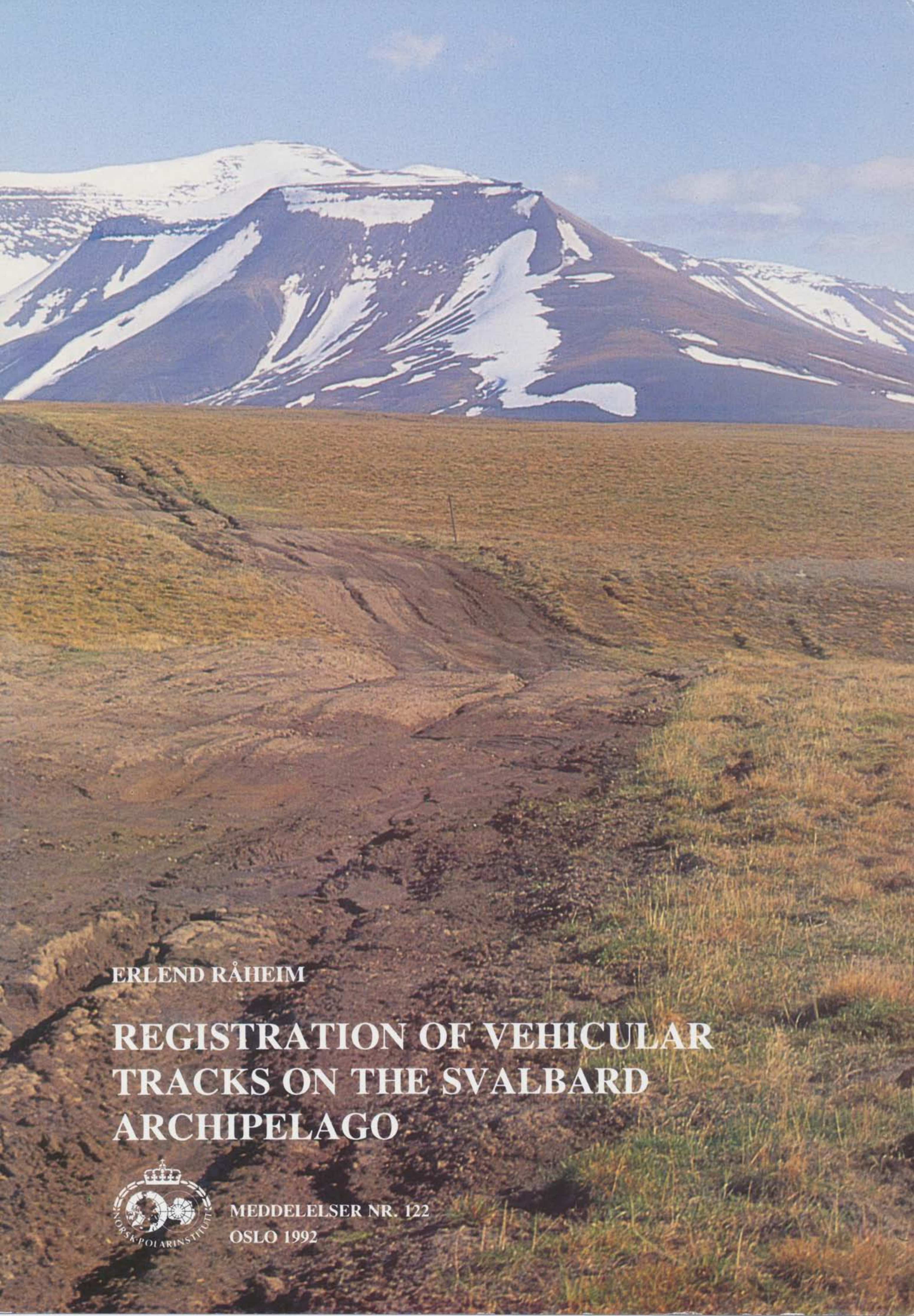

ERLEND RÅHEIM

REGISTRATION OF VEHICULAR TRACKS ON THE SVALBARD ARCHIPELAGO

NORSK POLARINSTITUTT
MEDDELELSER NR. 122
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Cover photo: Vehicular tracks north of Colesdalen, Nordenskiöld Land.

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SUMMARY

The main objectives of this project were to register and quantify vehicular tracks on Svalbard in order to establish a reference for future monitoring of existing and new tracks. The initial directives of the project were defined by the Norwegian Ministry of Environment and worked out in detail by collaborating scientists from the University of Oslo (UiO) and the Norwegian Polar Research Institute (NPRI).

The project was financed by the Ministry of Environment and carried out during 1991. An internal report in Norwegian (Råheim & Myrmæl 1991) provides the basis material for this report.

The main product is a comprehensive overview of classified tracks detected during fieldwork and aerial photography interpretation, providing a database for future use in environmental monitoring, activity planning and conservational contexts. Digital data and plots, along with this report, constitute the documentation of the work performed during the project.

Previous investigations of vehicular tracks have been performed in the area around Isfjorden, at Edgeøya, in Gipsdalen and Sassendalen, and in the Kapp Laila-Hollendardalen area.

Vehicular tracks have mainly been found where there has been activity related to mining and drilling. Some areas in Nordenskiöld Land are heavily affected (the vicinity around Barentsburg, Colesdalen, Bjørndalen, Platåberget, Adventdalen, and Reindalen). In Dickson Land, the area around Pyramiden is significantly affected. Track systems also occur in Gipsdalen, on Brøggerhalvøya, in Hornsund, on Edgeøya and in Kinnvika on Nordaustlandet. Most tracks have been made by track–vehicles.

Vehicular tracks were registered and classified by visual interpretation of false-colour infrared (IR) aerial photographs, the NP S90 series. The imagery gives a total coverage of Svalbard on the scale of 1:50,000 in addition to a partial coverage on the scale of 1:15,000 (mainly of Nordenskiöld Land).

Fieldwork was carried out in Colesdalen, Reindalen, Adventdalen and on Platåberget. The aims of the fieldwork were to quantify the impacts and calibrate the airphoto interpretation results.

Using geotechnical stability and vegetation coverage as the main classification criteria, six descriptive track classes were defined, summarised briefly as follows:

1. Self-enhancing tracks.
2. Tracks in areas of sparse vegetation coverage (more or less severe).
3. Marked tracks with sparse vegetation in the most eroded zones.
4. Less marked tracks with sparse vegetation in the most eroded zones.
5. Marked tracks with some vegetation in the most eroded zones.
6. Less marked tracks with some vegetation in the most eroded zones.

The classification scheme was constructed after the airphotos had been interpreted and the following fieldwork in selected areas on Nordenskiöld Land had been performed. A number of locations were investigated to evaluate correspondence between the classification based on the interpretation of aerial photos and that based on field work. Most misclassifications were due to erroneous estimations of vegetation coverage and underestimation of "impact severity" from the images. 31 of the 49 localities were classified identically by both methods. The relative number of the identical classifications could have been increased by simplifying the classification system, but this would also have rendered the system less suitable as a monitoring tool.

To evaluate the detection potential of the image scales, an investigation was made of the track detection percentages in a 10 km^2 area on Platåberget, corresponding to the coverage of a single 1:15,000 image. The result was that only the 1:15,000 scale gave satisfactory results. Only the most severe tracks (classes 1 and 3) were easily seen on 1:50,000-scale images.

All vehicular track registrations, including locations and characteristics, were entered into the ARC/INFO GIS (Geographic Information System). The tracks from each photograph were digitised separately and then corrected geometrically by means of a digital elevation model (DEM). Finally, they were converted for GIS inclusion. The main source of potential error in the database is expected to be the doubtful quality of the DEM used. Plots of all registered impacts are available.

