.8
906	Espanola ON	-24.1
907	Massey ON	-3.0
908	Open pit mine at Poncet ON	Data absent
909	Exposed rock around Killarney ON	-1.8
910	More exposed rock landscapes around Killarney ON	-0.5
911	Extens exposed till landscapes around Key Inlet ON	-16.4
912	Byng Inlet ON	-16.9
913	Exposed till hillside outside Leeburn ON	-1.0
914	Extens exposed till landscapes around Byng Inlet ON	-21.1
915	Agric landscape surrounded by forest W of Midland ON	-11.8
916	Midland ON	-31.2

917	Open pit mine SE of Port Severn ON	-15.1
918	Exposed till hillsides W of Mac Tier ON	-10.3
919	Mine 1 S of Mac Tier ON	4.0
920	Parry Sound ON	-13.2
921	Mine 2 S of Mac Tier ON	2.9
922	Mac Tier ON	-3.7
923	Huntsville ON	-11.6
924	Exposed till landscapes N of Killbear Park ON	-5.3
925	Exposed till amidst forested landscapes W of Huntsville ON	-2.8
926	Strip-cut forestry S of Nipigon ON	-0.5
927	Nipigon ON	-6.5
928	Patchwork of clearcuts w exposed till outside Hurkett ON	2.9
929	Decomm'd mine (?) S of Mac Tier ON	-2.3
930	Terrace Bay ON	1.3
931	Extens patchwork of clearcuts N of Thunder Bay ON	-0.6
932	Checkerboard clearcuts outside Terrace Bay ON	9.0
933	Old forestry adjacent to open pit mine outside Hemlo ON	10.0
934	Post-harvest regen and recent cuts N of Terrace Bay ON	10.9
935	Big open pit mine E of Hemlo ON	-8.8
936	Extens post-harvest regen E of Hemlo ON	2.4
937	Terrace Bay pulp and paper mill	-12.3
938	Extens post-harvest regen w exposed till SE of Hemlo ON	1.8
939	Extens landscape of post-harvest regen W of White River ON	9.9
940	More post-harvest regen w exposed till E of Hemlo ON	5.3
941	Extens patchwork of clearcuts N of White River ON	-2.1
942	Eagle River Gold Mine, ON	15.7
943	Extens landscape of post-harvest regen N of White River ON	-1.6
944	Old cuts SE of Wawa ON	10.0
945	Extens patchwork of clearcuts and strip cuts far E of White River ON	5.3
946	Killarney ON	-4.9
947	Big mine ops N of Neys ON	19.4
948	Exposed till amidst forest near Jackfish ON	18.2
949	Big forestry scar on N shore of Lake Superior ON	14.9
950	Exposed till/rock outside Middleton ON	Data absent
951	Exposed till near Pic Island ON	25.0
952	Landscape of exposed rock on shore of Lake Superior ON	-3.2
953	Coldwell ON	15.1
954	Patchwork of recent clearcuts, Sudbury District ON	-0.5
955	Upland decid forests W of Coldwell ON	24.9
956	Extens patchwork of regen and clearcuts, Sudbury District ON	1.2

