Scientific, Technical and Management Plan

1. Background and objectives

The unprecedented rate of climate warming observed in the last half century strongly influences boreal forests of the Northern Hemisphere (Barber *et al.* 2000). In Russia, the impact of natural changes induced by warmer temperatures is amplified by economic changes associated with the collapse of the Soviet Union and the sharp increase in the demand for natural resources. These factors combined put the forests of the Russian Far East (RFE) under severe pressure. A UNESCO world heritage site with one of the most biologically diverse temperate forests in the world is found in the RFE. These forests support a large number of endemic plant and animal species and subspecies. Two of these endemic animals – the Amur tiger (*Panthera tigris altaica*) and the Amur leopard (*Panthera pardus orientalis*) - are recognized by the World Conservation Unit (IUCN) as critically endangered (IUCN 2004). Over 90% of the Amur tigers remaining in the wild are found within the RFE (Miquelle et al. 1999; Miquelle and Pikunov 2003) and the Amur, or Far Eastern, leopards, of which only 25 – 44 remain (Pikunov and Korkishko 1992, Aramilev *et al*. 1998, Pikunov *et al*. 2000) are confined to an isolated population along the Russian-Chinese border (Miquelle&Murzin 2001).

In addition to the overall impacts of global warming, the loss of albedo from snow cover as the extent of evergreen forest in the RFE increases has the potential to create a powerful positive feedback to climate (Xiaodong and Shugart 2005). The potential impact of a warmer climate in the RFE has been simulated using the FAREAST model, an individual-based gap model, which showed that several current tree species – *Larix* (larch), *Abies* (fir), and *Picea* (pine) -- can only exist within a narrow band of temperature and precipitation conditions (Zhang and Shugart in draft). An accelerated rate of warming in this area, therefore, could drastically affect wildlife habitat and subsequent tiger and leopard distribution. The Amur tiger's northernmost distribution is limited by the availability of its main prey species - red deer and wild boar (Miquelle et al 1998, Kucherenko 1985). Both red deer and wild boar are found predominantly in temperate forests. Additionally, these species are known to avoid dark coniferous and larch forests during winter months. Leopards have a varied diet of avian and mammal protein, but depend on deer and wild boar in winter (Miquelle&Murzin 2001; Pikunov&Korkishko 1992). The expansion of temperate forests and the decline of Korean pine, which provide forage for ungulate prey, caused by the high rates of warming, have the potential to modify the extent of tiger and leopard habitat. A spatially explicit analysis of habitat change in this temporally dynamic framework is needed to ensure the connectivity of the current and potential future suitable habitats, which will facilitate the successful migration of the carnivores and their prey species.

The impact of climate change and anthropogenic disturbance on the recent changes on the biodiversity of the area and particularly on the Amur tiger and Amur leopard is currently not well-understood. Several parameters (e.g. roads, fires, logging) have been shown to influence the distribution and population dynamics of the tiger and leopard populations. Roads have been proven to dramatically decrease the survivorship and reproductive success of tigers (Kerley *et al* 2002). Tigers are also known to avoid crossing open areas, which impedes their dispersing capabilities (Seidensticker 2002), leading to social stress, injury and increased rates of disease distribution. Forest fragmentation also affects tigers' major prey species, which rely on free movement across the landscape to feed on various resources. Under certain conditions, it may prevent wild boar from traveling to the highly important winter feeding source – Korean pine or

Mongolian oak stands. There is also a large uncertainty associated with the influence of increased edge areas created by forest fragmentation on the Amur tiger and leopard habitat. Edge habitats present favorable feeding conditions for some ungulates, such as roe deer, which are an important prey for leopards, but not tigers (Miquelle *et al.* 1996). Disturbances within forest stands from selective logging can open canopies and increase forage production for tiger prey species such as red deer and sika deer. An increase in edges and openings in habitat, however, also facilitates the spread of wind-dispersed pest infestation, enhances fire occurrence and propagation, and improves human accessibility as a result of the associated road network. Additionally, edge habitat allows for greater possibility of tiger contact with domestic animals and their diseases (Seidensticker 2002), which are an emerging threat for Amur tigers (Goodrich *et al*. in press).

Climate induced landcover change is considerably accelerated at disturbed sites (Volney and Hirsch, 2005). The extent of landcover conversion in the RFE is not well known. The vast size and remoteness of the area, in addition to limited ground access, make remote sensing the only viable source of unbiased up-to-date information about the changes to forest cover for the entire region. Logging, forest fires and conversion of forested lands to agriculture are the major sources of habitat reduction and fragmentation in the RFE (Miquelle *et al.* 1999; WWF 2004). Deforested areas in boreal and temperate ecosystems remain discernable in remotely sensed imagery for decades, making it possible to quantify deforestation that occurred in this area prior to the availability of the current satellite record. Based on patterns of vegetation regrowth observed through multi-sensor data fusion techniques, we expect to be able to estimate the approximate time of the land cover change. The observed vegetation regrowth patterns, in combination with the results of forest restoration modeling, will make it possible to analyze long-term availability of large portions of suitable habitat for tigers and leopards under a changing climate.

The presence of snow cover in the RFE during winter months makes it possible to conduct tiger track surveys, which provide information regarding the number of tigers, their distribution and population characteristics. A number of tiger track surveys were performed in the RFE in 1959, 1965, 1970, 1976, 1979, 1985, 1990, 1996 and 2005 (Matyushkin *et al*. 1996; WCS, 2005), providing an unprecedented record of population distribution for a highly endangered species. The tiger track surveys of 1996 and 2005 provide spatially explicit information on distribution of the Amur tiger and the ungulates constituting the major source of the tiger's prey. The distribution of leopards was measured five times between 1997 and 2000 using a track-based approach. A Wildlife Conservation Society study in 2001 analyzed the relationship between preferred tiger habitat and human disturbance, land use patterns, and natural biotic and abiotic features of the landscape (Miquelle&Murzin 2001). Camera trapping is needed to confirm the estimates provide by track surveys, and especially to ascertain tiger and leopard distributions immediately after the disturbance occurs when there is no snow cover to facilitate the counting of tracks. We will investigate how different types of forest disturbances and patterns of vegetation regrowth influence the distribution of tigers, leopards, and their prey, and tiger and leopard population dynamics.

