IIASA
International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Tel: +43 2236 807 • Fax: +43 2236 71313 • E-mail: info@iiasa.ac.at • Web: www.iiasa.ac.at

INTERIM REPORT IR-98-059/October

Air Pollution in Siberia
A volume and risk-weighted analysis of a Siberian pollution database

N. Koko Warner-Merl (warnerme@iiasa.ac.at)

Approved by

Professor Sten Nilsson (nilsson@iiasa.ac.at)
Leader, *Sustainable Boreal Forest Resources Project*

Contents

Foreword

IIASA, the Russian Academy of Sciences, and the Russian Federal Forest Service, in agreeement with the Russian Ministry of the Environment and Natural Resources, signed agreements in 1992 and 1994 to carry out a large-scale study on the Russian forest sector. The overall objective of the study is to focus on policy options that would encourage sustainable development of the sector. The goals are to assess the forest resources, forest industries, and infrastructure; to examine the forests‘ economic, social, and biospheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies.

Within this study an extensive pollution database has been established. Mrs Koko Warner-Merl has used this database for quantitative analysis of organic and inorganic emitted compounds in Siberia. These quantitative analyses have been the base for indentification of possible abatement strategies in the region. The author has conducted this work as a guest researcher at IIASA.

Abstract and Principle Findings

Air pollution from industrial centers in Siberia pose observable environmental threats. Siberian ecosystems have begun to show stress from the accumulation of pollution depositions that come from cities and industrial plants. While some uncertainty exists as to the long-term effects of air pollution upon forests, in measurable terms such as human mortality and incidence of disease, forest species decline or forest die-back, observable impacts indicate that there is cause for concern. Industrial emissions from large production centers regularly release toxins into the air, pollutants that find their way into forest soils and water systems. The risk-ranked and volume based chemical profiles here provide insight into the possible threats posed to the environment in specific regions and by specific compounds. More dynamic models must come forward to account for accumulation of pollutants, environmental response, and effects upon biodiversity in these areas.

This report analyses a pollution database provided by the Russian Federation for Siberia from the years 1992 and 1993. It reveals a pollution profile with acute spots of emissions exposure and large areas of less-affected environments. The report uses two methods to analyze emissions and to identify possible abatement strategies. The first simply identifies the volume of given pollutants in given administrative regions (oblast, kray, republic), in specific towns, and in specific industrial sectors. The second approach applies a risk-weighting factor to help identify those chemicals that, regardless of total volume emitted, have higher destructive potential than the majority of reported pollutants. This approach reveals that Siberian policy makers can take several cost-effective steps towards reducing emissions and environmental threat in the region, while helping to improve industrial performance and the international competitiveness of Siberian enterprise.

1. Using volume-based emissions data, excluding SO_2, CO_2, and NO_x for which Nilsson *et al.* (1996) already provided analysis, the following pollutants appear to pose the greatest threat to Siberian environments, in order of reported volume emitted in 1992-1993:

Inorganic compounds	**Organic compounds**
V_2O_5	Benzol (benzene)
Carbon soot	Xylene
Ammonia	Styrene
Manganese	Toulene
Lead	Methanol
Chromium hexavalent	Phenol
Nitric acid	Butazulene
Hydrogen chloride	Ethyl acetate
Sulphuric acid	Formaldehyde
Flouric gasses	Acetone

These compounds appear in almost every administrative region (the main exception being regions in the Far East) in volumes exceeding 10,000 tons *per annum.* Particular areas have varied pollution profiles in which some chemicals appear to play a more dominant role than others in posing risk to the environment.

2. By introducing a risk-ranking methodology which couples toxicity information with sheer volume of pollutants emitted, the analysis changes significantly. Using a human-health based risk ranking, the following pollutants appear to pose the most serious threat to Siberian environments, in order of toxic rank in descending order:

Inorganic compounds	**Organic compounds**
Tetraethyl lead	Furfural
Cresol	Acetone
Mercury	Toulene
Carbon tetrachloride	Styrene
Arsenic	Hexane
Hexavalent chromium	Formaldehyde
V_2O_5	Naphtalene
Hydrogen sulfide	Phenol
Hydrocyanic acid	Ethyl ether
Manganese	Xylene

The above-mentioned inorganic compounds are all ranked absolutely and relatively higher than organic compounds in posing risk to human health. These metals are categorized in this report in “high” and “medium” risk groups. The organic compounds above rank in the “medium risk” group.

The chemical that emerges as the single most toxic and environmentally threatening emission using risk-ranked analysis is tetraethyl lead. Because of its high toxicity, lead dominates the pollution profile of every administrative region and poses the most significant risk for human health. Initial research upon the toxic effects of lead upon various species of trees shows reasonable evidence that lead, combined particularly with acidifying compounds, can cause an array of developmental distortions and damage. Applying risk thresholds to lead may, however, be inappropriate given research indicating that lead in any dose may have toxic effects on living organisms. The author employs human health in order to determine environmental risk posed by various chemicals in Siberian environments.

3. Using a volume-based analysis, the industries associated with energy production such as large and small coal burning plants, oil extraction and refining contribute the greatest quantity of pollutants into Siberian environments. Policy makers concerned with reducing weight of emissions released could focus upon regulating or taxing the energy sector to reduce the types of emissions of greatest concern there (SO_2, CO_2, and NO_x).

4. Following the risk-ranked analysis of air pollution in Siberia, a much different distrubution of industries appear to be the top culprits responsible for potential environmental damage from air pollution. Energy production is notably absent, while the polymetallic industry (because of its relatively high releases of lead), machine building, and machinery and tool industry command the highest risk emissions.

   In the current situation of economic transition and adjustment, when economy-wide regulatory mechanisms and political institutions may not bear a full reform of current environmental policy, it may be most efficient to use risk-ranking to target the chemicals of most concern. If human health, and by way of proxy forest health, is a high political and economic priority, following a policy which focuses on reducing emissions at the source (typically a small handful of mega-sources in industrial complexes) will abate the riskiest compounds.

5. Areas at risk from significant damage from air pollution: East Siberia tends to have the highest (th. tons) levels of emissions and the Far East the lowest. Following an observed pattern, emissions tend to be highest around the major centers of industrial production, with the highest levels of atmospheric emissions in the southern-central part of Siberia in the regions of Irkutsk, Krasnoyarsk, and Novosibirsk.

Two areas register as Siberia's most polluted areas in terms of volume: Tyumen oblast in West Siberia and Krasnoyarsk Kray in East Siberia. Anthropogenic activities here contributed over two times the volume of pollution as any other area in Siberia, amounting between 1992 and 1993 to just under six million tons. The next-worst polluted areas are Irkutsk oblast and Kemerovo oblast, again located in East and West Siberia respectively. After these most-polluted areas comes a large gap in volumes emitted.

6. Recommended policy approaches: The natural resources of Siberia stand at long-term risk from air pollution, but much hope remains if policy makers act quickly to abate the emissions that threaten forests, human health, and ecosystems. Policy makers must first decide if toxicity or volume of emissions is most important to set abatement goals. This consideration will be based upon the key weight which two possibly conflicting, current policy goals take. Under the Russian Federation‘sl pollution charge system, industries pay fines for emissions exceeding acceptable levels. The first goal is to use pollution charges to fund other environmental programs. The second goal is to use pollution charges as a deterrent for industries to continue polluting above specified levels. It appears as if the revenue goal dominates the current policy scenario. However, if abatement takes on higher value, risk-related information such as that presented in this report will become more relevant in shaping policy. Specifically, identifying general regions of environmental risk, identifying the chemicals of most concern (either by volume or risk-rank), and identifying the key industries that serve as source points are necessary steps preceeding the formulation of a sustainable environmental policy for pollution abatement.

This report indicates that focusing on a few administrative regions such as Krasnoyarsk Kray, Irkutsk, and Novosibirsk may envelope up to 80% of total emissions and total risk-weighted emissions. An efficient policy will first target these areas, and focus on abatement in the major point sources, such as the polymetallic industry for metal emissions. Augmenting the current pollution charge system with a direct regulatory approach for strategic polluters sectors appears to offer the most realistic policy option for sustainable development in the medium- and short-term. More ambitious long-term policies may include gradually shifting energy use away from fossil fuels, a restructuring of several industrial sectors and the elimination of redundant and outdated sectors in favor of globally competitive production. The protection, and concurrently, the sustainable development of, Siberia‘s unparalled forest resources must take high priority.

1. Introduction

As Russia positions itself for a new phase of economic development based upon its vast natural resources, assessing the environmental status of Siberia becomes increasingly important. The extraction of forest products, in addition to oil, natural gas and mineral wealth, promises new sources of prosperity for the region. However, without a policy that ensures the long-term survival and use of both renewable and finite resources, Russia may exhaust its bounty and create an environmental disaster with global consequences.

Under the auspices of IIASA's Sustainable Boreal Forest Resources project, a team of researchers has already investigated several topics related to Siberia's environment. Kiseleva (1996) provided a general overview of environmental conditions in Siberia in respect to atmospheric emissions, upon which the present study expands. Nilsson *et al*. (1998) calculated critical loads estimations for acidification from SO_2, and NO_x, while other researchers have performed numerous studies on Russian forestry, industry, and oil extraction.

To complete the environmental overview of air pollution in Siberia, this study analyzes the levels and potential risks to forest ecosystems of organic and inorganic compounds. The data upon which the analysis is based was recorded by the Russian Federation, which identified the chemical compounds of interest and measured emissions of these by administrative region, city, and industrial source for the 1992 to 1993. The concern of the present study is to assess the spatial distribution of toxic inorganic and organic emissions in Siberia--divided into three subregions: West Siberia, East Siberia, and the Far East--which facilitates estimating potential environmental risks and impacts for the area. The author has attempted a preliminary risk ranking of the most toxic pollutants in specific areas, which in future research may yield more concrete details about the risks posed to environmental resources in the region. Following a general overview, the author presents a more detailed look into each region, its industries, and the pollutants that could create the highest risks and impacts upon Siberian environments. Within this report one finds descriptions of the most polluted and most pristine areas in the region, as well as major industrial polluters and the toxic chemical compounds they emit. One of the primary objectives here is to provide a baseline report on the pattern of organic and inorganic emissions and potential environmental risks.

Future research will reveal specific, direct toxic effects on identified endpoints. This report provides a point of departure for general conclusions about the threats to Siberian ecosystems from atmospheric emissions, based on a stylized weighted risk assessment which identifies by toxic potential some of the most critical pollutants in the region.[1] The author does identify several endpoints to assess the

[1] Possible endpoints for future assessment may include biological production, for which forest productive capacity could serve as a proxy. For example, researchers could assess the proportion of a region devoted to biological production that is lost or lost from production due to chemical exposures (controlling for other factors) (trees).

potential environmental impacts and risks to the environment in Siberia. While most emphasis is given to forest ecosystems (for which tree health stands as a proxy), consideration is also given to human health in polluted regions.

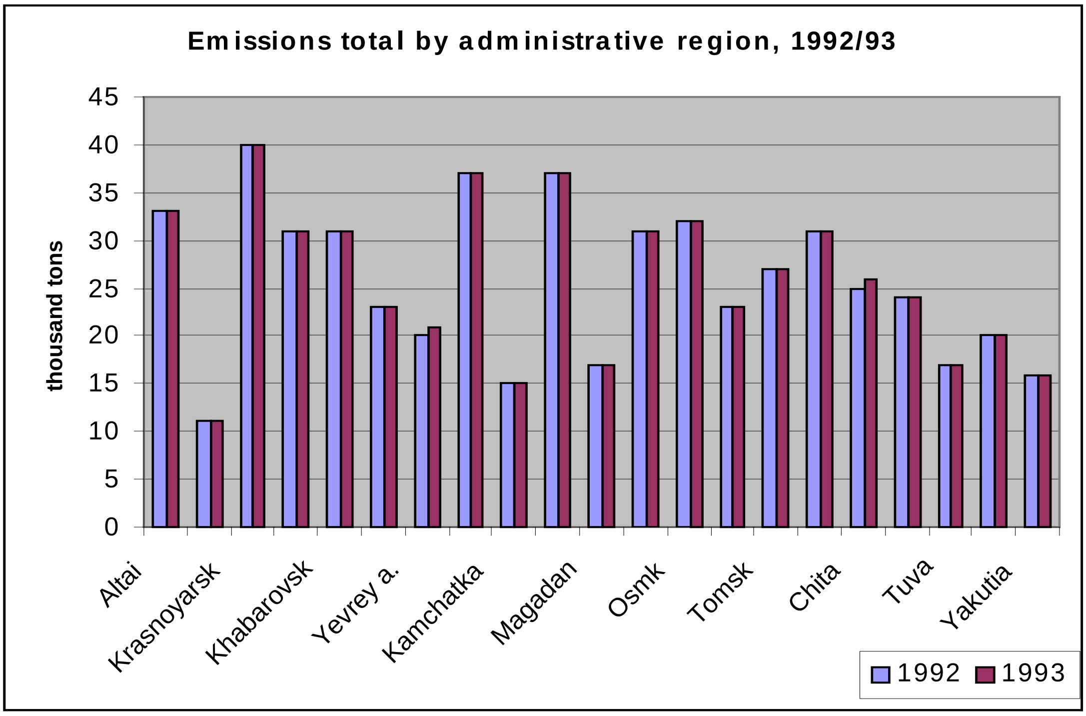
Some problems do occur with the data, which make some types of risk assessment more difficult. The data does not indicate seasonality of emissions releases. Background pollution levels for reported chemicals are not given, nor are depositions of these chemicals measured in Russian studies. “Expert opinion” seems to have played a role in some data, and discrepancies occasionally appear between regional estimates and those from Moscow. In addition the study covers only a two-year period of emissions, rendering time series analysis of air pollution less meaningful. To estimate possible environmental risks, the author has used proxy methods to assess emission impacts. These drawbacks do not, however, obscure the importance of the information presented here about the Siberian region.