Simultaneous as the field classification of tracks was being carried out, vegetation analyses were performed by botanist Anita Myrmæl. The results are presented as tables showing species abundance differences within and outside tracks.

Detection percentages in and near tracks were calculated and incorporated in the design of the classification system. Plant-sociological vegetation types were determined to aid in the evaluation of terrain-type vulnerability. Observations from track-line and reference squares were compared to classify species according to their fragility to disturbances or "pioneering abilities". A subdivision into "worn" and "moderately worn" localities was created. Plants growing in the "worn" track category may be regarded as pioneers, while persistence in the "moderately worn" tracks may indicate resistance to driving-imposed wear.

Vulnerability mapping of any specific area was not carried out during the project. However, track surveys facilitate the understanding of terrain type vulnerability. A classification system defined by Sørbel (1987) was adopted and terrain types were evaluated according to the class division given. Terrain type associations are reviewed as follows:

1. Invulnerable areas. Suggested associated terrain types are active alluvial plains, tidal shores, fans and fields dominated by stones or bedrock.
2. Moderately vulnerable areas. Areas of thin, discontinuous vegetation cover and coarse material, well-drained vegetated slopes in weathering material, vegetated inactive alluvial plains and stony ground with high lichen coverage and considerable fine material.

3. Vulnerable areas. Areas of continuous vegetation cover, dominance of fine material and high ground moisture. Wind exposed heath crests should also be classified as vulnerable.
4. Very vulnerable areas. The characteristics are the same as above, but due to inclination and proximity to drainage courses, wear easily causes further erosion.
5. Areas of conservational value.

Track classification and terrain vulnerability classification differ in their initial purpose and final applications: the former gives a monitoring directed situation description; the latter provides the basis for evaluating the consequences of planned and performed activities. Tracks must be used with caution as vulnerability indicators because varying driving practices may produce quite different effects on similar surfaces, and the amount of driving in each track case is unknown. The relationship between observed wear and terrain susceptibility cannot therefore be correlated directly.

The false-colour infrared imagery used for specific mapping purposes in this project also provides a wide range of biological and geoscientific information that may be of use in other contexts. Therefore, a discussion of the images as an information source for different thematic mapping purposes is given.

The lack of digital map data over Svalbard constrains the build-up of the NP GIS, a science -and management directed database at the moment. This is, however given high priority because enhanced data availability and GIS-based integration will aid significantly in terrain management and conflict visualisation, as well as in a wide range of scientific contexts. Four useful GIS-concepts are mentioned:
1. Use of overlaying data layers for studies and visualisation of covariations.
2. Use of quantitative models with multiple thematic data as input.
3. Enhanced visualisation of certain objects by use of buffer zones.
4. Combination of maps and area statistics.

GIS-based representations must be used with caution due to risks of model incompleteness, crude quantification and lack of relevant information which may be difficult to obtain or not quantifiable.

Further development is needed within the fields of information retrieval from the NP 90 image series and the use of GIS for terrain analysis, management and monitoring. Lack of digital data is the main constraining factor at the moment, and it is hoped that the track data made available by this project will be regarded a valuable contribution.

INTRODUCTION

During the 1960s and 1970s, concern about the long-term effects of off-road driving on tundra surfaces increased due to observed damage in northern Alaska and in the Canadian Northwest Territory. It was realised that the thermal instability associated with the removal of vegetation could lead to permanent surface modification. Commonly described effects were the deepening of the summer-thawed layer, the creation of permanent depressions due to differential thaw settlement, sediment instability and possible outwash and scar development caused by affection of runoff pathways.

Off-road driving with motorised vehicles on Svalbard has been taking place in connection with mining- and drilling-related activities during most of this century. Some of the transportation has been related to scientific investigations. During the last decades, ski-doos have been extensively used for personnel transport.

The need for long-term monitoring of the extent and characteristics of terrain disturbances created by off-road driving was a main motivation for this project. Registered data makes it possible to detect tracks formed after airphoto acquisition with a high degree of dependability, so that these can be regarded as new. Possibilities for monitoring of the development of registered tracks (revegetation or further erosion) can also be provided. The requested final product is a GIS-based registration that can be coupled to other information sources (e.g. digital thematic maps).

The intentions of environmental preservation on Svalbard are stated in the "Environmental Regulations for Svalbard". § 1 gives the main purpose:

§1
"The purpose of the regulations is to protect the natural environment of Svalbard and surrounding territorial waters from pollution, litter and other influences which may cause damage or detriment to human beings, the flora and the fauna and the natural environment otherwise, or appear unsightly."

The clear conflict between human activities which impose terrain wear and the nature-conservational intentions stated above necessitates requirements for registration of impacts and of consequential analyses of planned activities which may cause wear and disturbances. Travel restrictions have lately been included in the environmental regulations through the following paragraph:

§4
(......) "All use of motorised vehicles on thawed ground is prohibited. Exempted from this provision is driving on ground which has no vegetation, such as river beds, naked moraines and snow covered ground where the traffic can not leave permanent traces or lead to damage from erosion. The exemption to the provision also applies to traffic for purposes of economic subsistence in areas where, in pursuance of section 7, dispensation has been granted from the obligation to report in accordance with section 6." (........)

Only in rare cases do vehicular tracks represent significant ecological damage (e.g. by extensive removal of rare plant species). The geomorphological effect is, on the other hand, often outstanding. In every case, visible impacts reduce or destroy the impression of landscape virginity and the natural attractiveness of the surrounding area.

A system for the division of terrain types into vulnerability categories exists. It is precise enough to form a basis for travel recommendations and restrictions where new activities are planned. A good knowledge of the actual area is, on the other hand, necessary prior to use of the system for vulnerability mapping. The class correspondences of several occurring terrain types are only indicated with reference to general characteristics.

GEOGRAPHICAL SETTING

The Svalbard archipelago is situated between 74° and 81° north and between 10° and 35° east. The islands cover an area of 62,700 km². Around 60% of the total land surface of Svalbard is covered by glaciers.

All geological periods, from the pre-Cambrian to the Quaternary, are present on Svalbard. Tertiary rocks are mainly found in a central area from Isfjorden and southward and are underlain and surrounded by sedimentary strata from preceding periods. The older metamorphic and igneous rocks situated along the west coast and in the northern parts of Spitsbergen constitute another main unit.

The topography is strongly bedrock dependent, with plateau formations mainly associated with the gently inclined late Devonian to Tertiary sedimentary complexes. In areas with folded, pre-Devonian rocks, highly dissected alpine landscapes dominate. The highest peaks, Newtontoppen and Perriertoppen, both reach 1717 m altitude. The peak level typically undulates between 800 and 1200 m.a.s.l. on the main island, Spitsbergen.

Mountain slopes are mostly covered with weathering material and talus, and a great diversity of mass wasting forms occur.

The fjords and broad valleys in the western part of Spitsbergen indicate glaciations and a main ice movement towards this side from easterly located glaciation centres. Some of the valleys in the central parts of Svalbard morphologically indicate a fluvial origin. Upland surfaces are covered with unconsolidated deposits where in situ weathering material is an important component. Lack of erosional features as well as the absence of tills may be explained by cold-based ice conditions during glaciation periods (Sollid & Sørbel 1988). Most present glaciers reached their maximum Holocene positions during late parts of the last century (Liestøl 1988).