The overarching goals of the proposed research are to evaluate the extent and impact of past and future natural and anthropogenic disturbances, including climate change, on endemic species richness, inferred from the distribution of the Amur tiger and Amur leopard, and to create a basis for modeling activities aimed at predicting the distribution of these species in the future. A combination of computer modeling and remote sensing will be utilized to understand the nature and extent of changes in vegetation, which affects animal populations' distribution. The Wildlife Conservation Society's wildlife conservation biologists will conduct camera trapping and wildlife surveys to develop distributions and densities of tigers, leopards and prey in relationship to various habitat types and disturbance regimes.

The immediate objectives of the proposed research are:

1) Develop of a new methodology for observations of boreal and temperate forest disturbance and forest regeneration from data fusion of radar and optical remote sensing at the regional scale.

2) Quantify the disturbance in the Amur tiger and leopard habitat for the past 30 years.

3) Establish the dynamics of forest regeneration in this area through a combination of 3-D forest mapping from remotely-sensed data, field observations of forest regrowth, and modeling.

4) Assess the impact of forest disturbance at various stages of regeneration on the distribution and structure of tiger and leopard populations and the densities of ungulates – their prey.

5) Evaluate the potential availability of the habitat to the Amur tiger within the next 50-400 years based on the known and projected distribution of disturbance patterns, and use the FAREAST model to assess potential changes in vegetation under climate change scenarios.

The project utilizes remote sensing and modeling to increase understanding of the effects of human and natural disturbance on biodiversity and to develop tools to forecast the effects of such disturbances. The techniques and approaches utilized in the Russian Far East for this project could be adapted for use for other endangered species and other habitats around the world. The project also includes data fusion and synthesis, and a local scale gap modeling approach that can be integrated to show patterns and effects at a much larger spatial scale in order to better understand large-scale processes and their impacts.

2. Relevance to NASA's strategic objectives and expected significance

The proposed research supports NASA's 2006 strategic goal *to develop a balanced overall program of science, exploration and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration*. Specifically, it supports strategic subgoal 3A, *to study Earth from space to advance scientific understanding and meet societal needs*. The project also would contribute to the desired NASA Science Outcome 3A.3 *Progress in quantifying global land cover change and terrestrial … productivity and in improving carbon cycle and ecosystem models*. In addition, it supports outcome 3A.7, *Progress in expanding and accelerating the realization of societal benefits from Earth system science,* since the knowledge gained will help to increase understanding of the impact of disturbances such as fire, logging and climate change on local ecosystems, including vegetation, wildlife and the human communities that depend on them. The proposed research directly addresses four of the Carbon Cycle and Ecosystems focus area scientific questions: *1)how are global ecosystems changing, 2) how do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change, 3) what are the consequences of land cover and land use change for human societies and the sustainability of ecosystems, and 4) how will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?* It supports the Carbon Cycle and Ecosystems focus area's goal to *produce assessments of ecosystem response to climatic and other environmental changes and the effects on …biodiversity…* The project also supports the Interdisciplinary Research in Earth Science program by increasing understanding of the variability of Earth's systems, the *mechanisms by which and the manner in which the Earth responds to forcing, and the local and regional consequences of global climate change*. In particular, the project would support the program's objective of improving the capability to predict the *evolution of the Earth's system in both a prognostic and retrospective sense.* It utilizes an interdisciplinary approach that includes models as well as the traditional earth science discipline of ecology to interpret information from remotely sensed data. Finally, the project supports one of the twelve National Applications identified within the NASA's Earth Systems Enterprise strategic plan - Ecological Forecasting. The proposed research will provide assessments of "*land cover change, vegetation structure, and biomass,*" develop a basis for observing and modeling the Amur tiger habitat change and contribute "*to enhancing ecosystem sustainability as economics and populations shift and grow*".

The project would directly contribute to Subelement 3, *Biodiversity and Disturbance* by conducting research that would lay the groundwork for understanding monitoring and forecasting the impacts of disturbances on biodiversity so that humans might better manage and protect the ecosystems on which we depend. The proposed project directly addresses the mission of the Northern Eurasia Earth Science Partnership Initiative (NEESPI) to enhance scientific knowledge on "*the state and dynamics of terrestrial ecosystems in northern Eurasia*" and falls under the Ecosystem Health process studies identified within NEESPI Science plan (executive overview, December 2004). It will allow for the development of a retrospective analysis of forest change as a driver of large predator distribution as an indicator of ecosystem functioning.

3. Technical approach and methodology

We propose to use a combination of methods to depict and understand the history of land use and forest disturbance, which will provide the basis for developing algorithms that will be utilized to develop a model that relates disturbance and climate change to tiger and leopard distribution. The various components of the proposed research and their linkages are shown in Figure 1.