Following this introduction, section two outlines the parameters of the Siberian air emissions database upon which this analysis has its basis. The two methods of volume-based and risk-weighted pollutant ranking are described. Section three provides a pollution profile of the Siberian environment, based on both volume-based and risk-weighted analysis. Regions at risk are broadly described, and cities and specific industrial centers that appear to be the culprits for the majority of target pollutants are discussed. Section four reviews current research on the effects of various toxins on forest ecosystems and points out the various stress factors to forests which can be augmented by such chemical compounds. Section five outlines policy suggestions for the development of a sustainable, viable abatement program for the region and concludes with suggestions for future research.

2. Siberian emissions database

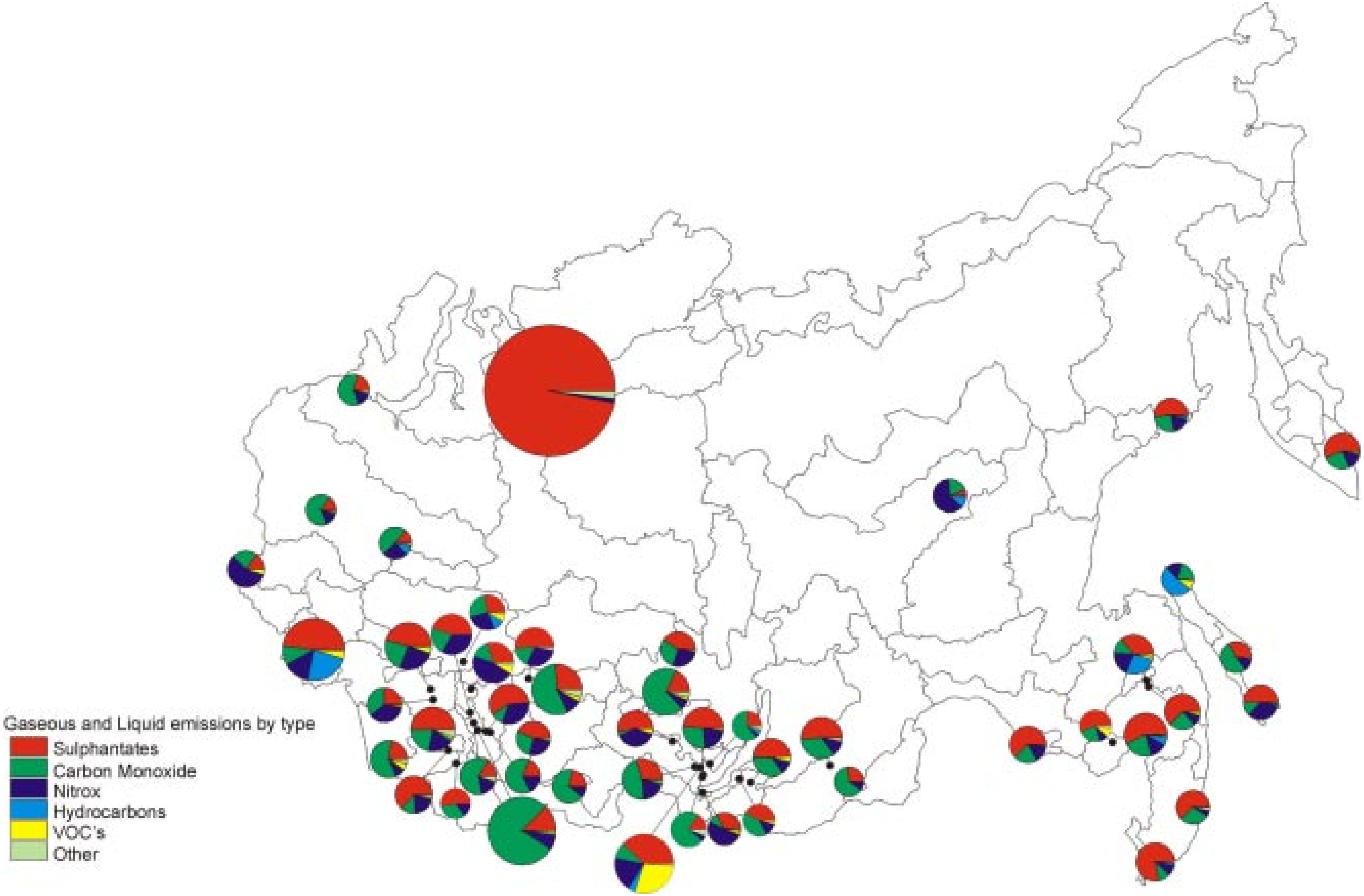
The emissions database upon which this report is based contains information about the volume of emissions in thousand tons for 22 inorganic compounds, 54 inorganic compounds, and numerous other particulates such as solid and liquid emissions, dust, flue gasses, filter residue, and recycled residue. The author focuses here upon the potential impacts of inorganic and organic emissions upon Siberian environments. These pollutants are also aggregated into eight general categories (solid, gaseous and liquid, SO_2, CO_2, NO_x, hyrocarbons without VOCs, volatile organic compounds (VOCs), and other gaseous and liquid compounds) for a broader overview of emissions. While the dispersion of these chemicals throughout the region remains unclear, initial reports estimate that a majority of pollutants deposit in a relatively near vicinity to their emission source. This creates a unique pattern in Siberia of areas of acute pollution damage and larger areas of lower risk. Chart 2.0.indicates the aggregate level of emissions in Siberia in 1992-1993.

Chart 2.0



Total Russian Federation emissions for the years 1992-93 were approximately 157,470 thousand tons and 138,200 thousand tons, respectively. During the transition period in which many industries slowed or stopped production, pollution also decreased in some locations. The total amount of pollutants from stationary sources in West Siberia 1988 was estimated at 19.3% of Russia's total, while just five years later the amount was 11,769.25 thousand tons (8.51% of Russia's total). Decreasing patterns prevailed for East Siberia and the Far East, where pollution from stationary sources measured in 1988 at 12.5% of Russia's total and 5% of Russia's total, respectively. 1993 levels were estimated at 8,515.56 (6.16 % of Russia's total) and 2,586.08 thousand tons (1.9% of Russia's total). These figures are subject to much "expert opinion," however there is reasonable certainty that they generally reflect reality as industries reduced production to meet the economic rigors of the transition phase. The situation in the past few years as industries have recovered has nevertheless changed the pollution balance again towards higher emissions. As the map below indicates, the pattern and distribution of emissions (by volume) vary significantly throughout Siberia.

Map 1 Emissions by volume, location, and type in Siberia.
Source: IIASA, Sustainable Boreal Forest Resources



The map shows that, considering only pollutant by sheer volume, SO_2 appears to be one of the most serious threats to the natural environment in Siberia, particularly around Norilsk. In Western Siberia, SO_2, CO_2, and NO_x contribute more equitably to environmental degradation. This map does not identify single pollutants that may pose particular threats to the environment. In order to move to this phase of the analysis, the author has employed a risk ranking methodology to distinguish and group the individual contaminants in the Siberian pollution database posing greatest environmental threat.

2.1 Toxicity rank of database chemicals

This study of organic and inorganic emissions reveals a pattern of particular importance for the development of a sustainable development policy for the Siberian region. While total volume of pollutants certainly concerns policy makers, of more importance will be to establish which pollutants correlate with the most environmental disturbance or damage. While it is useful to compare total volumes of chemical compounds emitted by given industries, knowing the toxic potential of the various compounds adds depth to the discussion of where emissions must be lowered, and what the potential risks for various endpoints may be.

Given the quality of the data which reports only volume quantities of emitted compounds, creating a risk ranking to determine which chemicals pose the greatest risk in Siberia becomes methodologically difficult. With more information from Russia, it would be feasible to follow the pattern set by the EPA in developing media-specific benchmark values for those chemicals commonly found in surface water, sediment and soil samples at sites (values for soil are still under development). The values are referred to as Ecotox Thresholds (ETs), and are defined as media-specific contaminant concentrations above which there is sufficient concern regarding adverse ecological effects to warrant further site investigation. ETs are designed to provide Superfund site managers with a tool to efficiently identify contaminants that may pose a threat to ecological receptors and focus further site activities on those contaminants and the media in which they are found.[2] In the future, a methodology such as that for calculating ETs could prove helpful in assessing risk from pollutants in Siberia.

Until such information becomes available, the author has employed the following methodology as an example of what could be used to estimate emissions risk in Siberia. The approach, which uses human health as an endpoint for determining the toxicity rank of the chemicals provided in the IIASA's Air Pollution database, does not accurately represent the threat to Siberian environments. Comparatively more

[2] Such an approach is most useful for screening a particular site, rather than for setting regulatory criteria, site-specific cleanup standards, or abatement goals. The approach may set thresholds too high at some sites for chemicals with the potential to bioaccumulate to toxic levels in upper trophic wildlife (e.g., methyl mercury, PCBs, DDT, dioxins, and lead).

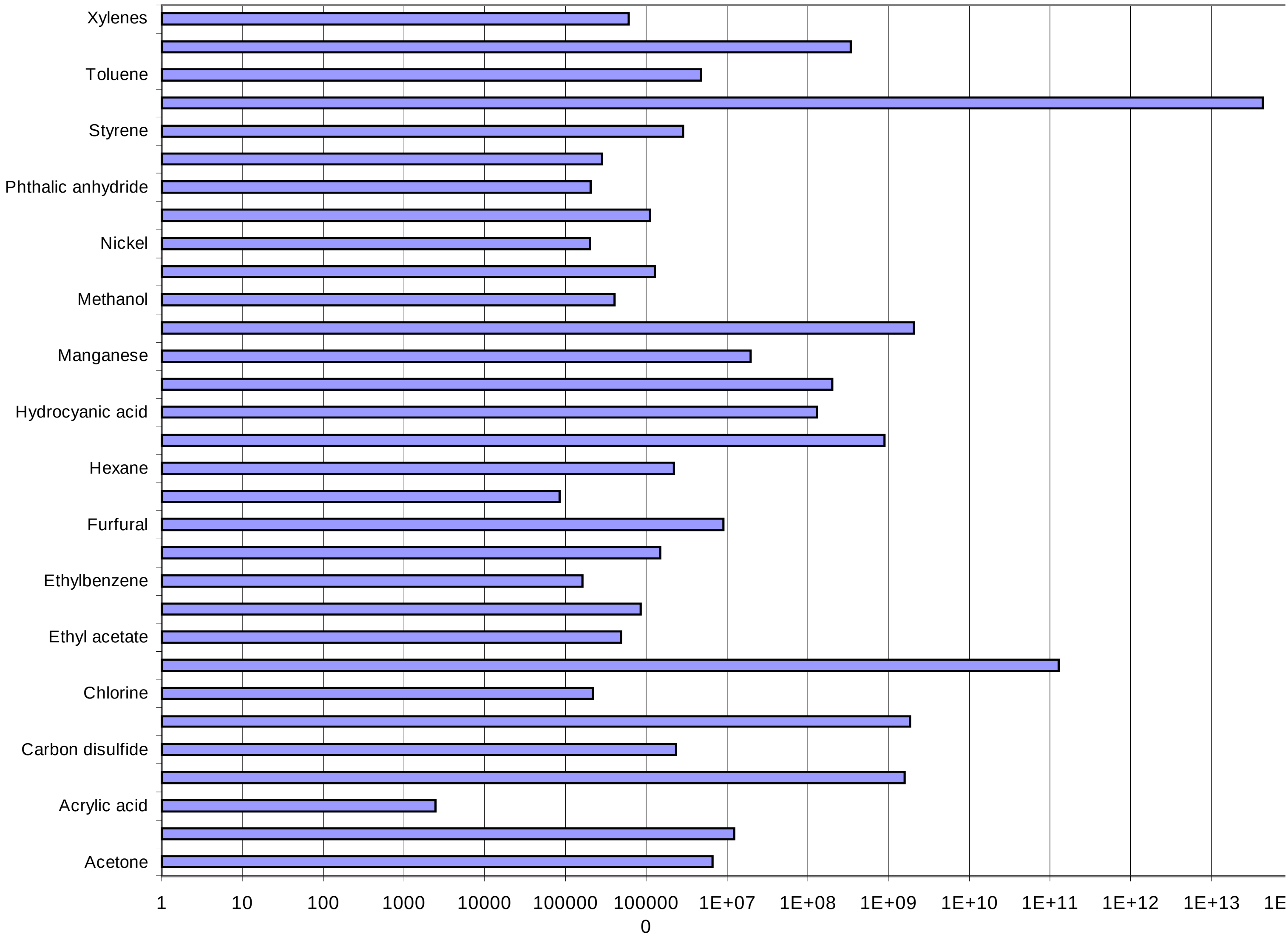
data exists for the analysis of toxic impact upon humans than for any other environmental endpoint, yet the analysis does move towards the general goal of assessing environmental impact. The report illustrates which chemicals appear to play the most important role in air pollution in Siberia and points to future areas of study for the region. As for the impact upon humans from exposure to harmful compounds, given low population densities in Siberia, exposure risk for humans to this set of atmospheric emissions appears relatively low for individuals living outside of industrial centers. Exposure risk for plants and animals, however, could be more significant. More detailed information about populations, exposure pathways, toxic impacts upon different environmental endpoints, and a variety of other chemical data is needed to carry out detailed impact assessments from air pollution in Siberia.

Using the volume of emissions by site for each compound, the author combined reference dose information for each identified compound with the volume of emissions by site for each compound. A reference dose (RfD) is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Multiplying RfDs for each chemical by total volume of each chemical emitted yields an estimate of the risk value for human health for each pollutant. Chart 2.1 illustrates the compounds which, following this method, appear to have a highly toxic impact upon humans at a given dosage (the RfD).