The thickness of the permafrost layer varies from about 75 to 450 m (Liestøl 1975). Permafrost-free zones exist beneath most glaciers. In valley bottoms, pingos are formed where water penetrates relatively thin permafrost. The thickness of the active layer is normally around 1-2 m in valley areas, dependent on soil texture and the amount of moisture in the ground.

Different types of patterned ground occur. These reflect soil characteristics and moisture content and vary in size from a few centimetres to tenths of metres.

The area belongs to the middle-Arctic vegetation zone. The growth season normally lasts for 6-10 weeks. Permafrost prevents downward penetration of moisture from the surface layer, and moisture is generally sufficient for plants.

Svalbard has a very mild climate for its latitudinal position. The North Atlantic Current affects the west coast in particular. Here, the coast line is ice-free most of the year. Typical annual middle temperatures are around -6°C. The average annual precipitation is around 300 mm.

Terrain vulnerability determining factors

Sørbel et al. (1990) list the following terrain vulnerability determining factors: vegetation cover, surficial material, topography, permafrost, local climate and water accessibility. These factors are strongly related.

The vegetation cover plays an important insulating role. Fig. 1 illustrates the correspondence between vegetation amount variations and thaw depth. Thawed soil was scraped off the permafrost surface in a cross section of a vehicular track and its closest surroundings, and it was clearly shown that much deeper thawing took place under the vegetation-free circles and the vehicular track than beneath areas with relatively thick vegetation.

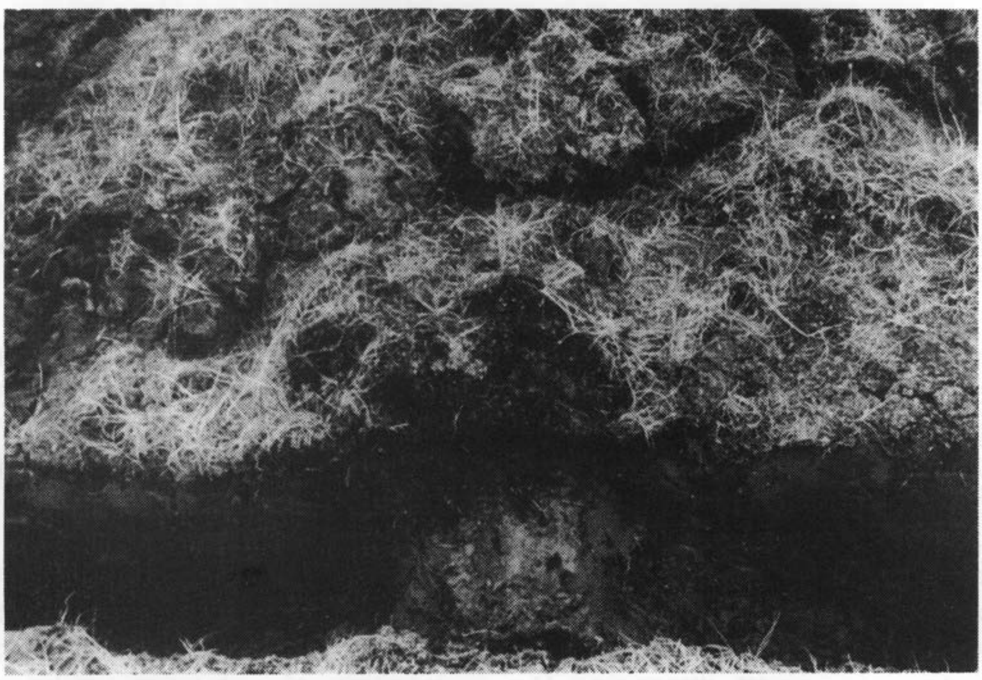

Fig. 1: Relations between thaw depth and vegetational variations. Track in the left part of the cross–section.

Underneath thick vegetation, permafrost is found near the surface during the whole summer. A removal of vegetation drastically alters the thermal balance, causing melting of ice in the ground.

Material type is a main factor which determines soil drainage, ice content and frost soil activity. Segregated ice units are easily formed in fine-grained soils during freezing. This makes areas dominated by fine material unstable and fragile during the melting period. Disruption of overlying vegetation easily causes deeper thawing and depression of the surface due to ice volume loss. In the worst cases, this may lead to water accumulation or earth slumping. Texture, thickness of the unconsolidated layer and clay fraction mineral distribution may also influence soil stability and terrain vulnerability.

In a sloping terrain, tracks may induce erosion from running water or the initiating of mass movement, e.g. in unstable scarps along rivers. Exposure to wind erosion is another topographically-determined factor worth mentioning. On exposed surfaces, revegetation may be hindered and erosional wounds may grow due to wind action.

Large segregated ice bodies occur in ice wedges and pingos. Disruption of the vegetation cover or disturbance of the active layer on such structures usually causes extensive melting and surface depressions. Pingos may also be regarded of conservational value because of their scientific interest.

Water supply determines the chance of track erosion in a sloping terrain. In water-saturated soils, driving can easily create depressions which accumulate water.

PREVIOUS INVESTIGATIONS

Vehicular tracks in the Isfjorden area were investigated by Hjeljord (1971). The main purpose of his investigation was to describe revegetation and surface damage development under different physical conditions.

A group of Dutch investigators participated during an oil survey on Edgeøya in 1972 and made registrations of impacts (Kuper & Van Rijn van Alkemade 1972). A new investigation was performed five years later (Berg 1977). Morphological and vegetational changes within the tracks were registered. Impacts were classified following a system developed and used for the same purposes in Alaska.

Registrations of tracks and consequential analyses in different regions on Svalbard have been performed by Leif Sørbel and co-workers at the Institute of Physical Geography, University of Oslo. A terrain vulnerability classification system is defined in a report describing the registration of vehicular tracks in Gipsdalen and Sassendalen (Sørbel 1987). This was later used for vulnerability mapping in Gipsdalen and along possible locations for a road between Longyearbyen and Svea (Sørbel et. al. 1990; Sollid & Sørbel 1991).

The Russian mining company Trust Arktikogul has quite recently started environmental studies in areas affected by their activities. Postnov (1989) establishes relations between types of surficial deposits, soil parameters and "geoecological vulnerability". He gives an overview of impacts in the area Kapp Laila - Hollendardalen, classifying track localities according to long-term effects and giving advice for restoration where continuing erosion is apparent.

Significant impacts have been the result of activity during test drillings in tundra areas in Alaska and northern Canada. The knowledge about lasting effects was initially poor. Early studies of terrain vulnerability and long-term effects of different types of impacts are reviewed by Brown et al. (1969) and Radforth (1972). In Canada and the USA, restrictions for off-road travel on tundra were established in 1971 and 1972, respectively (Rickard & Brown 1974). A lot of tests of erosive effects on vegetation as a function of vehicle type and traffic load have been performed (reviewed by Rickard & Brown 1974). Extensive multi-thematic mapping of areas affected by earlier impacts and where new activity was being planned has been carried out by the US Army Cold Regions Research and Engineering Laboratory (Lawson et al. 1978, Lawson 1982; Walker et al. 1980).