957	Former townsite of Jackfish ON	Data absent
958	Patchwork of big clearcuts, Sudbury District ON	-3.1
959	Big mine E of Kamiskota Falls ON	-0.2
960	Post-harvest regen, Sudbury District ON	0.2
961	Patchwork of clearcuts and post-harvest regen, SW of Timmins ON	-2.1
962	Patches of strip cutting on edge of burn scar, SW of Timmins ON	3.0
963	Agric landscape E of Sudbury ON	-18.5
964	Chelmsford ON	-13.0
965	Old cuts w exposed till NW of Neys ON	14.6
966	Decomm'd uranium mine NE of Elliot Lake ON	Data absent
967	Marathon ON	1.1
968	Patchwork of clearcuts NW of Sudbury ON	-4.8
969	Decomm'd uranium mine outside Elliot Lake ON	1.7
970	Mine 1 in Levack ON	Data absent
971	Decomm'd Milliken Mine - uranium - N of Elliot Lake ON	6.4
972	Decomm'd Stanleigh Mine - uranium - N of Elliot Lake ON	1.3
973	Old decomm'd mine outside Elliot Lake ON	-0.9
974	Another extens patchwork of regen and cuts, Sudbury District ON	-3.6
975	Former minesite(?) on Dunlop Lake ON	-2.6
976	Extens crescent of exposed bedrock around Kaladar ON	-7.2
977	Former minesite(?) N of Elliot Lake ON	Data absent
978	Port Colborne ON	-43.3
979	Extens post-harvest regen, Sudbury District ON	-2.0
980	Large agric wetland NW of Port Colborne ON	-14.3
981	Welland ON	-44.2
982	Open pit mine W of Port Colborne ON	-30.6
983	Decomm'd Marmora Mine, Marmora ON	-10.4
984	Another decomm'd mine N of Elliot Lake ON	-0.6
985	Decomm'd uranium mine N of Elliot Lake ON	3.1
986	Mine 2 in Levack ON	-15.1
987	Clearcuts outside Pogamasing ON	-4.9
988	Mine 3 in Levack ON	-4.5
989	Hamilton ON	-54.4
990	Mississauga ON	-47.0
991	Oakville ON	-40.1
992	Large open pit mine W of Milton ON	-36.7
993	Large open pit mine SW outside Kerr ON	-25.5
994	Large open pit mine, Kerr ON	-37.7
995	Open pit mine btw tailings ponds, Kerr ON	-28.5
996	Forests amidst agric around New Credit ON	-16.3

997	Caledonia ON	-29.5
998	Vegetated lacustrine sands outside Turkey Point ON	-35.5
999	Large forest patches around Haldimand ON	-17.0
1000	Large forested area N of Effingham ON	-13.3
1001	1 of 2 sulfur mines N of Ridgeville ON	-26.0
1002	Large forested area N of Fonthill ON	-28.6
1003	Agric-woodland matrix around Effingham ON	-17.0
1004	Small patches of forest amidst agric around Smithville ON	-19.4
1005	Fonthill ON	-26.3
1006	Very large forested area N of St Johns ON	-14.6
1007	Humocky agric landscapes SE of Smithville ON	-30.7
1008	Woodland-agric matrix SW of Simcoe ON	-16.3
1009	Long stretch of narrow forest NW of Dunnville ON	-15.6
1010	High biomass agric on Holland Marsh, Bradford ON	Data absent
1011	Brampton ON	-42.8
1012	NE end of Holland Marsh on Lake Simcoe shore ON	-23.0
1013	SW extent of Holland Marsh ON	-6.0
1014	Trenton ON	-33.6
1015	Lindsay ON	-26.6
1016	Woodland-agricultural matrix around Norfolk ON	-23.0
1017	Coubourg ON	Data absent
1018	Bancroft ON	-5.1
1019	Woodland-agricultural matrix outside Tweed ON	-7.5
1020	Woodland-agricultural matrix around Tyendinaga ON	-12.1
1021	Oxford House MB	-5.2
1022	Low dens forest or expose till, northern Mantario	4.6
1023	Lakeside open pit mine outside Colborne ON	Data absent
1024	Lakeside agric landscapes W of Port Maitland ON	-26.7
1025	N extent of entire valley clearcut in N interior Rockies, BC	7.3
1026	S extent of entire valley clearcut in N interior Rockies, BC	-6.8
1027	Exps'd sand at delta intersection of 2 large rivers, N interRockies, BC	-14.9
1028	Old clearcuts along mountainside(?) outside Hyland Post BC	-10.9
1029	Hyland Post BC	-12.7
1030	Extens serpentine patchwork of clearcuts NW of Hazelton BC	12.9
1031	Network of huge clearcuts along valleys NW of Hazelton BC	10.8
1032	Very large clearcut patchwork along Cassiar Hwy valley, BC	Data absent
1033	One very large riparian clearcut along Cassiar Hwy, northern BC	13.2
1034	Patchwork of large clearcuts along Meziadin Lake, BC	15.3
1035	Extens large clearcuts along Glacier Hwy valley, northern BC	12.4
1036	Extens patchwork of clearcuts and regen NW of Rosswood BC	13.8