Risk ranking in this way allows one to divide Siberian emissions into high, medium, and low risk groups. Knowing which chemicals pose greatest threats to human health (and by way of proxy to forest health), policy makers can more cost-effectively focus on specific abatement goals. For example, the most toxic compound which appears in this analysis is tetraethyl lead, which not only appears consistently throughout the region, but also has some of the most dangerous health impacts for humans. The use of leaded fuels and lack of lead regulation in industrial processes could be responsible for high levels of lead in atmospheric emissions.[3] Other toxins that fall into this “high risk” category include mercury, cresol, arsenic, and carbon tetrachloride. Many chemicals fall into the “medium risk” category, including V_2O_5, toluene, styrene, phenol, naphtalene, manganese, hydrogen sulfide, hydrocyanic acid, hexavalent chromium, hexane, furfural, formaldehyde, carbon disulfide, acrolein, and acetone. In the “lower risk” category fall compounds such as xylene, pyridine, phthalic anhydride, nickel, methanol, hexahydro 2H-azepin-2-one, ethylbenzene, ethyl ether, ethyle acetate, chlorine, and acrylic acid. While these rankings are limited to human health, they do illustrate which chemicals pose greater threats when introducing a dose indicator such as the RfD.

[3] The author acknowledges that risk ranking may not be appropriate for chemicals such as lead and mercury. Current research indicates that exposure to such heavy metals may prove toxic at any level.

Chart 2.1 RfD Ranked toxins based upon emissions in Siberia, 1992/93



The present risk-ranking methodology uses human dosage to assign toxic risk to the Siberian pollution database. Future research in the effect of emissions upon specific endpoints such as boreal forests, soil organisms, and animal life will give more insight to the present analysis. Because large areas of Siberia are covered primarily by coniferous and deciduous forests, such measurements would prove more appropriate to measure negative effects of atmospheric emissions. The present study indicates which areas have a higher probability for risk from excessive exposure to high-risk toxins, and what the potential and observed effects upon forest ecosystems are for Siberia and its subregions.

3. Pollution profile of the Siberian environment

In this section the author outlines findings of two analyses of IIASA’s Siberian pollution database. The first identified problem areas by total volume of pollution emitted in a given year, by administrative region (oblast, kray, or republic), by town and by industry. This approach revealed a geographically distinct pollution pattern in the region, without indicating which chemicals might pose greater environmental risk. The second approach applied a risk-weighted scale based on reported chemical toxicity. Using this method, the author pinpointed specific industries and chemicals most likely to threaten Siberian forests and human populations in the vicinity of the emission sources. The results are presented first as a general overview of regions at risk, followed by a look at which industries can be closely associated with high-volume and high-risk emissions.

3.1 Regions at risk

Spanning over 597 million hectares (forested area), some 94% of which fall under state forest management, Siberia encompasses a globally unique set of ecosystems, industrial economy, and environmental challenges. Controversy has raged over the degree to which both aggregate and singular areas are threatened from anthropogenic disturbance. This report finds that large areas of Siberia are indirectly exposed to high-risk ambient toxins, while some acute areas sustain significant short- and long-term damage from air pollution.

The unique geography of Siberia, enclosed largely by mountains on all borders has allowed pollution to remain relatively localized in many areas. The air pollution problem from organic and inorganic emissions appears in many cases to be a regional problem, with some notable instances of long-distance air pollution. For example, Tyumen Oblast receives pollution from the Southern Ural industrial zone, and Canadian scientists began reporting in the 1980s that the massive industrial Norilsk complex contributes markedly to arctic haze, acid rain and marine pollution (via the Yenisey River) (Saunders, 1990). American scientists have identified suspended particles in central Alaska as consistent with nickel and other heavy metals from Norilsk, indicating that some Siberian air pollution may correlate with trans-oceanic problems (Shaw, 1982). Environmental degradation in terms of forest damage and death occur in greatest magnitude along a southern corridor in West and East Siberia, the Norilsk complex in northern East Sibera, and along coast of the Far East region.

Pryde (1994) reports that 23 regions in Siberia have ‘very critical’ environmental conditions. Seventeen of these are located in East Siberia and the Far East. Industrial cities are the main producers of atmospheric emissions; the areas surrounding these cites are most at risk for environmental damage. Ongoing studies have assessed many of these cities and have reported extensive damage from toxic emissions in terms of natural loss such as tree die-back, and human loss such as higher incidences of disease caused by exposure to toxic emissions. Poor air and water quality, severe health problems, and deterioration of natural ecosystems characterize environmental degradation in these regions. In contrast, emissions remain low in areas far from industrial centers. Estimates about the environmental damage due to air pollution varies widely; however, this assessment shows that the environmental damage due to air pollution varies significantly by location.

For the entire territory, the Geographical Institute of the Academy of Sciences of the former USSR identified around 290 areas of acute ecological situations, occupying an area of 3.7 million km^2, or about 16 percent of the total territory. Of these areas, damage from air pollution accounted for all industrial sites and some non-industrial sites (Markuse, 1993). Air pollution in 1992 around major Siberian industrial cities adversely affected approximately 160,878 km^2 of land, caused an estimated 86,000 deaths from respiratory diseases and 300,000 deaths from cancers (many of which appear related to air-born toxins), and destroyed 431,877 hectares of forests (Kiseleva, 1996; *Gosudarstvennyi doklad*, 1994; Russian Federal Forest Service, 1994). The estimated economic costs resulting from environmental damage amounts to at least 50 billion Rubles *per annum*. However, such estimates do not currently employ “green accounting” methodology to value externalities of such as clean air and complex forest ecosystems. The loss in terms of human quality of life is difficult to put into economic terms, or remains inestimable.

3.1.1 Regional emissions by volume

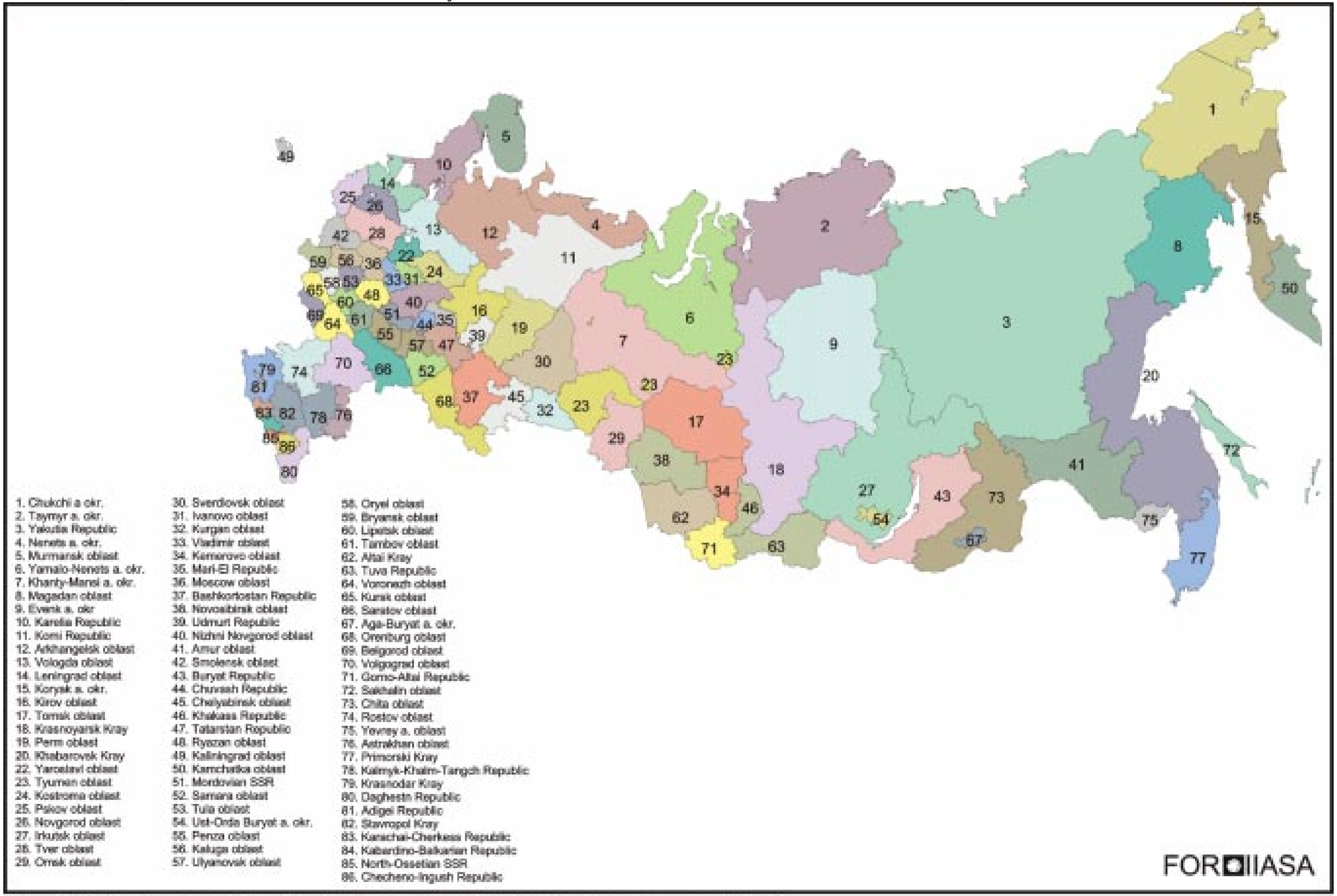
East Siberia has the highest volume of total emissions and the Far East the lowest. Following an observed pattern, emissions tend to be highest around the major centers of industrial production, with the highest levels of atmospheric emissions in the southern-central part of Siberia in the regions of Irkutsk, Krasnoyarsk, and Novosibirsk. Map 1 above illustrates the level of emissions by general category by region (indicated by relative size of each pie chart). The pattern of emissions becomes clear, with industrial centers serving as the principle sources of air pollution. The visual presentation also indicates the importance of applying risk weighting to pollution analysis in Siberia, for this analysis has shown that sulphur, nitrates, and carbon monoxide have less toxic impact than heavy metals and some organic compounds not shown in this aggregate by-volume map.

Two areas register as Siberia’s most polluted areas in terms of volume: Tyumen oblast in West Siberia and Krasnoyarsk Kray in East Siberia. Anthropogenic activities here contributed over two times the volume of pollution as any other area in Siberia, amounting between 1992 and 1993 to just under six million tons. The next-worst polluted areas are Irkutsk oblast and Kemerovo oblast, again located in East and West Siberia respectively. These industrial cities contribute a high percentage of total pollution by weight. The cities in Kemerovo oblast contribute 100 percent of solid emissions, carbon monoxide and nitrates, as well as volatile organic compounds. In Novosibirsk, industrial cities account for 90 to 100 percent of solids, sulphur, and carbon monoxide.

The remaining administrative areas contribute relatively little to overall atmospheric pollution in Siberia. The areas in the Far East emit the lowest volumes of the inorganic and organic pollutants studied here, between 100 thousand tons to 1,800 thousand tons of waste during the 1992/93 period.

Areas relatively free from environmental risk lie most often in the Far East. Vast Yakutia Republic sprawls across 3,103.2 thousand km^2, a third of the total land area of Siberia, and hosts few industrial activities. Here forest ecosystems appear to sustain the lowest levels of total emissions (averaging less than 600 thousand tons *per annum*) in all Siberia. The greatest anthropogenic threats appear to be from imprudent forestry practices. Such techniques strip permafrost soils of vegetation, exposing it to warming. At this intersection such practices become problems of atmospheric emission. As permafrost melts, potentially vast areas of once-forested areas could turn into methane and carbon-emitting swamp lands. Barring such a dramatic situation, the area appears pristine. Overall the Far East appears least harmed by atmospheric emissions, with the exception of Primorsky kray, where a well-developed transportation infrastructure, fishing, and forestry industries contribute to higher emissions weight. The Primorsky area may be of significant interest for its wealth of biodiversity and economic resources, but may be equally threatened as easier access exposes natural areas to human-related stresses (Newell and Wilson,1996). Map 2 below provides a reference for the following discussion, which focuses upon the pollution patterns and the locations in which they are manifest in Siberia.

Map 2 Political Map of the Russian Federation.
Source: IIASA, Sustainable Boreal Forest Resources Project.



Map 5.1 Political Map of the Russian Federation (Source: IIASA, Sustainable Boreal Forest Resources Project)

3.2 Cities, industry, and chemical patterns

Of immediate concern, the large industrial complexes negatively impact surrounding environments. Using a volume-based analysis of pollution, it appears that West and East Siberian industrial centers threaten surrounding natural areas, while the majority of the region sustains drastically lower impacts from organic and inorganic emissions. A similar pattern emerges in the Far East when applying volume-based analysis. Such an approach indicates that points of concentrated environmental degradation, at least in the short-term, pose low risk levels for the majority of ecosystems for the entire area.

Distinct patterns of pollution emerge from this analysis. Both volume- and risk-ranked analyses of the pollution database indicate broadly that a wide band ranging from Tomsk to Vladivostok along the 50^{th} to 60^{th} parallels sustains relatively higher risk from emissions than do other areas in Siberia. Four northern-lying exceptions exist: Norilsk, Yakutsk, Magadan, and Kamchatsky. Data from the Natsionalynyi Doklad indicate that areas around some of the largest Siberian cities and industrial centers may be chronically polluted. Areas manifesting the most significant damage in terms of square kilometers are found in Irkutsk, Krasnoyarsk, and Novosibirsk. The largest areas of damage according to this data are found in Abakan-Minusinsk and Kansk, areas around which iron ore, coal and mineral extraction contribute to emissions. The pollution emitted from Abakan industry contaminates an estimated 40% of the total land area in the Kemerovo oblast.