DISTRIBUTION AND CHARACTERISTICS OF VEHICULAR TRACKS

Regional extent and development through time

Tracks are mainly found where activities connected to mining and drilling have been taking place. The area between Barentsburg and Colesdalen is heavily affected. Many tracks also exist in Colesdalen and northwards on the mountain plateau's towards Bjørndalen. The upland surface between Bjørndalen and Longyearbyen (Platåberget) has been heavily trafficked. Furthermore, extensive track systems exist in Adventdalen. Parts of Reindalen bear traces of intensive transportation activity. All the mentioned areas are situated on Nordenskiöld Land. The nearest area around the mining settlement Pyramiden on Dickson Land is significantly affected by off-road driving.
Some tracks are also visible between Grønfjorden and Isfjord Radio. Remnants of a transport route from Grøndalen through Semmeldalen to a drilling station in Vassdalen can be seen as discontinuous traces in Grøndalen and on the eastward facing slopes towards Semmeldalen and Van Mijenfjorden. Some traces also exist in tributary valleys of Colesdalen and Adventdalen, from Sveagruva to the mouth of Reindalen and in Sassendalen on Nordenskiöld Land. Outside this area, track systems occur in Gipsdalen, from east of Ny Ålesund to Kvadehuksletta on Brøggerhalvøya, around Hornsund and on Edgeøya. Some traces from driving are also reported in Kinnvika on Nordaustlandet caused by activity around the scientific station situated there in the 1950 - 60s. On Fløysletta on Wedel Jarlsbergs Land, there are tracks made by German aeroplanes which landed during the war. These occurrences were not detected from the images (Otto Salvigsen, pers. comm.).

Impacts from the period 1950 - 1960 in the Longyearbyen area originate from diamond-drilling and transportation activity related to the establishment of new mines and transport lines. A permanent road was built in Adventdalen in 1958, and off-road driving probably ceased then (Hjeljord 1971). Soviet mining in Grumantbyen and related activities in Colesbukta came to an end in 1965, but a large Soviet drilling program was in operation in the mountain areas west of Grumantbyen until recently (P. Prestrud, pers. comm.). Transport routes to the drilling area are severely marked. Waste deposited during drilling affects a large area. Recent tracks also exist in Gipsdalen (Finnish drilling activities during early 1980s) and in Bjørndalen (test drilling performed by Store Norske Spitsbergen Kullkompani (SNSK) in early 1980s). The mentioned recent activities have caused significant tracks.

Fig. 2 shows the extent of impacted areas. Only areas where tracks are detected from the imagery have been shaded. Possible weak impacts may be expected to be found elsewhere.

Fig. 2: Location map showing areas affected by impacts.

Examples from areas on Nordenskiöld Land

Examples are given from areas where fieldwork has been carried out.

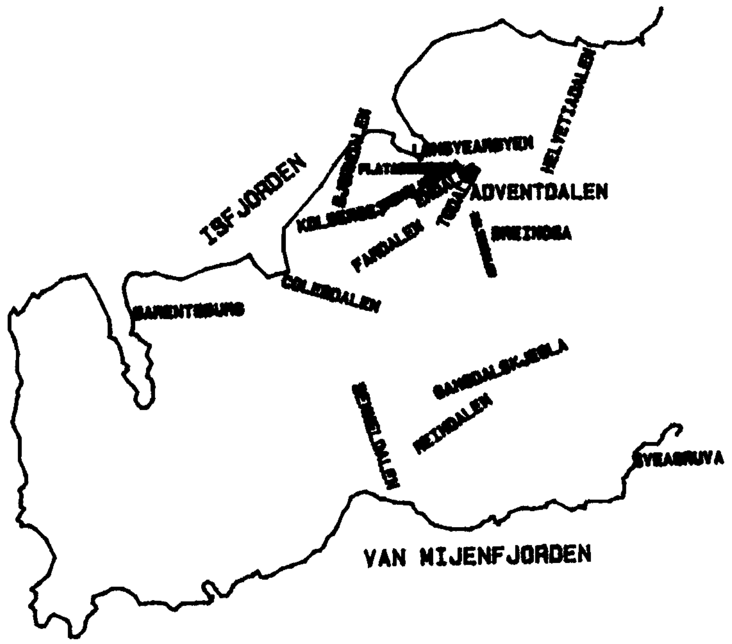

Fig. 3: Location map of Nordenskiöld Land, showing mentioned areas.

Colesdalen

This WNW-ESE trending valley consists of a large wetland area along the river, with gentle slopes consisting of alluvial, weathering and morainic deposits. A large marine deposit occurs in the valley mouth region.

Areas on the north side of the river, between the shore and a marked river bend, 4 km from the mouth were heavily trafficked before the mining activities ceased. Some routes have also been used later for transportation to drilling localities in Fardalen and north of Colesdalen.

In tributary valleys of Colesdalen, weak tracks occur. Some of these were not seen during airphoto interpretation. Tracks made by single passages in frost-active soil (dominated by hummocks and/or frost boils) were self-repaired to a high degree.

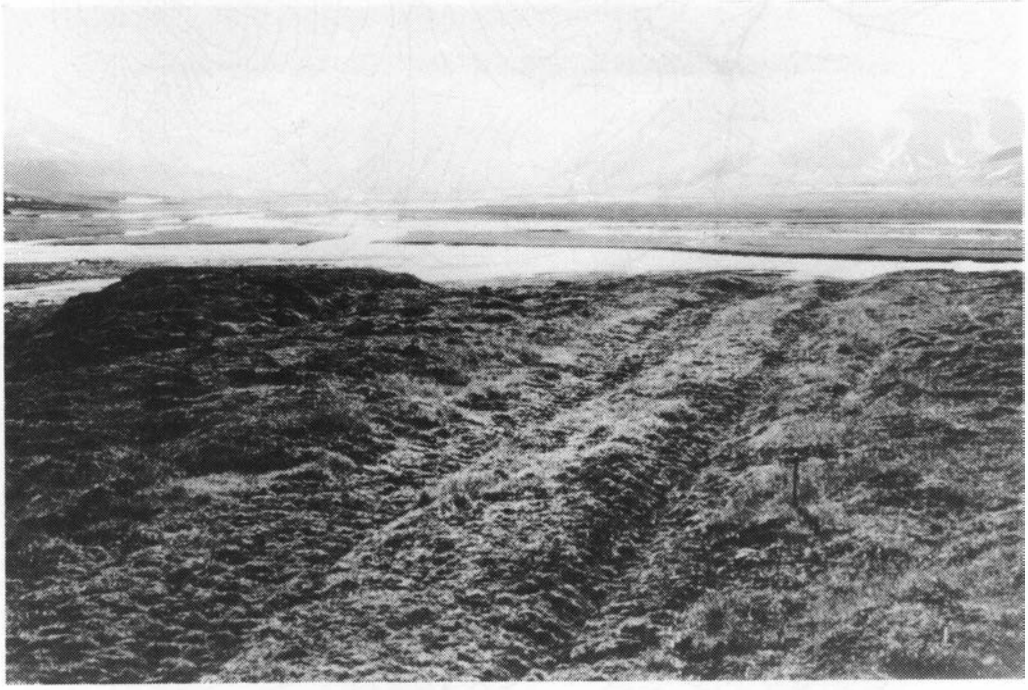

Fig. 4 From the middle part of Colesdalen. The area has been heavily trafficked.

Fig. 5: Heavily used track near Kolberget north of Colesdalen.