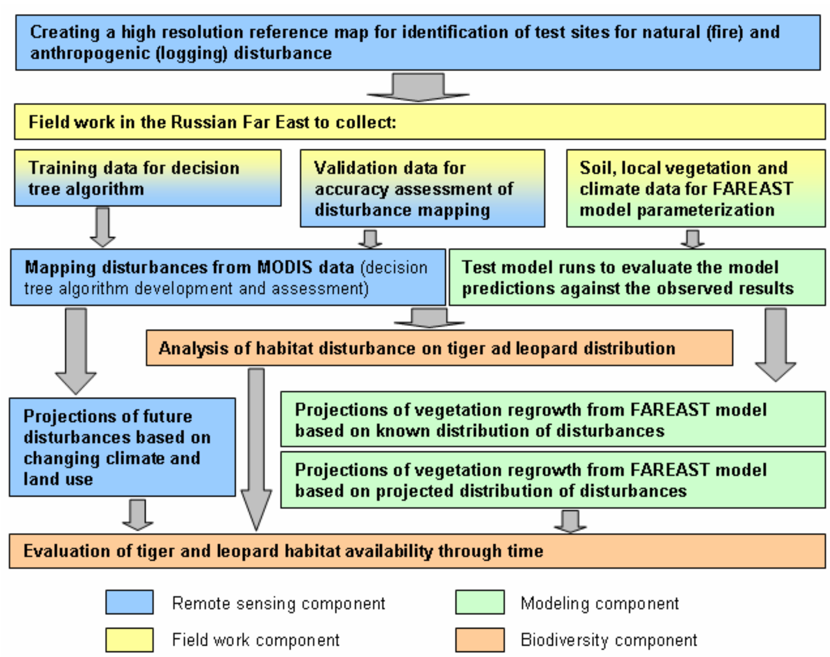

Figure 1 Flowchart of the proposed research

3.1 Remote Sensing

Analysis of remotely sensed imagery will comprise an important basis of the project. The vastness, remoteness and complex terrain of the study area make comprehensive in-situ observations of the Amur tiger and leopard habitat impossible. Traditionally, Russian aerial forest protection service "Avialesookhrana" has been responsible for fire observations and management over the forested areas of Russia. Due to the difficult political situation and shortage of funding, "Avialesookhrana" has not been able to provide accurate estimates of fire impact in the RFE. Information about logging activities is collected by local forest management offices and is based on the official figures presented by logging concessions. With the increasing demand on natural resources of the RFE, official statistics do not present an accurate estimate of legal logging and completely leave out illegal logging activity. In addition, both official fire and logging data are of low geographic accuracy.

Remotely sensed data provides unbiased spatially explicit information over the entire study area. The radiometric surface signature acquired by various satellite instruments provide a wealth of high and moderate resolution data which can be used to characterize the land cover of the study area and provide assessment of vertical and horizontal structure of disturbed areas. Within this project we will develop an approach to utilizing the capabilities offered by optical and radar data in order to improve four-dimensional (3-D + time) mapping of forest cover in the boreal and temperate forests.

3.1.1 Optical remote sensing

High resolution remotely sensed data from Landsat and Aster will be included in the analysis to create a database of disturbances of known origin and time, which will further be used as the training data for the decision tree based classification. We will utilize Landsat MSS, TM and ETM+ datasets available at Global Land Cover Facility (GLCF) and the University of Maryland holdings from previously funded activities. A high resolution (30-60m) map of known forest disturbances in the RFE will be developed through manual digitizing or change detection (whenever possible) at the beginning of the project. An additional map of high resolution observations from Aster will be developed for areas considered to be hot spots of change identified by satellite observations and local expert knowledge (Achard *et al* 2005). The map will be validated in the field where additional information about the disturbance type, the timing of the latest disturbance and vegetation regrowth will be collected through field sampling and information provided by the local forestry officials.

Remotely-sensed data from the Moderate Resolution Imaging Spectroradiometer (MODIS) serves as a unique source of high temporal, spectral and radiometric resolution and moderate/coarse spatial resolution global coverage data. The high spatial accuracy of image registration (Wolfe *et al.* 2002), complete global daily coverage and the availability of derived products of known accuracy encourage the use of MODIS datasets for land cover characterization at the global and regional scales (e.g. Vegetation Continuous Fields -Hansen *et al.* 2003; Vegetative Cover Conversion - Zhan *et al*. 2002; MODIS land cover product Friedl *et al.* 2002). We will build our approach on the methodological advances and derived products developed within previous land cover characterization efforts.

Our pilot study on the potential separability of spectral signatures from several MODIS bands and derived products has provided encouraging results. There is a considerable difference in spectral signatures obtained in the visible-NIR-SWIR. The disturbed areas are characterized by higher red reflectance than undisturbed areas, particularly in the early and late seasons, due to bigger contributions of soil signatures to surface reflectance. The overall higher NIR signature over disturbed areas is consistent with the NIR response of younger vegetation with less complex 3-d structure and consequently minimized shadowing. The disturbed areas also have high SWIR response due to lower levels of moisture accumulation in younger stands and grassy vegetations, which again is caused by simplified 3-d structure and minimized shadowing.

Disturbed areas have overall higher surface temperatures, which is expected over areas with reduced crown cover. Specifics of particular area response will be identified once the in situ observations of vegetation recovery are completed. Figure 2 shows daily examples of the diurnal temperature range (DTR) derived from daytime and nighttime cloud-free surface temperature data from Aqua. DTR, an indicator of the thermal inertia of the surface, is systematically the lowest for undisturbed areas and the oldest disturbances. For more recent disturbances, the DTR values do not follow chronosequence, particularly for logged areas, indicating differences in disturbance and regrowth.

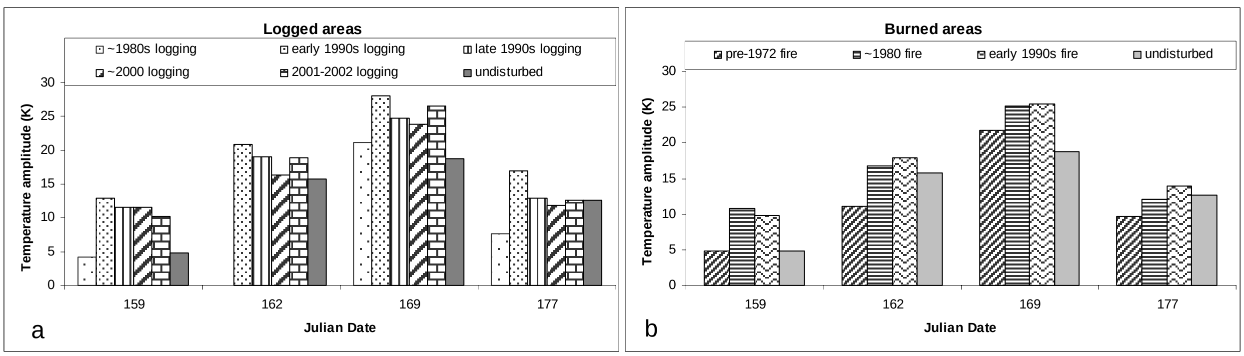

Figure 2. Examples of daily diurnal temperature range over a) logged and b) burned areas compared to undisturbed forests in the RFE.

In addition, we evaluated the information from several vegetation indices and derived products (Figure 3). All observed products demonstrate a clear separability of the remotely sensed signatures from disturbed and undisturbed areas as well as between areas of different type and timing of disturbance. The signal again is the most distinct during the green-up and senescence periods.