Chart 3.1 indicates the chronically polluted area as a percentage of the total area of administrative regions in Siberia in thousand km^2. Of note, while many areas surrounding industrial sites are chronically polluted and could be classified as “sacrifice zones,” areas lying outside them may also be affected by long-term effects of pollution such as tree die-back, increases in tree die-back due indirectly to pollution (such as weakening which leaves boreal forests more susceptible to disease and pests), and soil degradation indicate that Siberia faces greater threats from anthropogenic pollution than now estimated.

Less dramatic but still significant, Irkutsk city pollutes about 4% of the total area of Irkutsk, one of the larger administrative units in East Siberia. Norilsk industry appears to damage approximately 1.06% of the total land area in Krasnoyarsk kray. It is generally accepted that the Norilsk industrial complex is a main contributor to forest die back and earlier stages of forest decline for at least 7,520 km^2, potentially more when considering transport capabilities of the many heavy metals emitted from its heavy industries. Information in this chart, though incomplete, does indicate that industrial emissions claim about 1.05% of Siberia’s total area in what the Russian Federation calls “chronically polluted areas.” Other locations may be affected from pollution from industrial sources as well, but the above reported appear most serious.

Chart 3.1 Chronically polluted areas by administrative region in Siberia, area in km^3

Administrative Region	Total area of administrative area, km ^{3}	Chronically polluted area around industrial centers, km^3	Total polluted area in admin. area, km^3	% Total polluted area in admin. area	%Chron. polluted area in admin. area
Altai Kray	169.1		1.79		
Barnaul-Novoaltaisk		1.79		1.20%	1.20%
Gorno-Altai Republic	92.6				
Krasnoyarsk Kray	710		19.78		2.78%
Krasnoyarsk		10.72		1.51%	
Achinsk		1.54		0.22%	
Norilsk		7.52		1.1%	
Primorski Kray	165.9				
Khabarovsk Kray	788.6		6.65		0.84%
Khabarovsk		2.53		0.32%	
Komsomolsk-na-Amure		4.12		0.52%	
Amur oblast	363.7		3.89		1.067%
Blagoveshensk		1.81		0.5%	
Tynda		2.08		0.57%	
Yevrey a.oblast	36				
Irkutsk oblast	745.5		34.94		4.69%
Irkutsk		31.24		4.19%	
Baikalsk		0.7		0.09%	
Bratsk		3		0.4%	
Kamchatka oblast	170.8				
Kemerovo oblast	95.5				
Novosibirsk oblast	178.2		13.02		7.3%
Novosibirsk		13.02		7.3%	
Omsk oblast	139.7		4.58		3.27%
Omsk		4.58		3.27%	
Sakhalin oblast	87.1				
Tomsk oblast	316.9		2.02		0.64%
Tomsk		2.02		0.64%	
Tyumen oblast	161.8		4.43		2.74%
Tyumen		4.43		2.74%	
Chita oblast	412.5		1.54		0.37%
Chita		1.54		0.37%	
Buryat Republic	351.3				
Tuva Republic	170.5				
Khakass Republic	61.9		38.56		62.29%
Abakan-Minusinsk		38.56		62.29%	
Yakutia Republic	3103.2				
Total area, km^3		131.2	131.2	approx. 1.5% total area	
Source: *Obzor Sanitarnogo Sostoyaniya*, 1994.					

Analyses using diverse methodologies and with varying pollutant subjects have uniformly indicated that the areas most at risk for environmental degradation in Siberia center around the central-southern corridor of large industrial complexes (Bashkin *et al.* 1995, Kiseleva 1996, Nilsson *et al.* 1998). Pollution is worst in West and East Siberian locations. Other areas in these two regions appear less at risk. Depending upon the transport capabilities of the heavy metals and organic compounds emitted from southern towns, central and northern Siberian forests could exist almost undisturbed. However, while large tracts of land in both West and East Siberia lie far from industrial centers and may thus be at lower risk, these areas may sustain damage from: long-distance air pollution, weakening due to combined effects of pollution and natural factors, and degradation from new economic developments which can produce higher emissions. Gaps in the data prevent risk analysis for Khanty-Mansi a okr. and Yamalo-Nenets a okr. in West Siberia and Taymir a.okr, Evenk a.okr, Ust-Orda Buryat a.okr and Aga-Buryat a.okr in East Siberia.

Risk-weighted analysis adds some depth, identifying chemicals with the most destructive potential.

Risk-ranking analysis reveals that industrial centers focusing upon the production of chemicals and petrochemicals, steel, and the polymetallic products located mostly in East Siberia and centers like Norilsk and Kemerovo put those areas at higher relative risk than other industrial centers. However, because of the particular set-up of industrial complexes in Siberia, many major centers have all of the industries which tend to emit the most toxic chemicals.

3.2.1 City-source emissions of toxic substances

While the industries located in various Siberian cities determine the pollution profile there, almost all cites manifest a few similar characteristics in types and volumes of chemicals emitted. Carbon soot is emitted in large quantities in all areas, evidence that fossil fuels make up the base of energy production. Coal burning, oil combustion, and by-products from oil refineries, among others, release about 1,336,460 thousand tons of carbon soot into the air per annum in the average East Siberian industrial town (the amount rises to 2,061,510 thousand tons for Ulan-Ude in the Buryat Republic). All Siberian cities are sources of vanadium pentoxide, manganese, and chrome. Some of the major sources of chrome in Siberia are Krasnoyarsk, Novosibirsk, Barnaul, Osk, and Irkutsk. Irkutsk, the most significant producer of Cd in Siberia, discharged more than 100 tons of this, one of the most toxic identified metals. Norilsk and Belovo (Kemerovo oblast) emit tetraethyl-lead in the largest quantities, while Norilsk generally occupies first place for heavy metals emissions.

A handful of key industries appear to emit the majority of toxic emissions in Siberia by weight and by risk. These industries are located in four or five administrative regions in Siberia, with the remaining areas emitting low volumes of reported pollutants. The dominant industries for total volume of emissions in

Siberia are related to energy production and the burning of fossil fuels. These include energy production, large coal-burning energy and power stations, the fuel industry and oil dwelling (with Tyumen contributing by far the largest. The following charts show industrial contribution to emissions *by volume* in Siberia: the polymetallic industry (with industry in Krasnoyarsk the biggest polluters), and the steel industry (Kemerovo leads in emissions).

In 1987, four areas in Siberia ranked among the top ten Russian regions of industrial output. These were Sverdlovsk (27.28% cumulative share of total output), Tyumen (22.85%), Chelyabinsk (15.36%), and Bashkortostan (8.74%). Five years later after the Russian political and economic crisis, six of the top ten Russian regions of industrial output were located in Siberia, namely Tyumen (with 41.35% cumulative share of total industrial output), Sverdlovsk (35.06%), Chelyabinsk (21.05%), Bashkortostan (17.25%), Krasnoyarsk (13.56%), and Kemerovo (3.21%). The policy implications which come from this break down of industrial contribution to air pollution in Siberia include a necessary shift to increased scrubbing or away from fossil fuels and a new, less-polluting energy policy.

The analysis changes when applying a risk-weighting factor into the calculation of emissions and environmental impact. Based upon RfDs for human health, the destructive effect of heavy metals such as manganese or chromium hexavalent exceeds that of carbon soot by many magnitudes. Industries emitting smaller quantities of more harmful compounds, then, become the targets for abatement policy and reveal a pattern of pollution more serious than initially expected in Siberia.

Chart 3.2.1 Contrubution by Industry Type to Air Pollution in East Siberia

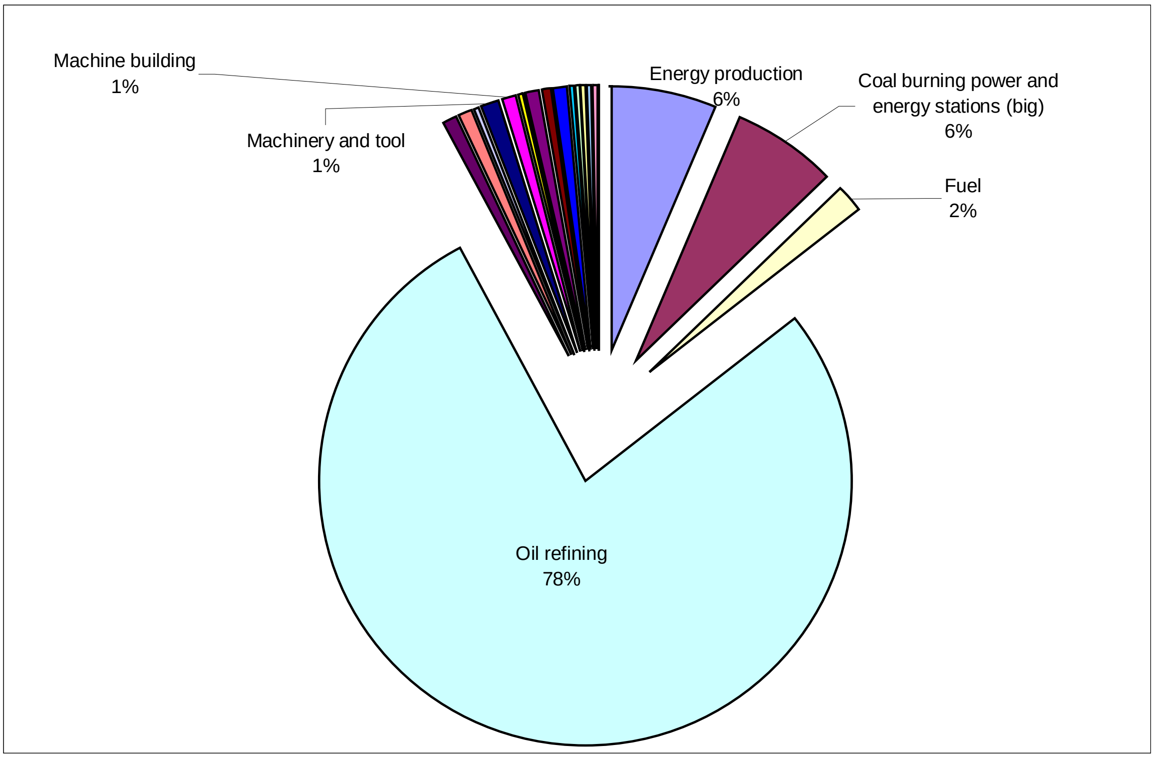


Chart 3.2.2 Contribution by Industry Type to Air Pollution in the Far East

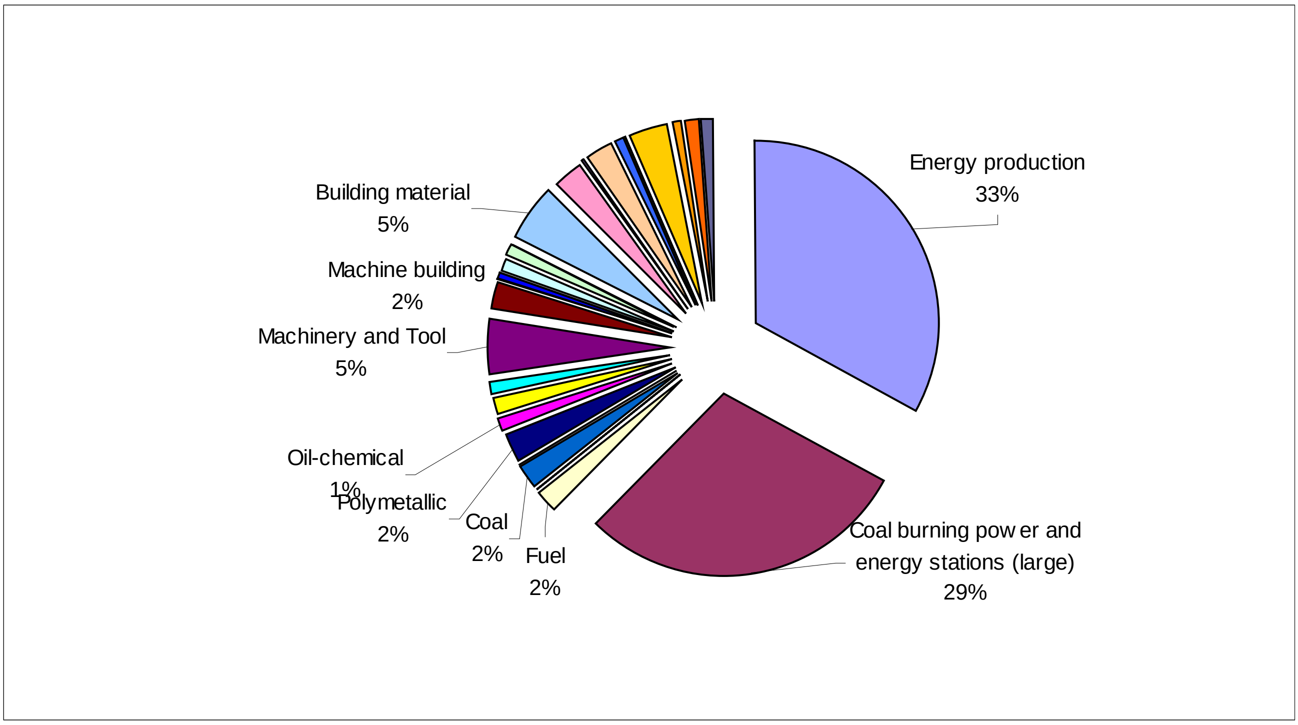
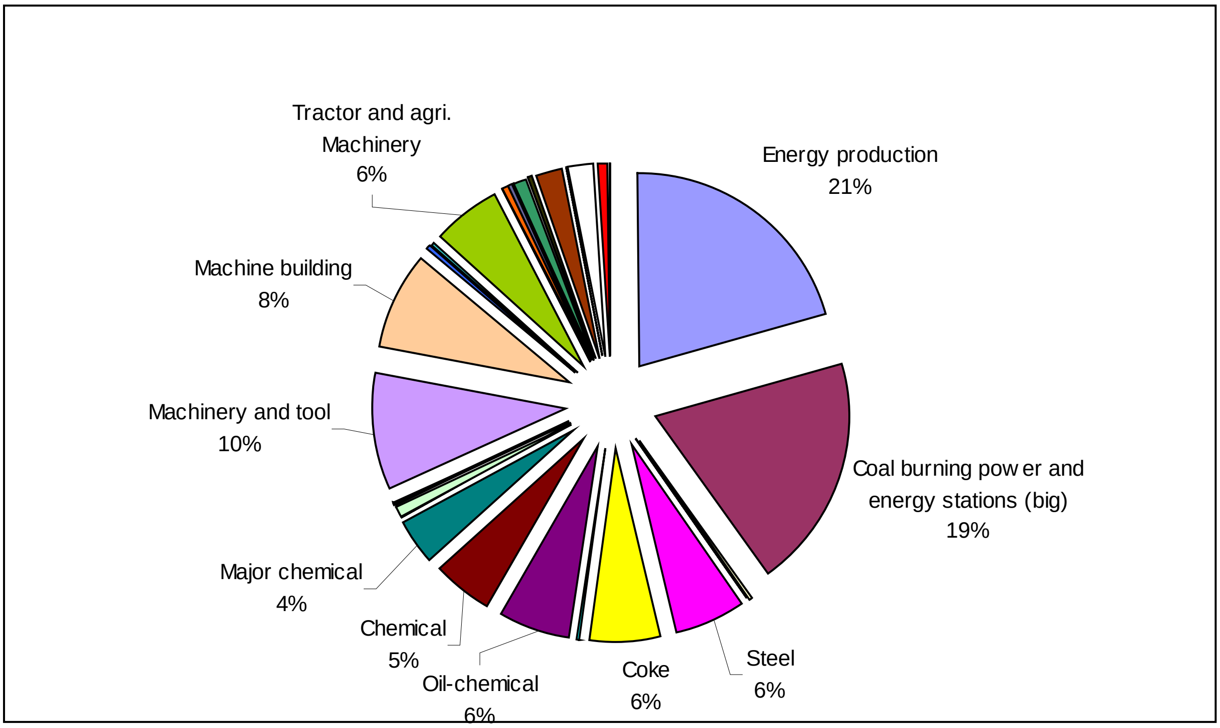