1037	Extens patchwork of clearcuts along N Kispiox Valley, BC	4.6
1038	Extens low elev clearcuts along valley near Terrace BC	-2.0
1039	Kitimat BC	-14.6
1040	Extens riparian clearcuts along valley outside Terrace BC	7.6
1041	Continous network of clearcut patches outside Smithers BC	1.8
1042	Pristine valley in far northern BC Rockies	9.5
1043	Terrace BC	-7.8
1044	Middle of entire valley clearcut, N interior Rockies, BC	-9.5

APPENDIX D – Land Cover Classification Tables

Table D1

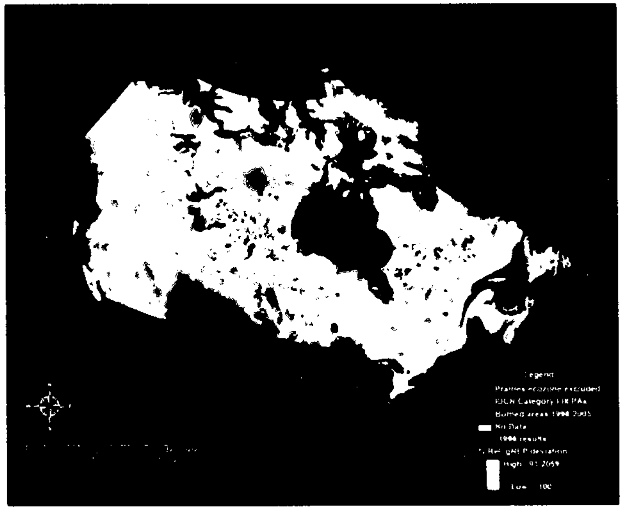
Land-use category and number (based on Cihlar et al. 2001 and Kerr & Cihlar 2003)	**Anthropogenic or Natural?**	**Removed from analysis statistical control?**
Grasslands/pasture	Anthropogenic	Yes
Rangeland/pasture	Anthropogenic	Yes
Pasture/natural vegetation	Anthropogenic	Yes
Very low vegetation cover (agr)	Anthropogenic	Yes
Grain/pasture mix	Anthropogenic	Yes
Grain - low moisture	Anthropogenic	Yes
Grain - good moisture	Anthropogenic	Yes
Grain/natural vegetation mix	Anthropogenic	Yes
Grain/canola	Anthropogenic	Yes
Canola	Anthropogenic	Yes
Corn/soya mix	Anthropogenic	Yes
Corn/soya/pasture mix	Anthropogenic	Yes
Woodland-agriculture mix	Anthropogenic	Yes
Other high biomass	Anthropogenic	Yes
Urban	Anthropogenic	Yes
Coniferous forest/very low density conifers	Natural	No
Southern coniferous, mixed deciduous forest	Natural	No
Northern coniferous forest	Natural	No
Very low density canopy forest	Natural	No
Deciduous forest	Natural	No
Post-burn/regenerating forest of various stages	Natural	Yes
Treed and open wetlands	Natural	No
Treed barrens	Natural	No
Treeless barrens	Natural	Yes
Bare rock/ice/non-vegetated	Natural	Yes