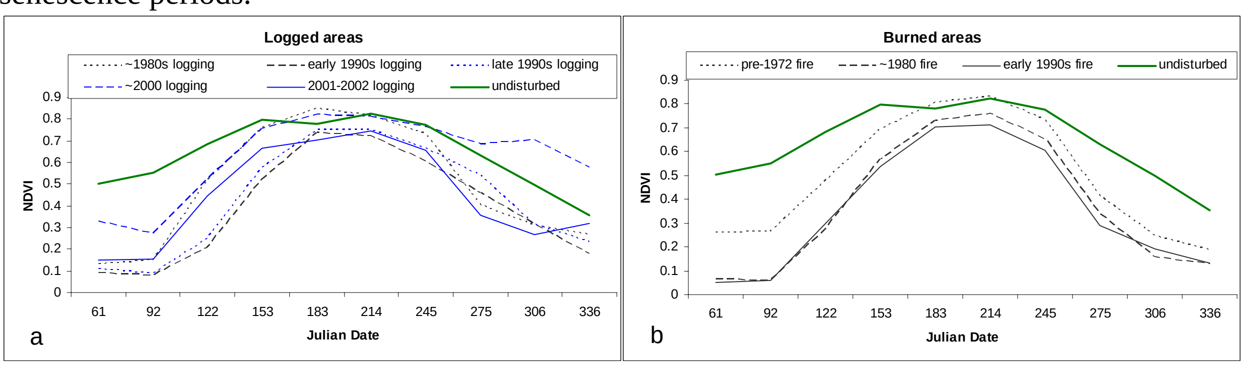

Figure 3. Signature over a) logged and b) burned areas from MODIS derived NDVI.

3.1.2 Radar

Optical multi-spectral imagery has been successfully used to map deforestation worldwide based on its capability to observe forest structure in horizontal dimensions (Patenaude *et al.*

2005; Kellendorfer *et al* 2004). However, the passive multi-spectral instruments have a limited ability to penetrate through the canopy and therefore provide little information about the vertical structure of forest cover. The SAR data provide complementary information for the studies. Previous studies showed the feasibility of using SAR data for discriminating between land cover types, and mapping forest biomass (Ranson *et al*. 1997, 2000; Sun *et al*. 2002a). Radar data is being successfully used for forest classification, disturbance mapping and forest biomass estimation based on the metrics of density and vertical structure provided by these data (Gaveau *et al.* 2003; Le Toan *et al.* 2004; Wagner et al., 2003; Ranson *et al.* 2001). The synergy of multi-spectral optical and radar data provides the basis for a more comprehensive analysis of forest disturbances and regeneration patterns. A number of studies which employed data fusion from optical and radar data have shown a systematic improvement of the results of forest classification and biomass estimates compared to those produced through the analysis of a single data type (Chust *et al*. 2004; Ranson *et al*. 2003; Lombardo *et al.* 2003; Moghaddam *et al*. 2002; Sun *et al.* 200b).

The ENVISAT ASAR and ALOS PALSAR data will be used for forest recovery studies and biomass mapping in intensive study sites. The maps from these intensive study sites will serve as "ground truth" in regional forest stratification and biomass mapping to be discussed later. L-band PALSAR data will be available free for this project through an approved research proposal to Japan Aerospace Exploration Agency (JAXA): "Forest Characterization and Biomass Estimation in Siberia and Northeastern China Using ALOS Data" (PI G. Sun). The C-band ASAR data will be provided by European Space Agency (ESA) through project "Mapping disturbances of boreal forests in Siberia and northern China using ENVISAT data" (PI G. Sun).

We will include ICESAT Lidar data to obtain direct vertical measurement of forest canopy at point samples. Additionally, MISR (Multiangle Reflectance Data) will be used at the training sites to characterize the 3D structure of the forests.

3.1.3 Fusion

We propose to use a multi-spectral combination of various MODIS (Moderate Resolution Imaging Spectroradiometer) products at moderate to coarse resolution with high resolution ETM+ (Enhanced Thematic Mapper Plus) and radar data.

Field data of collected from forest disturbances with a known history will be used as a training dataset to map disturbances at various stages of regeneration from individual Landsat/ETM+ images for the period 1999-2002. Additional information about the stage of forest regeneration (particularly type of forest and height) at these disturbances will be acquired from InSar radar and lidar. Metrics related to biomass (such as intensity at cross-polarization), forest type (such as the de-polarization ratio), canopy height (height of scattering center from InSAR data) will be derived from these data. Lidar provides direct measurement of canopy height and vertical structure, but only at sample sites. Radar and multi-angle imaging radiometry data will be used to extend the lidar samples to cover the training sites and the entire region.

The resultant 30m database of forest disturbances will be further applied as training data for the development of the MODIS 500m regional disturbance dataset. A decision-tree-based algorithm will be developed from MODIS products (2001-2005) and additional radar derived metrics of forest cover. We will use both the variability of static radiometric signature and variability of phenological changes as the algorithm drivers. The preliminary set of products includes MODIS/Terra Surface Reflectance Daily L2G Global 500m (MOD09GHK), MODIS/Terra and Aqua Land Surface Temperature/Emissivity Daily L3 Global 1km

(MOD11A1 and MYD11A1), MODIS/Terra Vegetation Indices 16-Day L3 Global 500m (MOD13A1), MODIS/Terra Leaf Area Index/FPAR 8-day L4 Global 1km (MOD15A2), MODIS/Terra Snow Cover 500m (MOD10A1), and MODIS/Terra Vegetation Continuous Fields Yearly L3 Global 500m (MOD44B). The relative contribution of these products and metrics derived from them will be further evaluated once the field data become available. Radar derived metrics at coarser resolutions will also be included in the decision tree classifier.

To avoid the issues raised by various types of data and differences in spatial resolution, we will create a decision-tree-based processing algorithm that will incorporate metrics derived from various satellites and band combinations. The contribution of individual optical and radar derived metrics to the class determination will be computed via probability Chi-square test. Although we will include 1km products into the decision tree parameterization process, the output data will be computed at 500m resolution. We expect the 500m resolution product to be a viable solution because the majority of input data will be provided at 500m and higher resolutions.