Chart 3.2.3 Contribution by Industry Type to Air Pollution in West Siberia



Some surprises emerge. For example, a random analysis of Siberian industrial cities showed that the city of Dalnegorsk was at higher risk for toxic compounds (particularly the polymetallic industry's lead emissions) than Omsk. Following Omsk, Vladivostok, Juzhno-Sakhalinsk, and Khabarovsk appeared to emit the highest risk-ranked volumes of lead in the region, indicating that environmental impact from lead depositions could be highest in the near vicinity of these points.

Industrial centers which emerge as the most serious points of emissions generally reflect those noted above for total volume emitted. Tetraethyl lead dominates the profile of toxic polluters, for which (in descending order) Irkutsk, Chelyabinsk (both significantly higher emitters of "high risk" toxins than Moscow), Krasnoyarsk (including Norilsk), Primorsky, and Novosibirsk (five magnitudes below Primorsky Kray). Although emissions by volume are higher in Norilsk, the largest emitter of metallic nickel and other metal compounds, industrial centers to the south including Irkutsk, Angarsk, Bratsk among others rank three magnitudes higher in terms of risk.

Because of the extreme toxicity of lead and its low reference dosage, the analysis of significant pollutants changes significantly when lead is excluded. The charts below compare volume-ranked emissions by industry in Siberia and risk-ranked emissions by industry in Siberia, excluding lead.

Chart 3.2.4 Volume-ranked emissions by industry

Compounds	**Associated industries in Siberia**
V_2O_5	Steel, chemical, polymetallic industry, oil refineries
Carbon soot	Coal combustion, transport, widespread industry, agriculture, chemical, paper and pulp, steel, oil refining, machinery, fuel industry
Ammonia	Energy production
Manganese	Steel, polymetallic industry, chemical
Lead	Widespread industrial use, leaded petroleum fuels, military, chemical, polymetallic, oil-refining
Chromium hexavalent	Polymetallic, chemical, widespread industrial use
Nitric acid	Energy production, large and small coal-burning energy plants, chemical, agriculture, military, fossil fuel combustion
Hydrogen chloride	Energy production, military, polymetallic industry, chemical
Sulphuric acid	Coal combustion, oil refining, polymetallic industry, wood and paper production, steel, military, chemical, agriculture
Flouric gasses	Military, polymetallic industry, chemical, cement, steel, fuel industry, agriculture, widespread industrial use

To isolate and reduce the detrimental effects of lead upon human and forest health, the chart below indicates that focusing upon the polymetallic industry (which emits up to 34% of risk-ranked pollutants in Siberia, of which lead dominates due to its extreme toxicity), the machinery and tool industry, and the machine building industry would prove most effective. Of note, other industries such as energy production, large and small coal production plants which contribute high volumes of soot and SO_2 do not contribute even one-percent of risk-ranked emissions.

Chart 3.2.5 Risk-ranked emissions by industry

Compound	**Associated industries in Siberia**
Hydrogen sulfide	Oil refineries, chemical, iron smelters, coke ovens, food processing, agriculture, oil-chemical
V_2O_5	Steel, chemical, polymetallic industry, oil refineries
Arsenic	Polymetallic industry, coal-powered energy plants, agriculture
Nickel	Steel, coal-powered energy plants, polymetallic industry, chemical, oil-chemical
Carbon disulfide	Chemical
Hexavalent chromium	Steel, chemical, polymetallic industry
Mercury	Chemical
Manganese	Steel, polymetallic industry, chemical
Hydrocyanic acid	Polymetallic industry, chemical, mining, oil-chemical

(ATSDR ToxFAQS 1993)

Of interest, when risk-ranked analysis is applied to industrial emissions data in Siberia, the following industries do not appear: gas, coke, coal, small coal-burning energy plants, major chemical industry, oil dwelling, military or transport. While the data may prove unreliable in some instances, the industries which appeared as the high-risk polluters (Pb excluded) were chemical (15% of high-risk emissions) the oil-chemical (15%), steel production (12%) and polymetallic industry (11%). Medium-risk industries included pulp and paper (8%), paper and wood (8%), energy production (6%), and large coal-burning energy stations (5%).

In the volume-based analysis, the energy sector appeared as the main culprit for total pollution emissions by ton. This lead-dominated analysis reveals that policy makers must first define the level of risk associated by individual pollutants for identified endpoints and then target specific sectors to reduce emissions. The distribution of industries contributing risk-ranked toxins into Siberia's environments changes when lead, with an RfD several magnitudes higher than the next most toxic substance, is excluded. Chart 3.2.5 indicates that for the reduction of chemicals such as inorganic arsenic, carbon disulfide, chlorine, chromium (IV), hydrogen cyanide, hydrogen sulfide, manganese, metallic mercury, metallic nickel, and V_2O_5, policy makers may find an economy-wide regulatory approach more effective than focusing on a specific sector.

This analysis reveals the aggregate contribution of risk-ranked emissions and indicates that a handful of industries pollute in high volumes, others in terms of high-risk emissions, and a few such as the chemical, polymetallic, and steel industries both in high volume and high-risk chemicals. Unlike the volume-based analysis, energy production and most oil-related activities do not appear as the major sources of particularly toxic substances.

While millions of tons of carbon soot and other petroleum fuel-related byproducts pose problems for Siberian environments, according to this analysis they may pose relatively less risk than initially thought. According to a risk-weighted analysis of the data, heavy metals and a handful of organic compounds could impose the most significant risks for Siberian ecosystems and human populations.

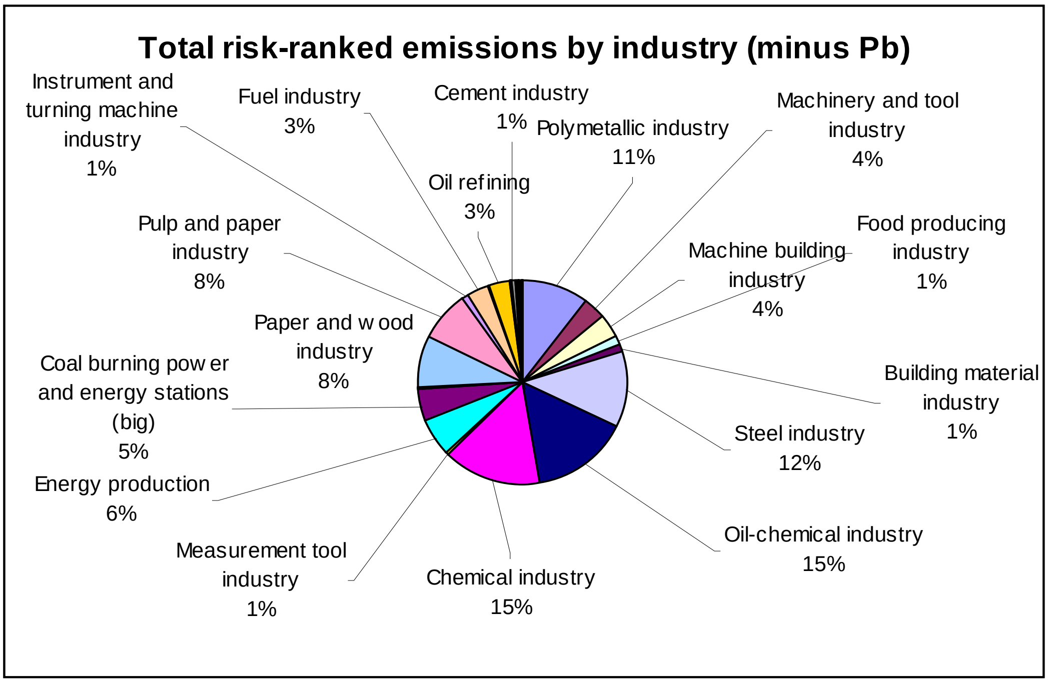
4. Threat of atmospheric emissions to forest ecosystems

Atmospheric emissions pose serious health threats to forest ecosystems. Michaelis (1997) reported the significant role which air pollution plays in forest damage, stating, “Slightly damaged trees may occur due to natural causes…but more severe damage or even the death of trees [has been] attributed to anthropogenic causes such as direct effects of air pollutants on plant organs, acid deposition, soil acidification and impairment of the mineral budget.” According to official reports forest die-back resulting from air pollution accounts for 95% of all anthropogenic factors (Obzor Sanitarnogo Sostoyaniya, 1994) and areas of loss appear concentrated along corridors of industrial activity. Forest die-back, increased susceptibility to disease and insect attacks, and simplification have all been linked with emissions in Siberia. Acidifying pollutants, heavy metals, and organic pollutants may also damage the lower plant forms of the tundra which form the food base for many animals and migratory birds (artic moss).
reversion to pioneer stages of succession. When a severe pollution stress is imposed for a long duration or in a particularly high intensity, the forest ecosystem may experience a retrogression characterized by reduction in structural complexity, biomass productivity, and species diversity (Whittaker, 1975). Abating pollution, particularly the high-risk chemicals identified in this report, would not only have a high certainty of improving forest health and preserving a valuable economic asset, but it might also halt possible forest simplification and reduction of biodiversity. Thus discovering the levels and potential risks of emitted chemicals associated with industry in Siberia becomes a priority for forest protection. Present research focuses upon estimating critical loads and their exceedances for single and combined chemicals for the regions various ecosystems (see Nilsson *et al.*, 1998).

In spite of a pattern of localized pollution, the extent of destruction in terms of total area percentage can be significant. Of most concern, up to 28% of the total area of Krasnoyarsk Kray appears to be chronically affected by toxic emissions coming from industrial centers within this administrative region (Kiseleva, 1996). Although the Natsionalynyi Doklad does not clearly define "chronic," the immediate effects upon forest die-back correlate strongly with these figures. Of a total area of 71,000 km^2, approximately 19,780 km^2 sustain damage from air pollution. These areas are in the immediate vicinity of Krasnoyarsk, Norilsk, and Achinsk. Between 1988-1993 approximately 130,000 ha of forest died due to emissions in the Norilsk industrial complex alone (Kasimov *et al.* 1993). While these numbers are significant, insufficient data may encourage official reports to underestimate damage to forest. The Russian Federal Forest Service primarily measures forest die-back rather than early stages of forest decline which may have some relation to atmospheric emissions. Combined with knowledge about the weather patterns and pollutant accumulation capabilities of the region, damage caused to forests and other parts of the environment in Siberia may concern larger areas than now estimated. In the longer term, atmospheric emissions from Siberian industrial centers could pose a serious threat to forests ecosystems far afield, weakening and destroying valuable economic and natural resources.

Primary and secondary pollution in the form of direct exposure to emissions such as sulphur dioxide, lead, and other toxic chemicals occurs on a broader level than earlier assumed in Siberia (Nilsson *et al.*, 1998). Exposure to particulates such as industrial dust, soot, lead particles, magnesium oxide, and sulphuric acid have clinically proven adverse affects on tree growth and may so affect Siberian forests, which receive moderate to high dosages of these emissions in local areas. Severe injury to woody plants may also occur in the area of large polymetallic complexes in eastern Siberia due to exposure to heavy metals, dusts and flourides. According to both volume and risk-ranked analyses below, there is reasonable certainty that forests sustain damage from these sources of industrial air pollution. The problems associated with acidification of the Siberian forests have been discussed elsewhere (Nilsson *et al.*, 1998); this report, therefore focuses on the potential adverse effects of risk-ranked chemicals (the most important of them heavy metals) upon forest health. The major sources of heavy metals in the Siberian environment include emissions from large industrial sources such as the steel industry, the chemical industry, and the polymetallic industry (including primary and secondary base metal smelters and refineries).