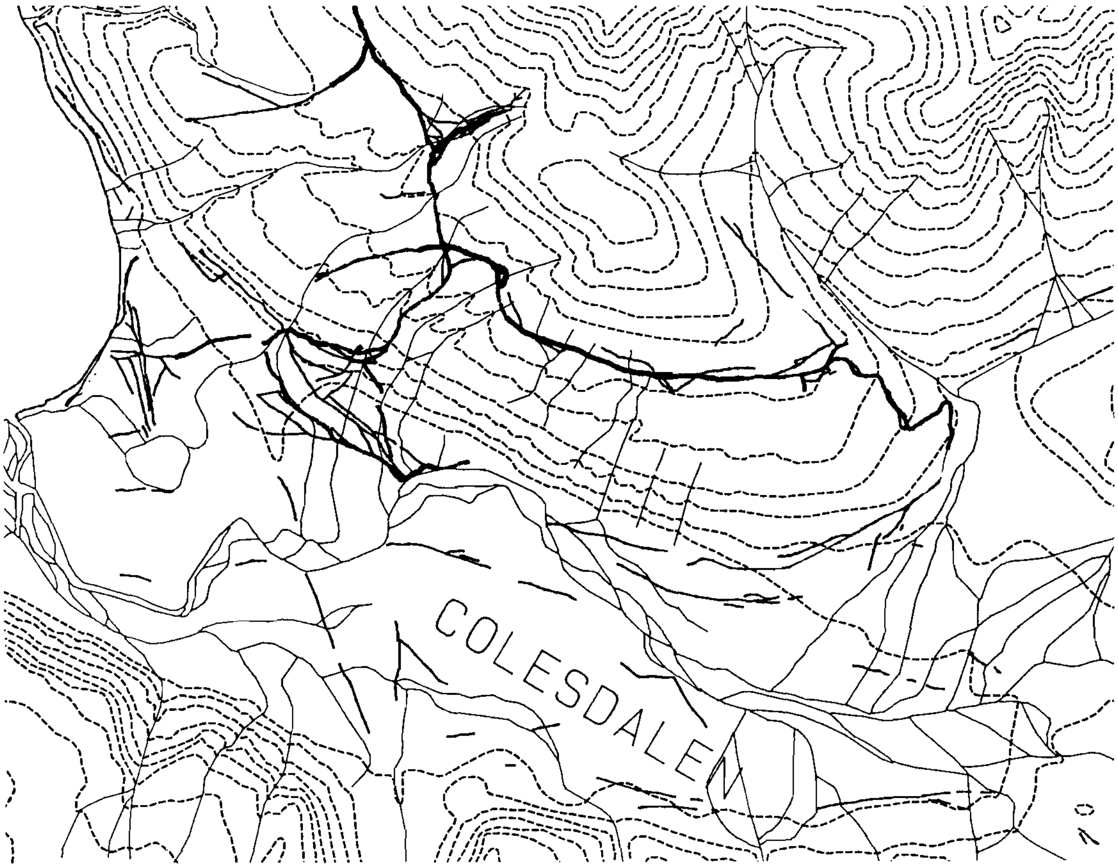

Fig 6: Driving tracks in and around Colesdalen.

Reindalen

This valley has a very wide, gently sloping or flat bottom with wetland delta - characteristics in the southern parts. The middle part of the valley contains large, gently inclining fans from tributary rivers and low bedrock-formed plateau's close to the central river. The north-eastern, upper part of the valley is narrower, and several glaciers and frontal moraines extend into the main valley basin.

Tracks are supposed to originate from Soviet test drilling in the 1950s. The transport lines through Semmeldalen are probably parts of the same system. In areas dominated by fine-grained soils with intermediate moisture content, frost soil processes have caused restoration of the tracks. This makes them difficult to detect from aerial images, even though large areas are affected by parallel passages. These often form broad zones, each single track representing a very limited impact.

In the southern, outer part of the valley, some tracks have been made by Soviet activity connected to the Vassdalen drilling, while other lines show the route of SNSK transportation's from Longyearbyen to Sveagruva.

In the coarser and drier surface material on the low plateau's, deposited tracks were more apparent because of weaker surface-modifying soil activity.

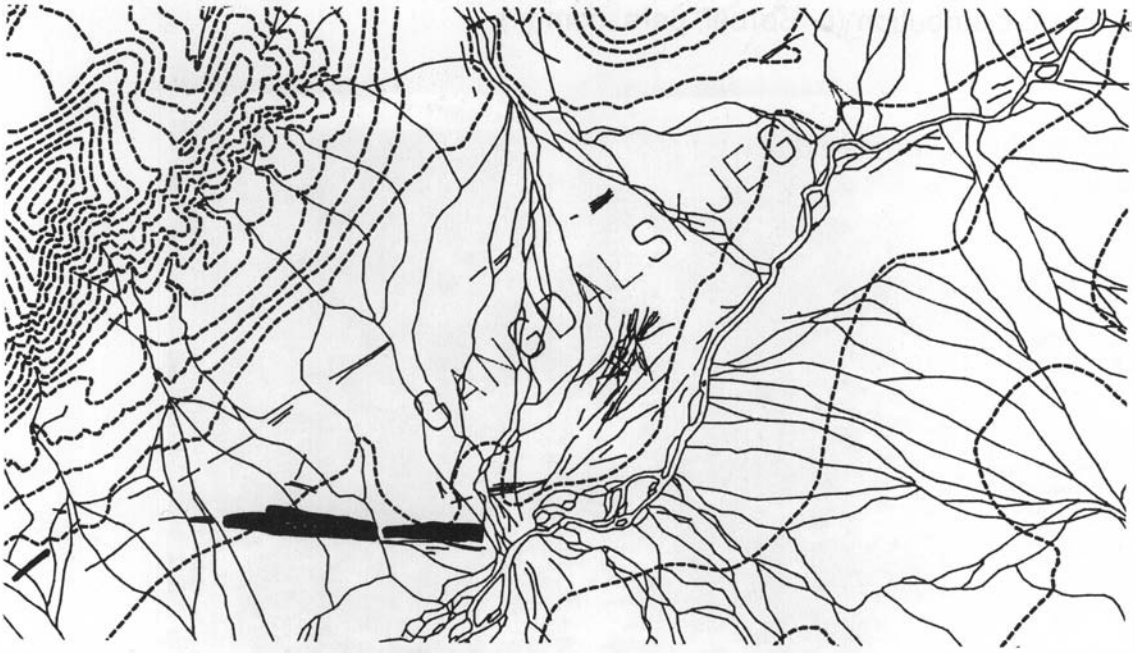

Fig 7: Registered tracks in the middle part of Reindalen.

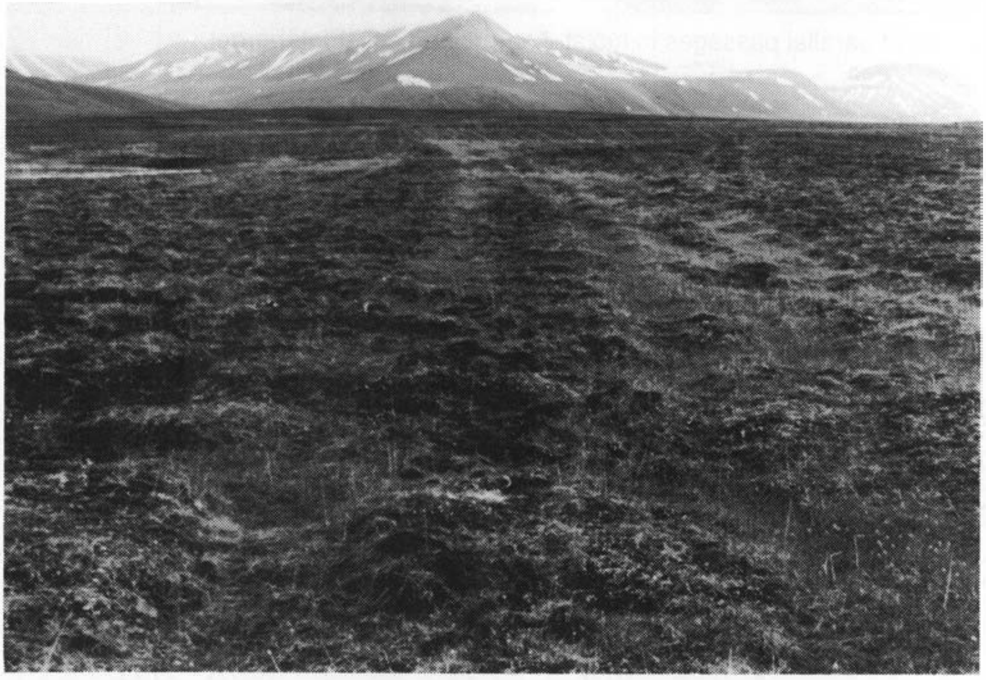

Fig. 8: Scenery from the low plateau between the alluvial fan Gangdalskjegla and Reindalselva river. The locality has been heavily trafficked.