3.2 Wildlife distribution monitoring and analysis

In addition to the overall importance of the Russian Far East in terms of biodiversity, this area is home to one of the most critically endangered species in the world – the Amur Tiger (*Panthera tigris altaica)*. The most recent survey results from winter 2005 suggest that between 334 and 417 adult tigers remain in the Russian Far East (Miquelle, unpubl. data), which represents probably at least 95% of Amur tigers in the wild (Miquelle and Pikunov 2003). Due to lower productivity in northern environments, the Amur tiger exists at considerably lower population densities than other subspecies of tiger (Smirnov and Miquelle 1999), making it particularly vulnerable to poaching and habitat reduction. Intensive illegal overharvest of the tigers primary prey (large ungulates) over the past decade are particularly troubling, (Sukhomirov 2004), given that prey population densities present the one of the most important determinants of tiger distribution and abundance (Karanth *et al.* 2004, Miquelle *et al*. 1999). A major conservation requirement for the Amur tiger, therefore, is availability of very large tracts of land sufficient for survival of prey species and a viable tiger population. The majority of habitat disturbance is a result of land use change, particularly the opening of the Sikhote-Alin ecoregion to broad-scale logging, and associated road construction, as well as large-scale fire events. A recent study on fire impact on Far Eastern leopards (*Panthera pardus orientalis*) and Amur tigers in Southwest Primorye showed that both leopards and tigers avoid recently burned areas (Miquelle et al., 2004).

Observations of the Amur tiger meta-population have been conducted for over 50 years. Since the first survey conducted by Kaplanov in the 1940s (Kaplanov 1948), all tiger surveys in Russia have been based either on expert opinions of local residents (via interviews) or by expert interpretation of track abundance during the winter period, or a combination of the two. Interview data (and reporting of tracks by local hunters) can provide valuable information on the presence of tigers, reproduction, and mortality, as well as status of habitat, while information on track abundance and distribution derived from transects provides a more unbiased estimate of tiger abundance. Because winter snow provides an excellent medium to record the passage of animals, because tracks of most species are distinctive to trained observers, and because cold weather insures the longevity of tracks, winter surveys based on tracks have long been used across Russia for surveying a wide range of species. Surveys conducted on tigers have generally attempted as “full range” censuses; that is, they have attempted to survey the entirety of tiger habitat to define the absolute number of animals. A full survey of the existing range of the Amur tiger is the only way to get a complete picture of the present status of the population (with details on its present distribution) and an assessment of population dynamics. Most importantly, a full range survey provides a "snapshot" of the whole range of the tiger population and its internal structure.

The most recent tiger surveys (Pikunov and Bragin 1985, Matyushkin *et al.* 1996, Miquelle *et al.* in press) relied on a two-stage sampling process for collecting data on tiger distribution, abundance, and reproduction. Throughout most of tiger habitat, individuals (nearly entirely local, professional hunters) who spend a large portion of the winter in the forest were employed to collect data on tiger tracks, tiger litters, and to estimate prey numbers on their hunting territories (referred to as "winter survey data"). Secondly, to insure standardized data collection procedures, nearly the entire known range of tigers was sampled "simultaneously" on a large number of transects (600 to over 1000 for these surveys) placed through Primorye and Khabarovsk Krais (referred to as "simultaneous transect data"). Within sampling units the combination of "winter survey data" tracks and "simultaneous transect data" were assessed to derive the number of tigers using each area. Simultaneous surveys have a higher probability of missing tracks of tigers that do not cross transect routes within the designated period, so the "all winter" tracks act as a double check to insure that animals were not missed. The "all winter" data set also provides a clear indication of the distribution of tigers across the entire area, but is limited by the availability of reliable people in the forest for extended periods.

To address labor shortage issues and, especially, for assessing the population and distribution of tigers and leopards when snow cover is not present, camera trapping will be used. Camera trapping is crucial to observe the species distribution before and immediately after the disturbance at times when tracks cannot be easily observed, as they are in snow. Camera trapping is based on the concept that each animal has unique, identifiable color patterns and has been used successfully to estimate tiger abundance in Ussuriisky Reserve in Russia (Kostyria *et al* 2003). In addition to allowing the counting of animals when tracks are not visible, it offers the advantages of 1) allowing observation of animals that, like tigers and leopards, tend to modify their behavior because of the presence of humans and 2) more accurately assessing wildlife activity patterns, e.g. it can help determine if animals are nocturnal or active both day and night (van Schalk 1996). The capture-recapture statistical protocol will be used to estimate population (Kostyria *et al* 2003; Karanth&Nichols 1998).

3.2.1 Tiger and ungulate track surveys

Detailed records of tiger and ungulate track distribution presently exist only for the 1996 and 2005 tiger surveys. These records were compiled in GIS databases. Two tiger survey datasets will be included in the analysis: 1) "all winter" survey – information collected by one or two local residents who spend extended periods of time in the forest report all records of tracks on delineated survey cells over an extended period; and 2) "simultaneous" survey conducted by people who traveled specified survey routes during the "simultaneous" count period and collected specific information on tracks of tigers and ungulates.

All winter questionnaire data: Collection of data by local residents. During their daily routine on their hunting blocks, hunters collected the following information: 1) presence of tigers (reporting date, location, and size of every tiger track encountered (especially important are observations of females with young); 2) an estimate of ungulate density (number of ungulates wintering on their unit (to compare with estimates derived from the survey routes). Information collected by local hunters began in November with first snow fall and continues through the end of February.

Simultaneous survey: Collection of data on survey routes. During a specified period (approximately 1 week in February), a predefined set of survey routes (preferably no less than 20-30 km per unit) were covered across the entirety of tiger range. These routes are covered to refine information on tiger distribution in each sampling cell where all winter questionnaire data is being collected, to provide the sole source of information where "all winter" data is not collected, and to provide estimates of ungulate abundance within the cell. Data are entered into a specially designed field diary, which includes two sets of maps (1:100,000) for each route – one for tigers (and other large carnivores, including wolves, lynx, and bears), and a second map for pinpointing locations of all ungulate tracks. For each tiger track a unique number is assigned, the width of the pad on the front paw is measured in at least 4 tracks, with the average reported, direction of travel denoted on the map, the counters estimate of sex of the animal (based on track criteria provided), and an estimated date of passage for the animal is noted. For ungulates, the species and number of tracks crossing the route are reported on a map and the field diary. Data on snow depth is also collected on survey routes.