Chart 4.0 Total risk-ranked emissions by industry (minus Pb)



4.1 Effects of metals on forest decline

Needle and root damage and nutrition imbalances have been observed in some areas in Siberia (Nilsson *et al.*, 1998). and acid rain may liberate metals in the soils, the most commonly accepted hypothesis on the mode of metal pathogenicity in forest trees. Constantinidou and Kozlowski (1976) reported how air pollutants induce adverse metabolic changes and injuries in plant cells, warning that "eventually pollutants affect entire forest ecosystems by inducing reduction in structural complexity, biomass, productivity, and species diversity. Growth reduction by pollutants has been shown by measurements of height growth, leaf growth, xylem increment, dry weight increment of roots, stems, and leaves, relative growth rate, and reproductive growth. Air pollutants inhibit reproductive growth by decreasing the physiological efficiency of foliage, influencing mechanism of flowering and fruiting and directly injuring reproductive structures.

Kozlowski and Constantinidou (1986) note that,"**t**he rate of photosynthesis in polluted plants is adversely affected in the short term by changes in stomatal aperture, occlusuion of stomatal pores, chlorophyll breakdown, and by changes in photosynthetic enzymes, phosphorylation rate, and buffering capacity. In the long term photosynthesis is adversely affected by reduced photosynthetic surface resulting from leaf necrosis, abscission, and inhibition of leaf formation and expansion." Although current emissions levels have decreased since the height of industrial production under the Soviet regime, one may assume with some certainty that Siberian forests have been exposed to at least low-level, long term compounds such as SO_2 and nitrates, Pb, Mn, chromium hexavalent, and other high-risk chemicals.

Findings on the effects of metals on forest health provide few definitive answers about tree damage and the presence of identified emissions. Although Finnish studies have found no positive correlation between the degree of tree damage and metal concentrations, evidence exists of less direct effects of metal pollution on tree health. These Finnish observations give no evidence for a general absence of such a correlation, but do indicate that researchers have found no relationship between tree damage and metal concentrations in areas of relatively low pollution levels (Ahti 1988). However, Finnish studies have noted *less direct effects* of emissions upon forest health. In the observation area of Kotka, Ahti (1988) found a correlation between the damage caused by *Blastophagus piniperda* to pines and concentrations of Cd and Zn in *Hypogymnia-physodes* in those pines. Ahti also found a positive correlation between the damage caused by *B.piniperda* and the levels of Fe and Zn in the needles. In addition, the degree of metal concentrations correlated with the degree of damage to lichens in the study.

Metal pollution appears to cause complex ecotoxicological disturbances in forest systems that should not be overlooked even when the volume of aggregate emissions appear to be low in large parts of Siberia. Volume-based analysis leads to the assumption that large tracts of Siberian ecosystems have relatively low exposures to air pollution because reported volume of emissions in these regions are low. Risk-ranked analysis reveals that, although levels of pollution may be relatively modest, the chemical makeup of the aggregate pollution (particularly if high risk chemicals such as metals mentioned here) may put even remote locations at risk for environmental degradation. Both methods of analysis, however, suggest that areas surrounding industrial centers sustain anthropogenic damage.

Lerman and Darley (1975) indicated that foliar injury (necrosis, chlorosis, and abscission) to forests is attributable to metal particulate exposure. Several studies have shown the destructive potential of heavy metal emissions on forests surrounding near power plants, smelters, and polymetallic industries (Scheffer and Hedgcock, 1955; Scurfield, 1960; Miller and McBride, 1975; Linzon, 1978; Smith, 1981; Kim, 1982; Pandey, 1983; Ulrich and Pankrath, 1983).

In the vicinity of industrial centers (located primarily in south central Siberia) the damage to trees and other types of life forms from the high risk chemical group appears acute. The impact of lead on forests is not yet fully understood, however developmental damage can occur in trees. Studies in the 1980s showed that lead accumulated in the soil as a consequence of rising acidification, dissolved below pH4, and that this process was enhanced by high concentrations of sulphate and chloride in the soil solution (Brümmer and Herms, 1983, Herms and Brümmer, 1984). Godbold (1984) showed that the availability of just 0.1ppm of lead reduces the growth of fine roots of spruce seedlings by more than 50%. The presence of increasing acidification in Siberian forests, combined with such industrial emissions therefore poses significant threats to forests. The effects of mercury, cresol, arsenic, and carbon tetrachloride, compounds identified as “high risk” in this report, also have negative impacts on various stages of tree growth, but more research is required to determine threshold values for specific species. Research shows that Siberian vegetation manifests damage in areas where heavy metal emissions are highest (Ruhling 1978, Ruhling *et al.* 1984, Tyler 1984, Beyer *et al.* 1986, Mankovska 1986, Folkeson *et al.* 1987, Jansen and van Dobben 1987, Kazmierczakowa 1987, Braniewski and Chrzanowska 1988, Beyer 1988, Oyler 1988, Pacha 1989).

4.2 Natural factors combined with anthropogenic pollution

Apparently low levels of emissions may disguise environmental risk by obscuring the effect of weather patterns on deposition and accumulation of toxic emissions over time. In Siberia, weather patterns combine with geographical formation to make large areas of the Siberian territory barely capable of ridding itself from toxic chemicals from air pollution. The low potential for self purification makes technogenic smog in the wintertime, and pollutant accumulation in general, common (Natsionalynyi doklad, 1991). The situation is even worse around cities, where unfavorable atmospheric conditions such as anticyclones and air inversions trap toxic fumes in valleys. The forest damage appears most critical in Krasnoyarsk, where toxic clouds form as water evaporates from the massive Krasnoyarsk water reservoir.

While the presence of insects, forest fires, and disease occur naturally in the region, the presence of anthropogenic air emissions may augment the degree of damage caused by these factors. The southern area of Siberia is characterized by warmer weather conditions which allow insects to develop. Kiseleva (1996) reports that the highest density of insect loca was observed in the Altai region, Novosibirsk oblast, Tuva republic, and Primorsky Kray, all areas lying in the southern part of the region. However, the highest losses of forest due to insect activities from 1989-1993 occurred in industrialized areas of Irkutsk, Tomsk and Tyumen oblasts, with relatively high damage from insects also occurring in Kemerovo and Omsk oblasts, as well as the southern region of Krasynoyarsk kray. These areas also appear sustain the largest forest die-back resulting from air pollution (Obzor Sanitarnogo Sostoyaniya, 1994).

Dust, emitted in large quantities from Siberian factories of all types, can also severely weaken trees and make them susceptible to multiple forms of stress that contribute to tree die-back. Dust may be a locally important stress factor for trees (Nuorteva 1990). Dust pollution causes mite outbreaks but also kills some species of small insects on trees (Alstad *et al.* 1982). Studies reveal that damaged trees with characteristic symptoms of forest die-back are clearly concentrated around industrial centers and major roads.

4.3 CO_2 and the role of Siberian forests

One key pollutant, CO_2, surprisingly not included in the database upon which this analysis is based, deserves mention here. Carbon dioxide emissions in Siberia are of particular interest in light of intense discussions prior to and following Kyoto about green house gasses, Siberian industrial emissions, and the role which the forestry sector can play in emissions abatement or augmentation in terms of volume, are unique (see, for example, Kohlmaier *et al.*, 1998). CO_2 is the main polluting substance in the Siberian region (Danilov-Danily‘yan, 1993). As of 1990, the Russian Federation contributed 10.7% of the total global CO_2 emissions (UNFCCC, 1998), much of which is a result of either direct consumption of fossil fuels or as a result of fuel extraction and processing of those fuels in energy-rich Siberia. Table 4.3.1 illustrates 1990 levels of green house gases in the Russian Federation. Taking into account the significant carbon sink provided by Siberian forests, net emissions in 1990 were still 451 million tons of CO_2, over three times the carbon sink potential (estimated at160 MtC/yr).

Chart 4.3.1 Anthropogenid emission of greenhouse gases in the Russian Federation (RF) 1990

Gas (Mt)	**RF Emission/RF Sink**	**Global emission, Mt/yr[1)]**	**RF share in global emissions, %**
CO_2	651/200	6100	10.7
CH_4	27	375	7.2
N_2O	0.82	8.2	10.0
Source: UNFCCC (1995). Interagency Commission of the Russian Federation on Climate Change Problems, 1st National Communication, Moscow, Russia. 1) IPCC data			

The patterns of emissions in European Russia and Siberian Russia vary significantly, with transport and individual motorized traffic playing a significant role in the west, and primarily industrial and forest sectors playing a significant role in Siberia. Although the Kyoto Convention dealt primarily with emissions levels as of 1990, it is important to note that because of the transition, many industrial sources of CO_2 actually reduced their emissions. For example, the city of Novokuznetsk experienced a roughly 50% reduction of CO_2 and other major airborn emissions between 1987 and 1992 (Pryde, 1991). However, increased use and potential abuse of Siberia‘s vast forest resources, in addition to growth in the use of low quality materials and fuels, could offset this downward trend and exaccerbate the CO_2 problem.

The distribution and magnitude of carbon dioxide emissions also vary, according to both anthropogenic and natural forces in the region. Following the pattern of emissions seen above, CO^2 is emitted heavily in industrial pockets, particularly those where the energy sector dominates (available data indicate that the industrial corridor of south-central Siberia including cities such as Novisibirsk, Novokuznetsk, Kemerovo, Tomsk, Krasnoarsk, Irkusk, and Bratsk manifest the highest emissions of carbon dioxide). CO^2 appears to have more stationary source points than other chemicals, primarily because of widespread energy extraction and production activities, and because of the energy inefficiency of Siberian industry. Russian experts estimate that 460-540 Mtce could be saved (currently 40-45% of current energy consumption) through more effective use of energy resources. Over a third of these savings could be made in the energy production sector alone, which would lead to a 0.35-0.4% rise in national income (ICRFCCP, 1998).

Unlike the body of the analysis here which points towards chemical, steel, and other metals-related industries as the prime culprits of risky emissions, the fossil fuel industry accounts for 98% of CO_2 emissions in Siberia. In contrast, industrial production accounts for only 1.7% of technogenic carbon dioxide (UNFCCC, 1995). Although energy consumption per capita declined from 8.46 tons of coal to 6.7 tons in 1995, and from 104 million tons of motor fuel to 74 million tons in 1995, consumption levels are forecasted to rise again to (near) their 1990 levels by the year 2000 for all major types of energy (OECD, 1996).Table 4.3.4 shows the distribution of emissions according to specific features of the fossil fuel composition in Russia. Targeting energy production, particularly coal-based, as well as the use of oil and gas for fuel after processing, might make the greatest initial inroads towards carbon dioxide abatement in Siberia and the Russian Federation.

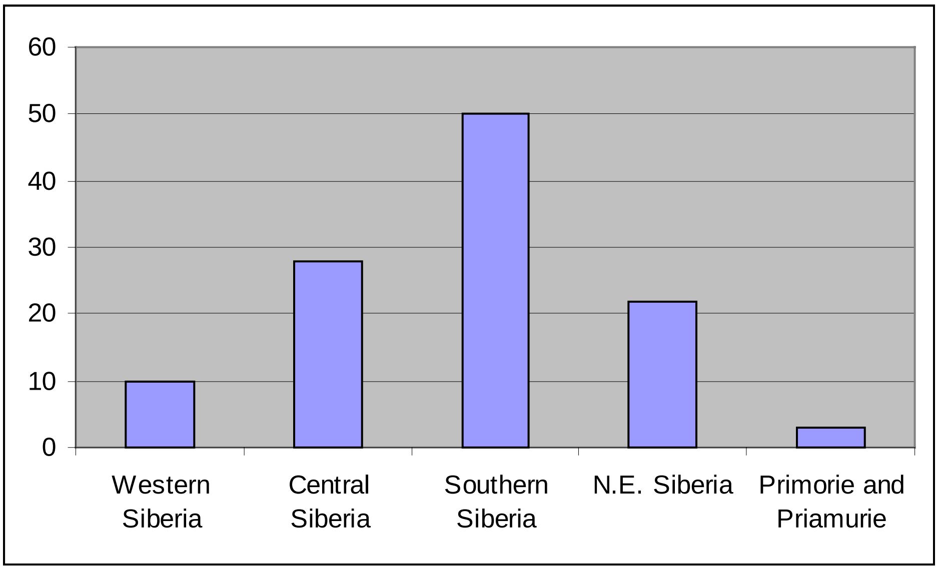
Chart 4.3.2 Types of fossil fuels and contributions to CO_2 emissions.

Fuel type	**% of CO_2 emissions**			
	Direct transformation to electric and heating energy	Use as a fuel after processing	Needs in industrial and technological processes, and other needs [1)]	Total
Coal	58.5	21.2	20.3	100.0
Oil and gas condensate	0.5	99.4	0.1	100.0
Natural gas	64.4	1.0	34.6	100.0

Source: UNFCCC (1995). Interagency Commission of the Russian Federation on Climate Change Problems, 1st National Communication, Moscow, Russia.
[1)] Including direct use as a fuel in industry and other branches of the economy.

Siberian forests are at risk from CO_2 pollution, but with wise management, they also provide a key to CO_2 abatement. Depending upon the natural climate, it is estimated that Siberian forests have the potential to absorb a significant amount of global greenhouse gasses, with European and North American forests the IPCC estimated the CO_2 mitigation potential of between 12 and 15% (Kohlmaier *et al.*, 1998).

Chart 4.3.3 Distribution of the total carbon sink by natural climate regions, MtC/yr



An increase or decrease in the carbon stock of Siberia's forest ecosystems depends upon many factors, among them: changes in land use and forested areas, changes in the age and species structure of forests (caused by harvesting, planting, or natural reforestation), and the influence of climate changes and other external forces on forest growth and decomposition of forest matter. In 1993 up to 100MtC/yr were emitted as a result of harvesting and decaying roots and branches. Anthropogenic stresses mentioned above exacerbate insect and disease attacks, the risk of forest fires, and forest growth itself, and could cause transformations of Siberian forests away from their natural roles as CO_2 sinks. The special role of Siberian forests in CO_2 abatement, and the current challenges facing the forestry sector in Siberia, underscores the need for prudent management and use of forest resources.