Platåberget

This highland plateau is situated north of the Nordenskiöldfjellet mountain. It is areally delimited by slopes down towards Blomsterdalen, Bjørndalen and Isfjorden. The elevation is 400 - 500 m.a.s.l.. The surface deposits probably consist of weathering soils of local origin (Kristiansen & Sollid 1987). Block-dominated fields, different types of patterned ground and plains with moist, relatively homogeneous fine fraction dominated material are characteristic features. Variations in the underlying bedrock and snow cover seem to be factors determining the landform distribution (L. Sørbel, pers. comm.).

Fig. 9: Broad zone of parallel passages in moist, fine-grained soil, Platåberget.

Fig. 10: Registered tracks on Platåberget.

Vehicular tracks originate from drilling in 1953. Impacts occurring in the area are single tracks, broad zones of parallel passages and areally influenced fields (drilling sites and installation basements). In addition to tracks, drilling waste, remnants of buildings, wire segments, metal bins and vehicle spare parts have been left in the area. Parts of Platåberget are strongly affected by wastage.

Impacts were field-mapped in the whole area to provide a basis for further studies of track development. The data were also used for an evaluation of the suitability of the available image scales for track detection.

Adventdalen and surroundings

The outer 13 - 14 km of Adventdalen are dominated by an extensive sandur plain. On the south side of the valley, the mountains rise stepwise from the level of 350-400 m.

Extensive tracks occur in the main valley from the river outlet to the mouth of Bolterdalen. The tracks have probably been used until 1958, when a permanent road was built (Hjeljord 1971). Some tracks are made during the construction of the now abandoned wire transport system for coal.

Tracks also exist in the tributary valleys, Bolterdalen, Todalen, Endalen, Helvetiadalen, and on the mountain plateau's Breinosa and Lindholmhøgda. Tracks in the side-valleys mostly follow river basins to interior drill sites. In Bolterdalen, a primitive road has been built along the river from the Adventdalen road to the western outlet glacier of Foxfonna.

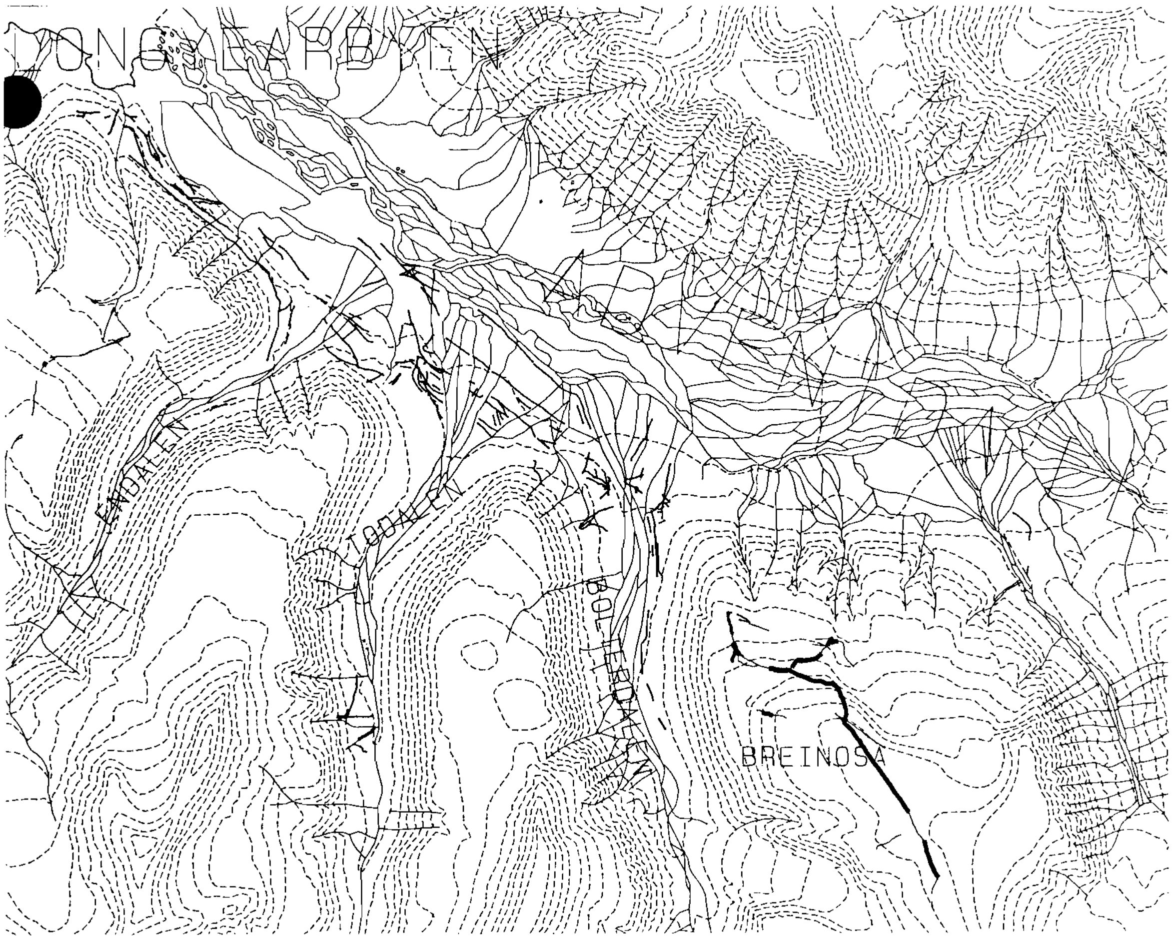

Fig. 11: Registered tracks in Adventdalen and surroundings.