3.2.2 Methodological approach to analysis of tiger distribution as a factor of forest disturbance

Tiger distribution can be fairly accurately mapped based on the data collection processes of tiger surveys. Although there may be some percentage of potential tiger habitat not surveyed the extensive ground surveys provide a nearly exhaustive full range survey that fairly accurately maps tiger distribution. By creating buffers around each tiger track (with size of buffer defined by known travel distances and home range parameters) it is possible to fairly accurately define tiger distribution (Figures 4 and 5). By looking at relative density of tiger tracks, it is possible to access the probability of encountering tracks in different forest types, including those regions that incur high human disturbance.

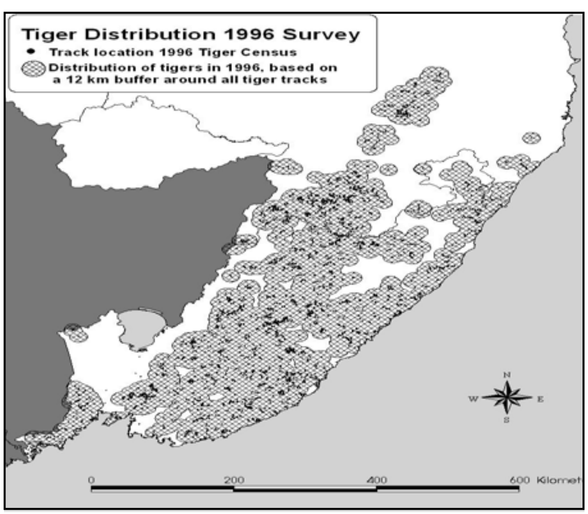

Figure 4. Tiger distribution in 1996, based on 12-km radius buffer around all locations

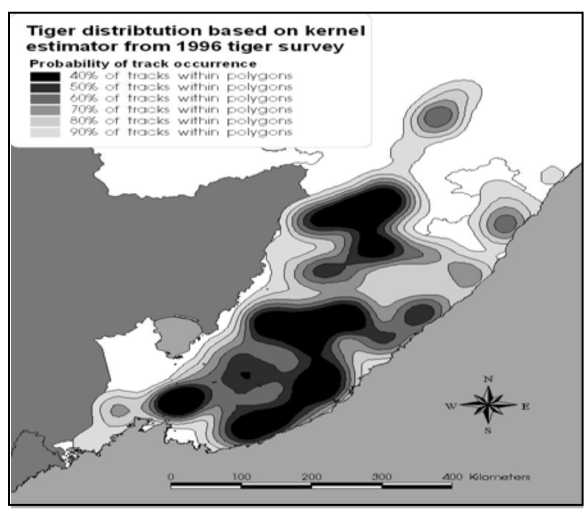

Figure 5. A kernel estimator that calculates the probability of a track occurring in any given location.

The analysis of forest disturbance and regeneration as a driver of tiger distribution will be based on the approach introduced in the analysis on fire impact of the Amur leopard in the Southwest Primorye (Miquelle *et al* 2004). We will conduct the analysis on tiger distribution in regard to disturbed areas at various stages of regeneration for the 2005 survey. We will then hind cast the disturbances to 1996 and conduct a similar analysis for the 1996 survey and tiger as well as ungulate populations in the RFE.

3.2.3 Leopard camera trapping and track surveys

Camera trapping will be used to assess leopard distribution when snow cover is not available and to confirm results of track-based methodologies when snow cover is present. Camera trapping will also provide time-sensitive assessments of leopard presence, which will assist in ascertaining the degree to which animal behavior is affected on a temporal basis by natural and anthropogenic disturbance. This technology was used for the first time to study leopards in the RFE in the winter of 2002-03 and, while images were successfully recorded, the study area had to be divided into two territories because of a lack of camera traps (Kostyria *et al* 2003). The proposed study seeks to improve the density of traps and, therefore, the accuracy of leopard inventory methods.

3.3 Computer modeling of disturbance impact on vegetation at the landscape scale

The proposed project is aimed at simulating the likely changes in vegetation in tiger and leopard habitat range on a detailed basis, but at a regional scale, under natural and human-caused disturbance conditions, including fire, logging and climate change scenarios using the FAREAST model. FAREAST utilizes a gap-based approach in which the growth, regeneration, lifespan and environmental needs of each individual tree is modeled and then combined to simulate a forest stand. The model has demonstrated the ability to reproduce vegetation patterns, including forest succession, to achieve the species' distribution and composition of current mature woodlands at 23 of 31 sites in the Russian Far East under current climate conditions (Yiaodong&Shugart 2005). Model output has corresponded with actual, observed forests with respect to species composition, successional processes, and carbon biomass, demonstrated, for example, in a comparison of observed and simulated basal area (m^2/ha) at four elevations (740m, 890m, 1190m and 1680m) on the north slope of Changbai Mountain (42.2^{o}N, 128.0^{o}E) in northeastern China (Figure 6).

In the sites where FAREAST output did not correspond with observations, the discrepancy may have been caused by historical events such as past fires, since the observed forest corresponded to vegetation typically found at lower elevations (Xiaodong&Shugart 2005). The proposed project would integrate disturbance parameters into the model with the intention of increasing its accuracy. Other parameters will be sourced from existing as well as field data (soil, local climate, and local vegetation) and recent climate models (temperature and precipitation). Data would be inputted to the model across the estimated current extent of Amur tiger (266,349 km^2) and Amur leopard (4800 km^2) habitat (Miquelle1991; Miquelle 2001). The outcome expected is a hypothesis as to the likely future forest composition of the ecosystem on which tigers, leopards, and their prey depend, given projected climate change.