5. Policy suggestions for the sustainable development of Siberia

By making explicit the pattern of emissions in Siberia, policy alternatives become more clear. This section discusses the possible policy tools which could be used in Siberia for pollution abatement, focusing upon regulatory (command and control) and market-based approaches. Siberia's past experience with these tools is briefly noted and suggestions for further improvement of the current system are added. Beginning in the early 1970s, the chief instrument for the control of pollution was a centralized command and control system. Market based incentives were introduced in the 1980s (such as fees for the use of natural resources). A pollution charge system was implemented in 1991, which relies on enterprise specific maximum permissible levels of pollution (MPLs). However, based on numerous reports (see Kiseleva, 1996) not only were MPLs frequently exceeded in the major points of consideration for this study, but the ability of firms to avoid the charges and not reduce emissions seems great. The mechanisms used to control environmental degradation under the former regime did not effectively reduce air pollution.

In the present era of economic transition and transformation towards privatization of formerly state-owned industries, environmental policy must also change. The current pollution charge system weakly achieves revenue goals but will likely fail to encourage abatement under more stabile economic conditions. Yet a strictly regulatory approach would also prove ineffective in abating air pollution within Siberia‘s somewhat weak institutional parameters. An altered pollution charge system, augmented by regulatory measures for higher-risk compounds, has the potential to reduce and stabilize air pollution emissions in Siberia in the short- to medium-term.

5.1 Regulatory and economic approaches to abatement

The pollution profile of Siberia has special parameters that set it apart from cases in OECD countries, in which pollution emanates from millions of point sources, particulary mobile sources. The regional analysis performed here, both by volume and by risk rank has shown that up to 80 or more percent of high-risk emissions come from a handful of identifiable sectors clustered in large industrial complexes. A policy that can take into account these pollution “hot spots” while creating incentives for protection of less endangered Siberian areas is needed. Based on the above discussion, several steps could be taken to form a sustainable development policy for the region.

5.1.1 Improve measurements and data quality

Russian officials must move beyond the measurement of emissions to the accurate measurement of depositions of the given chemical compounds. This will enable researchers to more precisely determine zones of emissions influence and delineate how large these zones may be. The government has already identified chronically polluted areas, and areas where pollution appears to have caused forest die-back. Combined with deposition information, officials may be able to create “sacrifice zones” where pollution problems are most severe, “transitional zones” where air pollution may endanger the environment, and “pollution-free target zones” in which the primary goal is to prevent environmental degradation from pollution. Measuring depositions could indicate pollution pathways, and help officials define more appropriate emissions levels which would allow transitional and target zones to remain as pollution-free as possible. Further, Russian researchers should participate in defining critical loads for Siberia’s diverse ecosystems, and for at least the chemicals identified here as high-risk. As progress continues on measuring critical loads, policy makers could define “protection isolines” for specific areas, and set emissions standards so as not to exceed these thresholds. Such a step would improve the ability to assess environmental impacts and risks from emissions in Siberia.

Russian officials could also take the following steps to improve data gathering and reporting:

- Employ systematic thresholds for environmental evaluation (such as EPA's Ecotox Thresholds, critical loads)
- Improve reliability of data, fill in gaps where data is not currently present
- Improve openness and public awareness about pollution profiles for different industrial sectors and by region or town
- Develop an indexing system with parameters such as bioaccumulation, toxicity, deposition velocity and/or mobility, and bioconcentration.

5.1.2 Simplify systems and focus attention on the most important polluters and pollutants

To implement effective regulatory and market-based programs, and to most efficiently employ limited financial and human resources of Siberian environmental agencies, policy should focus primarily on the major pollutants discussed above. If volume of pollution is the primary concern, policy should focus on setting and better enforcing threshold standard s for compounds such as vanadium pentoxide, carbon soot, ammonia and nitric acid. The policy could improve economic incentives for compliance through the use of permits and charges to reduce these particular compounds. Dealing with a few industries such as the energy sector (including fuel and energy production and oil dwelling, accounts for 37% of total volume emitted in Siberia), the polymetallic sector (18%), and large coal-burning power stations (12%), could reduce the volume of ambient emissions significantly.

While some economists recommend focusing on less toxic pollutants which do not generate large environmental devastation (in order to create incentives for cost-effective pollution abatement), the author suggests that focusing instead on those "high-risk" compounds identified in this report would bring both the greatest returns to societal and environmental well-being. The potential health benefits would be seen in the short- and medium-term as child mortatily could drop, children born with congenital defects or with other pollution-related medical conditions ("yellow disease," underweight, brain damage, etc.). If toxicity were the key issue for policy makers in Siberia, focusing on abating chemicals such as cresol, carbon tetrachloride, arsenic, hydrogen sulfide and manganese could significantly improve environmental conditions. Introducing regulations to ban or penalize the use of leaded fuels could also mark a significant step towards the reduction of this most toxic chemical. Accordingly, effective regulation of industrial production processes in the chemical and oil-chemical sectors (which together account for 30% of risk-weighted emissions in Siberia), steel (12%), and the polymetallic sector (11%) could reduce high risk toxic emissions in Siberia by half.

5.1.3 Alter current pollution charge system by selecting a core set of priority air pollutants and a multi-level charge structure linked to facility performance limits

Rather than focusing on the point sources for almost one hundred reported chemicals, abatement of the most important pollutants (either by volume or by risk) will allow greater efficiency in monitoring. In addition, a multi-level charge structure fits well into Siberia's existing abatement policy (charge systems are integrated into permit structures). It would allow base rates for pollution up to a threshold limit, and charge significantly higher penalties for emissions exceeding these thresholds. This works well when many different types of pollution are dealt with simultaneously. To target high-volume pollutants, providing straightforward economic incentives to reduce emissions would place most emphasis on base rates, with penalties at appropriate multiples of the base rate and with limits playing a less important role. For the abatement of high-risk compounds such as those identified here, charge systems could place sharp penalties on excessive emissions to prevent flexibility in exceeding threshold limits. In Siberia, to a certain extent this approach has been applied; but because of poor data or misreporting, and low charges, penalty rates have not served as a sufficient stimulus for abatement of high-risk chemicals.

5.1.4 Develop cost-effective and non-adversarial approaches to implementation and enforcement

For greatest cost-efficiency, the author recommends focusing on industrial sectors mentioned above. In the past monitoring of every site has been problematic and sporadic. By focusing on key polluters and enforcing environmental standards and a permit system there, policy will more effectively achieve pollution abatement in a cost-effective manner. In some cases regional environmental authorities already implicitly follow this approach in an effort to economize on monitoring activities.

Although most transition countries have said that in principle *all* polluters should be permitted and charged for specific pollutants if they pollute above some minimum level. The question of appropriate minimum levels is therefore an important policy question not adequately addressed in the literature. In the case of Siberia where a very small number of large polluters account for the vast majority of stationary source emissions, there may be little benefit and net social costs of fully including small polluters in permit and charge systems. Such small polluters should probably be exempt from charges if the charge revenues do not justify the administrative costs associated with collecting and recording transactions. Regulatory levels could be a useful way to focus attention and regulators' efforts on the core set of important polluters.

Regulators and environmental agencies in Siberia already face a difficult political, economic, and institutional situation in which to attempt abatement. It is desirable for environmental officials to prevent relationships from becoming adversarial with polluting industries. In order to enforce pollution regulation and a permit and charge system, regularly scheduled inspections, as well as short-notice spot inspections would be preferable.

5.1.5 Integrate the system of pollution charges into the general system of income/profits taxation.

Abatement programs can work synergistically with tax systems and provide funding for environmental efforts (hypothecation). Regulation can lower barriers to environmental investment and aid society in reaching lower emissions levels and better use of resources by blocking off the most wasteful alternatives through regulation and standards setting activities.

Siberia has some experience with pollution permits, which are contracts between polluters and regional environmental authorities and the local department of the State Committee for Sanitary and Epidemiological Inspection. However, Siberian enterprises have had little incentive to reduce emissions below MPL levels and few enterprises conformed to those norms. Powerful energy and forestry-related enterprises have had the ability to persuade authorities to waive excess charges or faced few hard budget constraints which would have motivated them to lower pollution and save surplus income in the form of corporate income tax breaks.

Siberia has implemented a few other market-based environmental policies aimed at reducing air pollution. The fuel excise tax, amounting to 3-5 percent of retail fuel prices, provides some incentive to switch to lower sulphur content fuels. Revenues from the fuel tax are hypothecated to a special environmental fund. Enterprises can also qualify for up to a 25 percent corporate income tax exemption if it provides environmental services. For non-complying firms, a pollution charge-based "tax approach" was intended to provide extrabudgetary funds for environmental protection in a time when the fiscal system was collapsing under transitional pressures (Danilov-Danilyan and Kozeltsev, 1990).

Taxing key inputs such as fuels and chemicals levied at the point of manufacture or distribution could be much less costly from an administrative viewpoint. Such taxes could be set in *ad valorem* terms to avoid the problem of indexation and inflation. However, taxing inputs rather than pollution itself may remove incentives to reduce end-of-pipe cleanup measures. To restore this distortion, rebates to enterprises making such investments would need implementation. At best ecotaxes aimed at air pollution reduction should serve as complements to regulation. Command and control instruments such as charges on key emissions, combined with negotiations with the few large sources and direct regulations of the most problematic chemicals released (such as lead) will prove most effective.

5.1.6 Implement cleaner technology and provide information about abatement options

Where financially possible, better filter technologies could be installed in old plants to reduce air emissions. The most obvious problem in this solution is the expense of reforming current industrial production structure and of implementing cleaner, often costly technologies. Financing such programs in the face of an unstable employment and production profile appears difficult. However, considering that many sectors have extremely outdated equipment, implementing even simple end-of-the-pipe filters could greatly reduce emissions at a relatively low cost. For opponents of regulatory abatement approaches, research has found little evidence that command and control measures to reduce air pollution have seriously harmed industrial profits or that they have created pollution havens. Repetto (1992) reported that "the many empirical studies which have attempted to test these hypotheses [of regulatory harm] have shown no evidence to support them." In addition, environmental agencies could disseminate information to firms about the least cost options available for abatement. Uncertainty about abatement costs and the marginal benefits and marginal environmental degradation resulting from polluting activities could be reduced for firms through such a provision of information.

6. Conclusions

The natural resources of Siberia stand at long-term risk from air pollution, but potential solutions can be found if abatement measures are implemented quickly and effectively. Policy makers must first decide if toxicity or volume of emissions is most important for Siberian abatement goals, and whether raising revenue exceeds the value of abating emissions. Identifying general regions of environmental risk, identifying the chemicals of most concern (either by volume or risk-rank), and identifying the key industries that serve as source points are necessary steps to take the appropriate environmental policy.

Chronically polluted areas may never be restored to the original state, but a more prudent industrial emission policy may reduce the risk to human and environmental health posed by industry. Offering economic incentives for industry to improve their technology and production processes could also have a downward pressure on emissions. Siberia's current experience with permits is relatively obstacle ridden. Under a national policy for pollution abatement, Siberia set pollution charge rates based upon the effects of pollution on the economy and human health, aiming to compensate affected parties. This damage approach was inadequate for the calculation of pollution charges because they did not correspond to new market-based methods more appropriate for the transition period. The level of pollution data aggregation was too high to accurately estimate damages, which were measured in terms of loss of production rather than loss of welfare (for human health) leading to underestimation. In addition, the most powerful sectors (such as oil, polymetallic, and chemistry) may be politically and economically strong enough to block implementation of such market-based tools to reduce air pollution.

In spite of these weaknesses, the structure of pollution charges did reflect a desire to reduce the most toxic emissions. Emissions were differentiated by toxicity, and payment per ton of each substance was established proportional to its potential danger to human health. The gap between the most and least toxic substances was several orders of magnitude; and supposedly provided industry enough motivation to cut levels of the most hazardous pollutants.

A survey of actual emissions data does show that high-risk chemicals tend to be emitted in significantly lower volumes than lower risk ones. This may indicate the charge system in place was already having some positive impacts (although such effects are obscured by general declines in emissions which accompanied industrial decline during the transition period). However, levels of toxic emissions still impose significant health impacts and further steps should be taken to reduce environmental risk in Siberia. Such measures may involve updating industrial processes in ways that improve competitiveness by using resources more efficiently while reducing both the input and output of high-risk chemicals.

Implementing cleaner technologies and improving efficiency of key industries should lead not only to a less-burdened environmental system. It could lead to the development of a diverse economy not reliant wholly upon outdated industry or forest resources. Such an approach could simultaneously improve the prospects of forest-product related industry by making the most wise use of these resources to ensure their availability in the future. Market-based incentives could complement the regulatory approach and help industries make the transition to market-responsive and environmentally responsible economic actors.

6.1 Future research

Future studies of biodiversity and environmental health in respect to emissions in Siberia, will undertake more formal risk assessments. While the preliminary attempt to risk-rank chemicals has been useful in helping to identify the most dangerous compounds as emitted by region, a toxicologically correct method will make more fine-tuned estimates and reduce the uncertainty of environmental degradation in Siberia. One possible framework would be to combine features of the national Academy of Sciences/National Research Council framework for health risk assessment and the US Environmental Protection Agency (USEPA, 1992) framework for ecological risk assessment. This framework has four components, the first of which is dealt with in this study: 1) hazard identification (or problem formation) 2) exposure assessment and exposure-response assessment 3) risk characterization and 4) risk management. Such an assessment would better-inform policy makers and researchers about sustainable development options for Siberia as regards atmospheric emissions.

Future risk research should focus on the following steps.