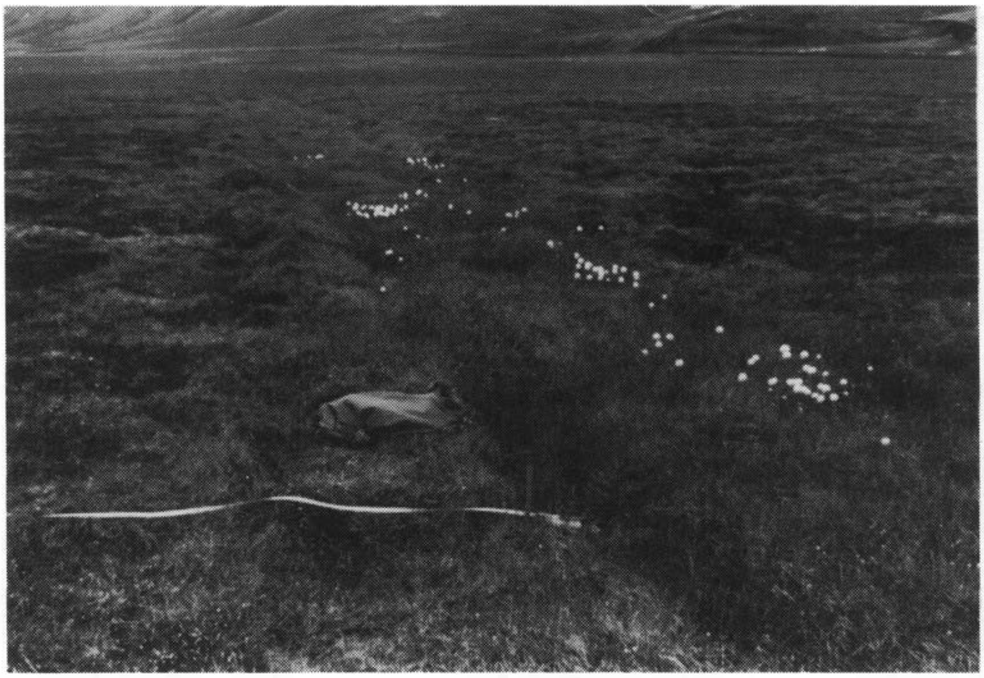

Fig. 12: Track on a subrecent, intermediately moist river plain in front of the mouth of Todalen, Adventdalen. View towards the east.

Vehicle types

Most of the observed traces are from tracked vehicles. Single pass track widths measured in the terrain were typically 2.40 - 2.60 m. Some tracks made by jeep-like vehicles were seen in Adventdalen. Snowscooter tracks were seen in Adventdalen and Colesdalen. The prints were marked, which indicates driving on snowfree, thawed ground. In the inner parts of Colesdalen, long, continuous traces were seen (Fig. 13). In Adventdalen, most marks indicated crossing of snow-free patches and thawed creek depressions.

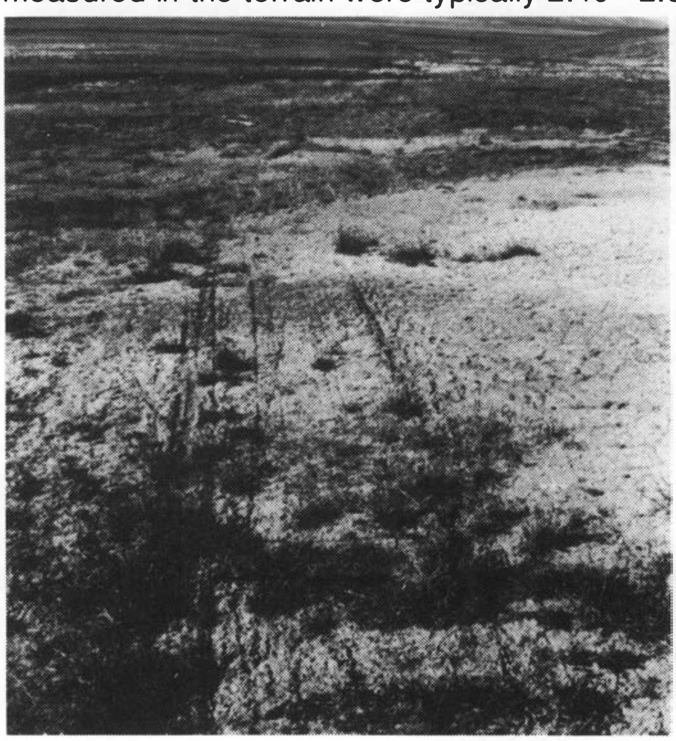

Fig. 13: Snowscooter trail, Colesdalen.

A track probably made by off-road motorbike driving was seen on Platåberget. The track was marked and showed no signs of modification.

REGISTRATION AND QUANTIFICATION OF IMPACTS

Imagery in scale 1:15,000 provided coverage for Nordenskiöld Land, Agardhdalen and surroundings, Bünsow Land, Brøggerhalvøya and the Pyramiden and Kapp Wijk areas on Dickson Land. For the rest of Svalbard, 1:50,000 imagery was used. Usefulness of the different scales for track detection is discussed.

Data retrieval and transfer

Tracks were registered from aerial images using a Zeiss-Jena interpretoscope at the Laboratory of Remote Sensing and Thematic Cartography, Department of Physical Geography, University of Oslo. Final registration and classification were performed after the fieldwork was completed to benefit from field experience.

On Edgeøya, tracks were registered from helicopter in 1989 (Iversen 1989). During the mapping of quaternary geology and geomorphology in Gipsdalen and on Kvadehuken on Brøggerhalvøya, vehicular tracks were registered (Tolgensbakk 1990; Tolgensbakk & Sollid 1987). These data were checked, adjusted and classified using aerial images. Tracks in the Hornsund and Pyramiden areas were visually transferred to maps. The registrations on Edgeøya were made in the same manner.

The abandoned railway line between Colesbukta and Grumantbyen, the road undergoing construction in Bolterdalen and other trails made for permanent use were not registered as tracks. Doubtful cases, like the road / track from Kapp Heer towards Colesbukta, were, on the other hand, included.

Data transfer between single image based registration and geometrically correct map format was performed by use of a TELLUS GIS application specially made for such purposes. An elevation database had to be constructed prior to data transfer, and this was generated from existing topographic maps. The transfer process included the establishment of transformation geometry by using control points detectable both in images and on maps, digitising of manually registered tracks with automatic correction of image-inherent geometrical errors, and format conversion prior to ARC/INFO GIS inclusion.

Positional quality

Many factors determine the positional accuracy of GIS-registered data that have undergone transformation and editing:

a. Drawing during registration and digitising of tracks may create errors corresponding to some tenths of metres.

b. Map quality determines control point and elevation data accuracy. The topographic maps are constructed from oblique images acquired during the period 1936 - 38. Elevation data accuracy is therefore expected to vary rather much.

c. Control points that are identifiable both on images and on the maps are necessary for image to map coordinate data transfer. Several terrain elements, such as river systems, have undergone significant changes since map construction. Such features were only used as control points when alternatives were lacking, which was unfortunately sometimes the case. This resulted in the reduced transformation accuracy of track data, which had to be compensated for during digitising.

d. Deviations between the real and the modelled terrain surface (used for image parallax compensation) may cause location errors, but these are expected to be small in the flat valley bottoms, where most of the tracks are situated.

e. Graphical editing and line topology generation during the final GIS-based track data treatment may also have caused errors. Tracks digitised as single lines are automatically connected in intersections, causing them to be somewhat moved from their initial positions. Lines may also be merged when their spacing is smaller than a user-set line connection tolerance. In general, such errors are almost avoided by careful use of automatic "cleanup" procedures. The outline of track systems is not influenced by editing and topology creation, and minor errors mostly occur where tracks are closely spaced.

Classification system needs

One of the main purposes of the project was to quantify impacts caused by off-road driving. Two kinds of information are necessary in order to perform this quantification: firstly, the extent and areal frequency of tracks has to be known; secondly, the tracks have to be characterised by a qualitative description. A classification of impacts must therefore first be carried out and a classification system must be chosen.

Descriptive simplicity is required to allow track classification from the image material. In addition, the system must provide sufficient information to allow monitoring. The development of existing tracks (further erosion or revegetation) must be detectable and updatable. Experience from fieldwork as well as airphoto interpretation were both taken into account during work with the classification system design.

Track classification

Rickard & Brown (1974) used a 4-class scale for tracks and other impacts. The system is used in a somewhat modified form by Berg (1977) in studies of vehicular tracks on Edgeøya:

1. Tracks caused by few or single passages. Vigorous vegetation increase in track lines is the only apparent physical effect.