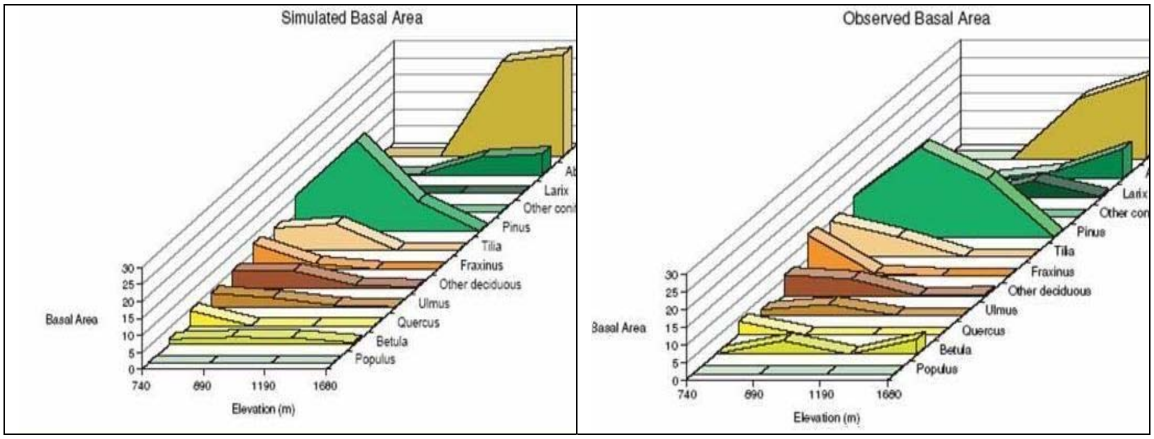

Figure 6. A comparison of simulated and observed basal area (m^2/ha) at four elevations (740m, 890m, 1190m and 1680m) on the north slope of Changbai Mountain (42.2^{o}N, 128.0^{o}E) in northeastern China.

3.4 Project stages and deliverables

1. Creating the base reference map for disturbed forest sites in the Russian Far East from available high resolution imagery (Landsat MSS, TM and ETM+ and Aster data). During this step we will identify a set of test sites which developed due to various types of disturbance (fire, logging and insect damage) and determine the approximate time of disturbance.

Deliverables: a high resolution GIS based map (in vector and raster formats) identifying the known locations of disturbances. The attributive data will include type and approximate time of disturbance.

2. Field work in the Russian Far East to collect training data within identified disturbance sites for development of decision tree metrics and soil, vegetation and climate data for FAREAST model parameterization.

Deliverables: a GIS compatible database of *in situ* observations of vegetation regrowth in the sites of known disturbance in tiger and leopard habitat. The attributive data will include information about geographic coordinates, topography, type of the latest disturbance, approximate time of disturbance, pre-disturbance vegetation type, and post-disturbance vegetation type.

3. Assembling the decision tree based algorithm for automated mapping of forest disturbance within the potential tiger habitat. This step involves evaluation of signatures from optical and radar data to identify the potential contribution of various remotely sensed metrics to identification of forest disturbance and monitoring vegetation regrowth. Additionally, accuracy assessment of the output product will be conducted during this step. The map will be validated during the year 2 field campaign in the RFE.

Deliverables: a GIS map (in vector and raster formats) of regional disturbance for the Amur tiger habitat. The attributive data will include the type and approximate time of the latest disturbance, type of replaced land cover, type of replacement land cover. Accuracy assessment of the map will be provided with the metadata.

4. Analysis of the distribution of the Amur tiger as a factor of forest disturbance. During this step the direct impact of forest conversion on the spatial distribution of tigers will be identified through the analysis of tiger track surveys from 1998 and 2005. We will also attempt to observe indirect impacts of forest succession on the Amur tiger through evaluation of distribution of

tiger prey (ungulates) as a factor of proximity to disturbed areas at various stages of regeneration based on the 1998 survey.

5. Computer model projection of expected changes in forest cover and composition as a result of climate change for up to 400 years. A selection of the most recent climate change scenarios, such as from the IPCC 2001 report, will be used as sources for projected climate data.

Deliverables: an analysis of possible future vegetation composition in existing Amur tiger habitat projected up to 400 years in the future.

6. Development of potential scenarios of forest disturbances as a function of climate and land use change.

Deliverables: a set of GIS based scenarios of disturbance maps for the RFE

7. Evaluation of the potential availability of the habitat to the Amur tiger within the next 50-400 years based on the known and projected distribution of disturbance patterns, modeled regrowth and expected changes in vegetation composition under the influence of natural and anthropogenic disturbances, such as fire, logging and climate change. The analysis will include the evaluation of present and projected habitat fragmentation and connectivity.

Deliverables: a set of GIS based maps (in vector and rater formats) of projected habitat availability for up to 400 years from the present time.

3.5 Expected impact and relationship to previous work

This project builds upon current NASA-funded activities in RFE. It will provide the possibility to extend the record of natural and anthropogenic disturbances developed within the project on “Comparative Studies on Carbon Dynamics in Disturbed Forest Ecosystems: Eastern Russia and Northern China” (PI- Guonqing Sun). In addition, it will develop a new methodology of mapping forest disturbances and vegetation recovery, which will be validated against the results of Dr. Sun’s study. This project will also broaden the scope of study “Impact of Climate and Land Use Change on Wildland Fire and the Amur Tiger” funded through NASA ESS Fellowship (PI- Tatiana Loboda) to include observations of impact of logging on the tiger distribution. Additionally, a number of methodologies (automated impact severity assessment, field protocols for evaluating impact severity and vegetation regrowth) and products (2001-2005 burned area product, know and potential logging coverage) developed within Ms. Loboda’s project will be applied in this study.