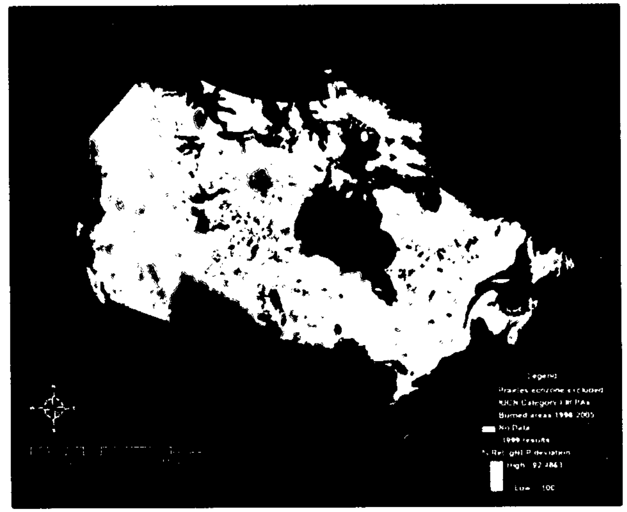
Table D2

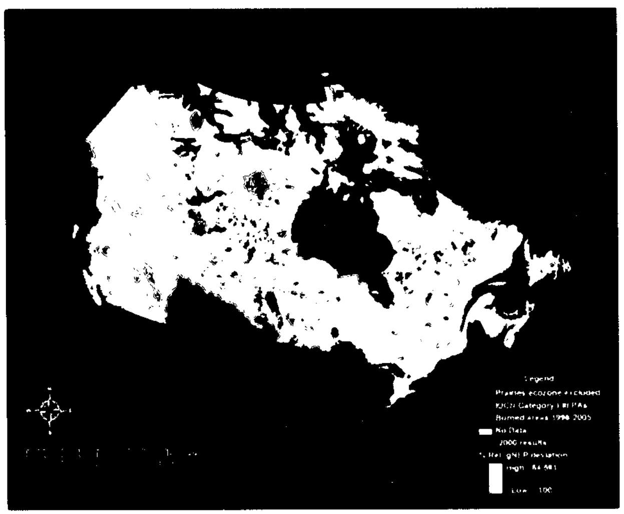
Description of Land Cover Type (based upon interpretation of Google Earth control point descriptions)	**Treatment Level for non-parametric multiple comparisons**
Urban/settlement/developed	1
Forestry (extensive and intensive methods)	2
Regenerating forest	3
Mixed disturbance (e.g., forestry with agriculture)	4
Agriculture (all crop and livestock production)	5
Mining activity & infrastructure	6
Natural (e.g., intact, remote forest)	7
Protected natural area	8
Oil & gas exploration activity	9
Unknown (e.g., indistinguishable land-use/cover)	10

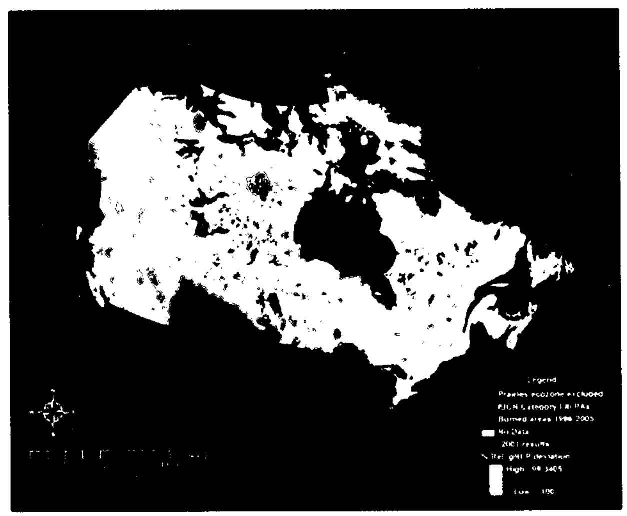
APPENDIX E – Annual relative gNEP deviations maps (1998-2005)

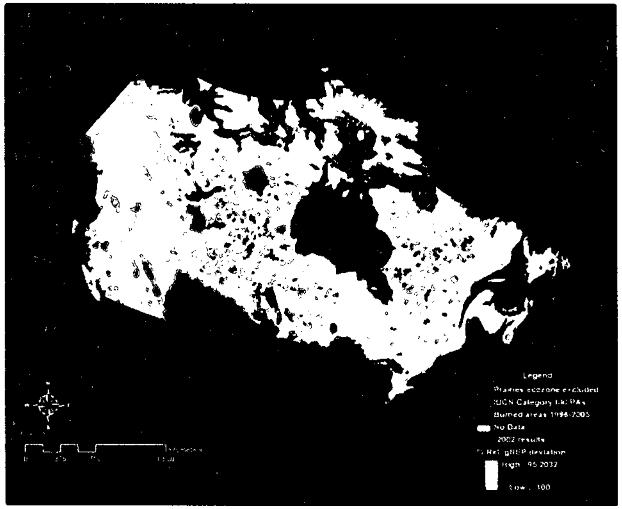
Annual relative gNEP deviations (1998-2005) calculated using equation 4. Deviation magnitudes and symbol information are provided in the map legends. All deviations are calculated relative to the mean 8-year expected gNEP baseline.