Exposure assessment

- Characterize chemical sources and releases (using Siberian database)
- Analyze chemical transport and fate
- Identify relevant exposure pathways
- Quantify exposures to receptors
- Develop exposure profiles

Effects assessment

- Develop a chemical indexing system to indicate threat to environment
- Apply transport models to assess the risk of long-distance air pollution
- Develop indicators for environmental effects of emissions on biodiversity

Risk Characterization

- Compare exposure/dose concentration response profiles
- Analyze uncertainty
- Integrate risks and assess regional impacts on Siberia
- Discuss ecological significance

6.2 Towards sustainable development in Siberia

An important component of creating sustainable development policy for Siberia is to protect valuable natural resources that might otherwise be compromised through imprudent use. Air pollution is such an anthropogenic disturbance that threatens human and natural resources. Taking the steps identified in this report will move the region significantly closer to preserving its vast and globally unique resources for the future.

Forests suffer from environmental degradation whose sources often lie in relatively distant industrial centers. Studies show that air pollution has serious effects on tree die-back, as well as less certain effects on long-term forest development. As pollutants deposit in forest soils, the toxic effects on forest organisms (which may account for up to 95 percent of forest biodiversity (Zasada *et al.*, 1997) could cause significant changes in life cycles and reproductive capabilities. Addressing the sources of pollution in industrial centers must be the next step in protecting Siberian ecosystems. In addition, creating a political will to protect environmental services and resources from external sources of pollution is necessary. Taking advantage of the current international attention given to the importance and value of ecosystem biodiversity, as well as emphasizing both the market and non-market value of forests could help create a political agenda for protecting Siberian environments.

Even though industrial emissions affecting the entire area have subsided in recent years along with industrial decline, regional development policy will play a key role in the protection or destruction of sensitive ecosystems. The author recommends pursuing a mixed approach of command and control tools with market-based incentives.

In regards to toxic emissions, a key part of that regional strategy must involve a long-term energy policy less dependent of fossil fuels. In the medium- to short-term, regulation of toxic chemicals associated with fossil fuels, particularly lead should be introduced to immediately begin the abatement of the more serious pollutants. This study has shown that the overwhelming majority of emissions by volume come from the energy sector, from oil dwelling and processing, and from the burning of coal. Development strategies must be modified for their host environments, and in regions where air pollution has particularly noxious effects, deliberate shifts away from these industrial energy sources could dramatically improve air quality.

Although present economic conditions are troubled, relatively great gains in pollution abatement can be made in cost-efficient ways in the short term to reduce environmental impacts on Siberian ecosystems. Making relatively inexpensive changes in the use of energy could improve energy efficiency. These market-based mechanisms could include “getting the energy prices right,” government regulation and structural changes in specific industrial sectors as well as housing and transport to create incentives for energy conservation rather than waste (Russian Ministry of Fuel and Energy, 1996).

References

Ahlander, A.S. (1993) *The effect of the Soviet shortage economy on the environment and the use of natural resources.* Dissertation. Department of Economics, Stockholm University.

Ahti, J (1988) Mannyn neulasten ja sormipaisukarveen raskasmetallipitoisuudet verrattuna mantyjen ja jakalien vaurioitumiseen Kotkassa. Thesis, Department of Environmental Conservation at the University of Helsinki, Finland.

Akopian, A. (1992) *Industrial Potential of Russia: Analytical Study Based on Fixed Asset Statistics to 1992*. New York, Nova Science Publishers, Inc.

Alstad DN, Edmunds GF, Weinstein LH (1982) Effects of air pollutants on insect populations. Annual Rev Entomol 27:369-384.

ATSDR (1993) ToxFAQs, Agency for Toxic Substances and Disease Registry, Division of Toxicology. Altanta, Georgia.

Bashkin, VN; Snakin, VV; Kozlov, M, 1993. Critical loads in Northeast Asia. in Downing, Hettelingh, and de Smet (eds.). Calculation and Mapping of Critical Loads in Europe: States Report 1993 RIVM, the Netherlands. 102-122.

Beyer, NW (1986) A reexamination of biomagnification of metals in terrestrial food chains. Environm. *Toxicological Chemistry* 5:863-864.

Beyer NW (1988) Damage to the ecosystem on Blue Mountain from zinc smelting. In: Hemphill DD ed. Trace substances in environmental health XXII, University of Missouri Publishing, Columbia, p. 249-262.

Bluffstone, R, Larson, BA (1997) *Controlling Pollution in Transition Economies: Theories and methods*. Cheltenham, Edward Elgar.

Braniewski S, Chrzanowska E (1988) Effect of dusts from electrofilters of different industrial works on the vegetation. Scientific Papers Krakow Agricultural Academy 226: 146-166.

Brümmer, G and Herms, U. (1983) Influence of soil reaction and organic matter on the solubility of heavy metals in soils. In: Ulrich B, Pankrath J (eds.) Effects of accumulation of air pollutants in forest ecosystems. D Reidel, Dordrecht, 233-243.

Constantinidou, HA, Kozlowski, TT (1976) Effects of sulfur dioxide on *pinus resinosa* seedlings in the cotyledon stage. *Journal of Environmental Quality* 5, 141-144.

Danilov-Danil‘ian, V, Kotliakov, V (eds.) (1993) Problemy ekologii Rossii (Russia in Environmental Crisis) Federal‘nyi ekologicheskii fond Rossiykoi Dedetatsii: Moscow.

Denisov, N.B., Henry, D.J. (1995) Circumpolar Arctic Eco-regions Project Report, 1995. UNEP/GRID-Arendal, Norway.

Folkeson L, Andersson-Bringmark E (1987) Impoverishment of vegetation in a coniferous forest polluted by copper and zinc. *Canadian Journal of Botany* 66: 417-428.

Godbold, D.L. (1984) The uptake and toxicity of heavy metals in Picea abies (Karst.) seedlings. In Ber des Forschungzentrums Waldökosysteme/Waldsterben, Univ. Göttingen, Bd. 4, 197-212.

Heck, WW (1973) Air pollution and the future of agricultural production. In *Air pollution damage to vegetation* (edited by Naegele, JA) *Advances in Chemistry Series*. No. 122. 118-129.

Herms, U. and Brümmer, G. (1984) Einflussgrössen der Schwermetall-Löslichkeit und –Bindung in Böden. Z Pflanzenernahr Bodenk 147: 400-424.

Huber P, Nagaev S, and Woergoetter A (1996) The Relocation of Russian Industry 1987-1993, WP-96-162, IIASA, Laxenburg, Appendix 1, 1.

ICRFCCP (1995) First Communication: Internagency Communication of the Russian Federation on Climate Change Problems. Moscow.

Jansen E, van Dobben HF (1987) Is decline of *Cantharellus cibarius* in the Netherlands due to air pollution? *Ambio* 16: 211-213.

Kasimov VD, Martyniuk AA, Kondratov VI, Serdiukova AV, Golutvina LS, and Ramzevich GA (1993) Status of forest stands and the ways of increasing their resistance within the zone of the influence of Bratsk Industrial Complex. Forest Ecology and Nature Protection, Moscow, VNIILM, 19-34 (in Russian).

Kazmierczakowa, R (1987) Degradation of pine forest Vaccinio myrtilli - Pinetum vegetation under the influence of zinc and lead smelter. Zaklad Ochrony Przyrody Zasobow Naturalnych Polskiej Akad Nauk Ser A 31:29-80.

Kim, TW (19820 Studies on the ecological changes of the forest community by the pollution at Ulsan district. *Journal of the Korean Forestry Society* 58, 60-69.

Kiseleva, V. (1996) Environmental stress to the Siberian forests: An overview. WP-96-45. IIASA. Laxenburg, Austria.

Klinova, N.L. (1990) Faktory razvitiia recreacii na Baikale, in: Voprosy geografi I ekologii Vostochnoi Kibiri, Irkutsk.

Kohlmaier, G.H., Weber, M., Houghton, R.A. (eds.), 1998. *Carbon Dioxide Mitigation in Forestry and Wood Industry*. London: Springer Verlag.

Lerman, SL, Darley, EF (1975) Particulatesl In Mudd, JB, Kozlowski, TT (eds.) Responses of plants to air pollution. New York, USA, Academic Press. 141-158.

Linzon, SN (1978) Effects of airborne sulfur pollutants on plants. In Jarvis, PF, Mansfield TA (eds.) *Sulfur in the environment, Part II, Ecological impacts*. Cambridge, UK; Cambridge University Press. 137-161.

Mankovska, B (1986) Accumulation of As, Sb, S, and Pb in soil and pine forest. Ekol CSSR 5:71-79.

Markuse, G. (1993) Ecological Aspects of Development in Siberia. Bothe, M Kurzidem, T. and Schmidt, C. (eds.) Amazonia and Siberia: Legal aspects of the preservation of the environment and development in the last open spaces. London, Graham&Trotman.

Michaelis, W. (1997) *Air pollution: Dimensions, trends, and interactions with a forest ecosystem*. Berlin, Springer-Verlag.

Miller, PR, McBride, JR (1975) Effects of air pollutants on forests. In Mudd, JB, Kozlowski, TT (eds.) *Responses of plants to air pollution*. New York, USA, Academic Press. 195-235.

Mnatsakanian, R.A. (1992) *Environmental Legacy of the Former Soviet Republics*. Centre for Human Ecology, Institue of Ecology and Resource Management. University of Edinburgh.

Natsionalnyi Doklad SSSR 1990 k Konferentsii OON 1992 goda po Okruzhayuschei Srede.

Nilsson, S., Blauberg, K., Samarskaia, E. (1998) "Pollution stress of Siberian forests," in I. Linkov and R. Wilson (eds.) *Air pollution in the Ural Mountains*, Netherlands: Kluwer Academic Publishers, 31-54.

Nuorteva, Pekka (1990) Metal Distribution patterns and forest decline. Seeking achilles' heels for metals in Finnish forest biocoenoses. Department of Environmental Conservation at the University of Helsinki No. 11. 43.

Obzor Sanitarnogo Sostoyaniya Lesov Rossil za 1993 god, 1994, (Review of Environmental Status in Russia in 1993), Moscow, Rosagroservis (in Russian).

OECD (1996 Russia's Energy Efficient Future: A regional approach. Conference proceedings. Chelyabinsk, Russian Federation. 25-26 September 1996.

Oyler, JA (1988) Remediation of metals -contaminated site near a zinc smelter using sludge/fly ash amendments: Herbaceous plants. Procedures from the University of Missouri 22nd Annual Conference of Trace Substances in Environmental Health: 306-320.

Pacha, J (1989) The influence of chromium on the biological and physicochemical properties of soil. Uniwersytet Slaski, Katowice.

Pandey, DN (1983) Impact of thermal power plant emissions on vegetation and soil. *Water, Air, and Soil Pollution* 19, 87-100.

Pryde, Ph.R., 1994, Observations on the Mapping of Critical Environmental Zones in the Former Soviet Union, *Post-Soviet Geography*, 35 (1): 38-49.

Repetto, R. 1986. World Enough and Time. Yale University Press, New Haven, Conn

Roodman, D.M. (1997) Getting the signals right: Tax reform to protect the environment and the economy. World Watch Paper 134. Washington, D.C., World Watch Institute.

Ruhling, A (1978) The occurrence of higher fungi in an area polluted with copper and zinc. *Publ Statends Naturvardsverk* 1cyclohexane (C6H12):1-32.

Ruhling A, Bath E, Nordgren A, Soderstrom B (1984) Funi in metal contaminated soil near the Gusum Brass Mill, Sweden. *Ambio* 13: 34-36.

Saunders, A. (1990) "Poisoning the Arctic Skies," *Arctic Circle*, September/October 1990, 22-31.

Scurfield, G (1960) Air pollution and tree growth. *Forestry Abstracts* 21, 1-19.

Shaw, G.E. (1982) "Evidence for a central Eurasian source of Arctic haze" *Nature* 28 October, 815-18.

Sheehan, Patrick (1995) "Assessments of Ecological Impacts on a Regional Scale" in R.A. Lindhurst, P. Bordeau, and R.G.Tardiff (eds.) *Methods to Assess the Effects of Chemicals on Ecosystems*, SCOPE: John Wiley and Sons, Ltd.

Scheffer, TC, Hedgcock, GG (1955) Injury to northwestern forest trees by sulfur dioxide from smelters. *Technical Bulletin, USDA*. No. 117.

Smith, WH (1981) *Air pollution and forests*. New York: Springer Verlag.

Soikelli, S. (1981) Comparison of cytological injuries in conifer needles from several polluted environments in Finland. *Annales Botanici Fennici* 18, 47-61.

Turner, R., Pearce, D., Bateman, I. (1994) *Environmental Economics*. New York, Harvester Wheatsheaf.

Tyler, G (1984) The impact of heavy metal pollution on forests: A case study of Gusum, Sweden. *Ambio* 13: 18-24.

Ulrich, B, Pankrath, J (eds.) (1983) *Effects of accumulation of air pollutants in forest ecosystems*. Dordrecht, Netherlands. Reidel Publishing Company.

USEPA (1989) *Risk Assessment Guidance for Superfund*, Vol. I, *Human Health Evaluate Manual* (Part A). Report No. EPA 510/1-89/calcium oxide (CaO). US Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

Vladimirov, V.V., Istomin, S.A., Mazurov, Iu.L. (1990) Ekologischeskie konflikty v SSSR – prognozirovanie I puti preodoleniia, in: Geoekologiya – regional'nye askpekty, Leningrad.

Whittaker, RH (1975) Communities and ecosystems. New York, USA. Macmillan.

Zasada, JC, Gordon, AG, Slaughter, CW, Duchesne, LC. (1997) Ecological considerations for the sustainable management of the North American boreal forests. IR-97-024/July. IIASA. Laxenburg, Austria.

Ziegler, C (1987) *Environmental Policy in the USSR*. Frances Pinter, London. 155.