Although several UMD team members are also involved in the proposal “The use of remote sensing to study the effect of disturbance on biodiversity in protected areas” (PI Dr. V. Radeloff, University of Wisconsin), the proposed projects present distinctly separate efforts. While mapping vegetation disturbance is the common theme for both proposals, the scale, spatial extent, and level of disturbance characterization differ greatly between the projects. This project presents a regional scale analysis of a large spatially contiguous study area with a limited number of land cover (temperate forests and southern taiga) categories. In contrast “The use of remote sensing to study the effect of disturbance on biodiversity in protected areas” project presents a continental study of sample areas at local scale. The two projects also differ considerably in the methodological approach to biodiversity. This project explores the impact of disturbance and subsequent forest regeneration on the endemic and highly endangered species (the Amur tiger and the Amur leopard) as the indicator of biodiversity and ecosystem functioning. “The use of remote sensing to study the effect of disturbance on biodiversity in protected areas” project uses different metrics of biodiversity such as species richness and abundance. Additionally, there are significant differences in approaches to mapping forest disturbance from remotely sensed data for these projects.

The two projects have an area of spatial overlap (the Sikhote-Alin Nature Reserve) which provides the opportunity for developing linkages between them. This overlap will allow for exploring the relationships between impact of disturbances on biodiversity within protected areas and how representative these findings are in the regional context. It will also provide a basis for evaluating the response of different types of biodiversity metrics to disturbances. Additionally, it may lead to the development of approaches to scaling up local scale studies to the regional scale.

The project will create a strong basis for understanding the future of the Amur tiger and leopard and their prey species distribution in the changing climate and land use of the RFE. It will address the issue of time-driven changes in biodiversity of a given area following the recovery of natural and human-induced land cover conversion and deforestation. The methodology developed within the project can be used to create an operational monitoring tool with potential applications to boreal and temperate forests world wide. In addition, the project presents modeling efforts aimed at evaluating future sustainability of this unique ecosystem and success in species conservation efforts under various disturbance scenarios. The metadata associated with individual deliverables will be made available via the NERIN (Northern Eurasia Regional Information Network) Metadata Database which provides information about and links to data in support of the NEESPI scientific objectives. NERIN Metadata Database facilitates the access of interested parties to scientific and operational datasets for the Northern Eurasia.

3.6 Work schedule

We plan to complete the proposed project within three years. The timeline for completion of various steps of the proposal identified in the work schedule is shown in Figure 7.

Year 1 (01/01/2007 – 12/31/2007):

1. Identification and mapping of known disturbed forest sites within the Amur tiger and leopard habitat from high resolution imagery.
2. Field work in the Russian Far East:
    a) to collect data on vegetation re-growth patterns at previously identified disturbance sites.
    b) to collect soil and weather data for the modeling inputs.
3. Field work data processing and conversion to GIS-compatible format

Year2 (01/01/2008 – 12/31/2008):

4. Evaluation of metrics derived from remotely sensed data (optical and radar) for decision tree algorithm development
5. Compilation of decision tree algorithm
6. Production of regional disturbance history and vegetation regrowth map for the RFE habitat and its accuracy assessment.
7. Comparison of test runs of the FAREAST model with observations from remotely sensed data.

Year3 (01/01/2009 – 12/31/2009):

8. Analysis of the Amur tiger and Amur leopard distribution as a factor of forest disturbance and vegetation re-growth patterns.
9. Analysis of the ungulate distribution as a factor of forest disturbance and vegetation regrowth patterns.

10. Evaluation of changes in the spatial patterns of tiger distribution based on the known and projected disturbance patterns, expected vegetation regrowth, and model simulation of potential long-term vegetation change associated with projected climate change.

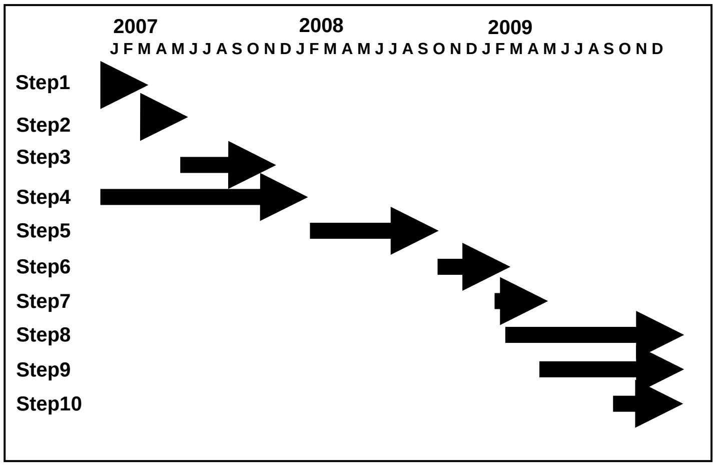

Figure 7. The timeline for completion of individual steps within the project.

3.7 Management approach

Dr. H. Shugart (UVA) will be responsible for oversight and coordination of the project. He will facilitate senior level relationships among the organizations involved, including Russian scientific contacts. He will oversee application of the FAREAST model.

Dr. I. Csiszar (UMD) will be responsible for the overall management of the vegetation disturbances mapping. He will coordinate the efforts of the UMD team members, insure the timely completion of the individual project stages and facilitate information sharing with the project PI and other collaborators. Dr. Csiszar will also be involved in the development of the overall methodological approach to optical and radar data fusion.

Ms. T. Loboda (UMD) will be responsible for processing and evaluating optical remotely sensed data from high and moderate resolution imagery. She will lead the development of the automated decision tree based algorithm for MODIS data processing. She will also participate in the development of the methodology for field data collection.

Dr. G. Sun (UMD/NASA GSFC) will provide radar derived metrics and conduct their analysis for forest cover classification. He will also be responsible for investigation of the usefulness of the lidar (GLAS) data and MISR data for forest disturbance characterizations.

Dr. D. Miquelle (Wildlife Conservation Society) will provide 1998 and 2005 tiger track surveys and 1998 ungulate survey in the Russian Far East. He will help in facilitating field data collection as an on-site collaborator. Dr. Miquelle will also be involved in the analysis of tiger distribution as a factor of forest disturbance and climate change.

Ms. N. Sherman (UVA), a PhD student, will be responsible for collecting soil, climate and vegetation data for use in the FAREAST model and for running the model under various climate change scenarios. She also will coordinate the interpretation of the FAREAST model's results with respect to the impact on tiger habitat of changes in vegetation associated with climate change.

Dr. Miquelle, Ms. Loboda and Ms. Sherman will be responsible for producing maps of potential habitat availability to the Amur tiger in 2100.

All investigators and collaborators will participate in field data collection.