Legend
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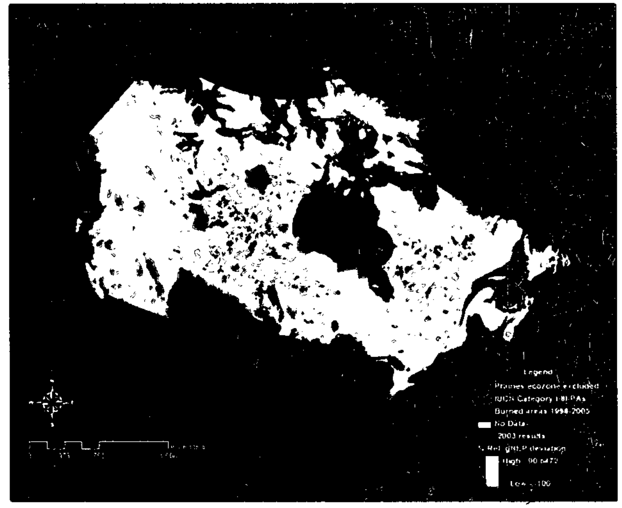
2002 results


Legend
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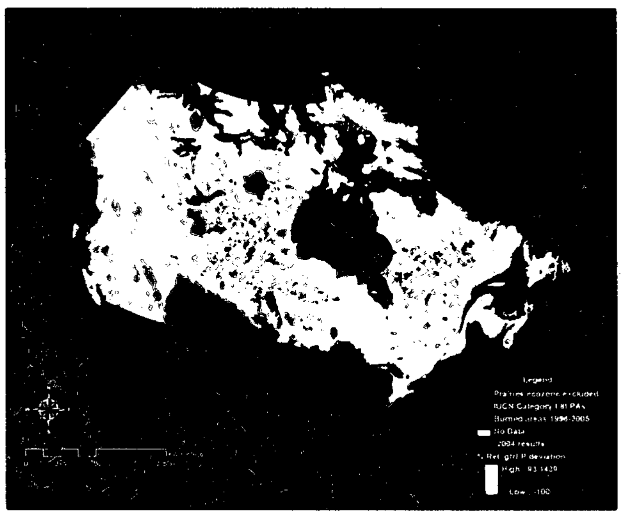
2003 results


Legend
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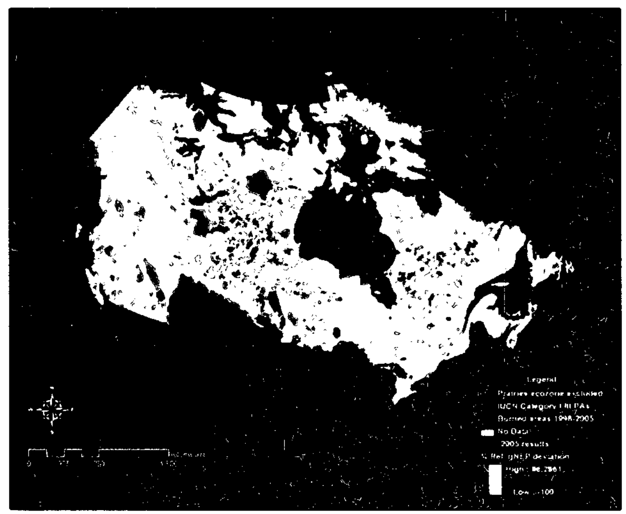
2004 results


Legend
No Data
2005 results