2. Tracks with vegetation disturbances. Other influences on the substrate are insignificant.

3. Tracks with significant disturbance of the vegetation cover and compression of organic surface material. Thaw depth is measurably increased, but further erosion does not take place.

4. Impact characterised by removal of a thick vegetation carpet. This causes a marked depression, and erosion may take place. The thaw depth is severely increased.

For this study, a more complex system with greater information content is preferred. Six classes are defined, of which two are subdivided. Due to more strict definitions of class division criteria, it is possible to give more detailed impact descriptions. A more detailed description also provides a better monitoring base.

A disadvantage of this system is that the use of calculated numbers for track classification may seem artificial. On the other hand, according to project definition, tracks are regarded as quantifiable features. Therefore, a quantitative approach is considered suitable, although class definitions may be discussed.

Class division criteria should, as far as possible, provide a complete model of the observed significance of impacts. Point site observations were used for testing and adjustment of the system. These were randomly selected within relatively homogeneous track sections, chosen from the imagery. Descriptive parameters were measured or estimated.

For vegetation coverage and composition estimation, reference points outside the track and points in the most worn zones were compared. Crustal lichens and dark or dead mosses were not included in vegetation coverage calculations for reasons stated below. Fig. 14 describes sample point geometry within an observation site and gives the used zone designations.

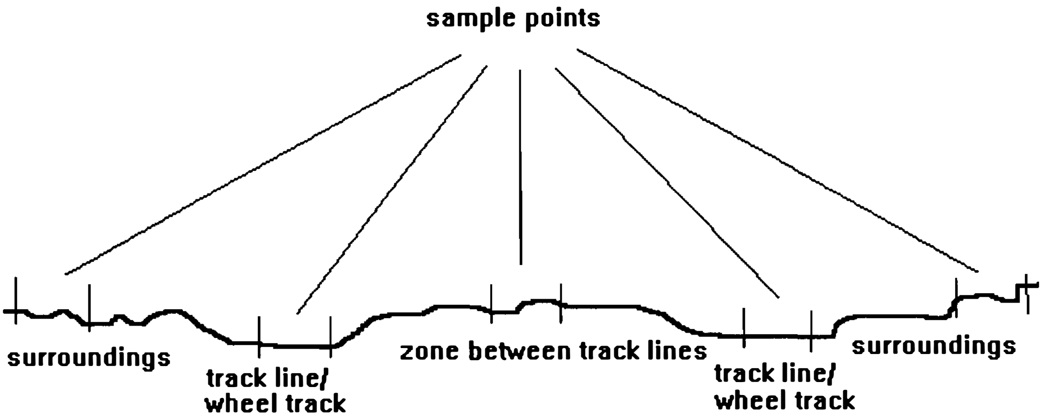

Fig. 14: Cross-section of a vehicular track, indicating sample points and zone designations.

The following parameters were used as class division criteria:

- Continuing erosion. This gives important information for track monitoring and indicates terrain type vulnerability and / or consequences of a certain driving practice. Visualisation of track segments undergoing further erosion is also useful in identifying areas where the need for restoration is highest.

- Whether the vegetation coverage in the surroundings is more than 20%. This influences the appearance of the impact.

- Whether the vegetation coverage of the most eroded zones of the track is more than 20%. Coverage is calculated as the average of coverage percentages of the main depressions (wheel tracks) or of the zone between these.

- For division between "marked" and "less marked" tracks, a "severity index" is calculated. Morphological parameters and vegetational differences are taken in concern. An "average case" is defined as a track with the following characteristics:

  - Width: 3 m
  - Depth: 10 cm
  - Positive difference between vegetation coverage in the unaffected surroundings and the zone between the main depressions: 20%.
  - Positive difference between vegetation coverage in the unaffected surroundings and in the main depressions: 20 %

The above figures and constants used for calculation are set so that an "average case" is given 1 as single index values. The "severity index" is calculated by summing the four single indexes:

1. Track width index, calculated as (width / 3 m).
2. Track depth index, calculated as (depth / 10 cm).

3. Vegetation wear between the main depressions, calculated as: 0.6 + 0.02 x (positive difference between vegetation coverage percentages in the unaffected surroundings and between the main depressions).
4. Vegetation wear in the main depressions, calculated as: (0.4 + 0.03 x (positive difference between vegetation coverage percentages in the unaffected surroundings and in the main depressions).

The class division is given schematically in Fig. 15:

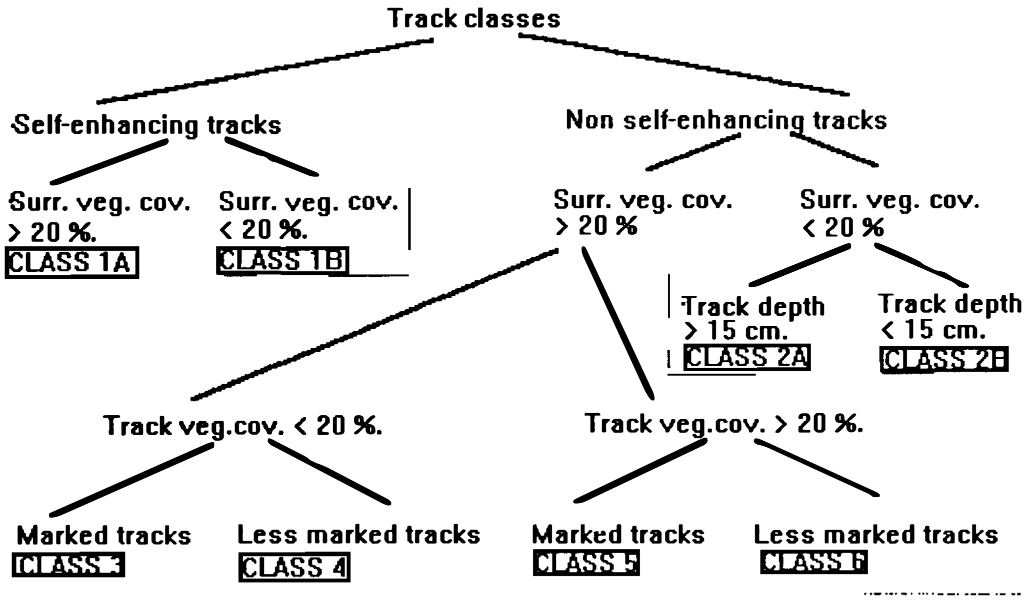

Fig. 15: Schematic outline of class division.

1. Self-enhancing tracks

Characterised by continuing erosion or accumulation of water, eventually causing a depression with a wider extension than the track itself.

Subclass 1A: Vegetation coverage of the surroundings (excl. crustal lichens and dark mosses) > 20%.

Subclass 1B: Vegetation coverage of the surroundings (defined as above) < 20 %.

Fig. 16: Track with continuing erosion, type 1A, between Colesdalen and Kolberget.

Remaining classes (2 - 6): *Non-self-enhancing tracks*

2. Tracks in areas with vegetation coverage (defined as above) <20%

Subclass 2A: Depth > 15 cm.

Subclass 2B: Depth < 15 cm.

Fig. 17: Track classified as type 2B, Platåberget.

Remaining classes (3 - 6): *In areas with vegetation coverage > 20%.*

3. Marked tracks with little vegetation in the most eroded zones.

Either: vegetation coverage of the surroundings > 70% and vegetation coverage of the most eroded zones < 20%,

or: vegetation coverage of the surroundings between 40 and 70% and vegetation coverage of the most eroded zones < 10%,

or: vegetation coverage of the most eroded zones < 20% and impact severity index > 4.

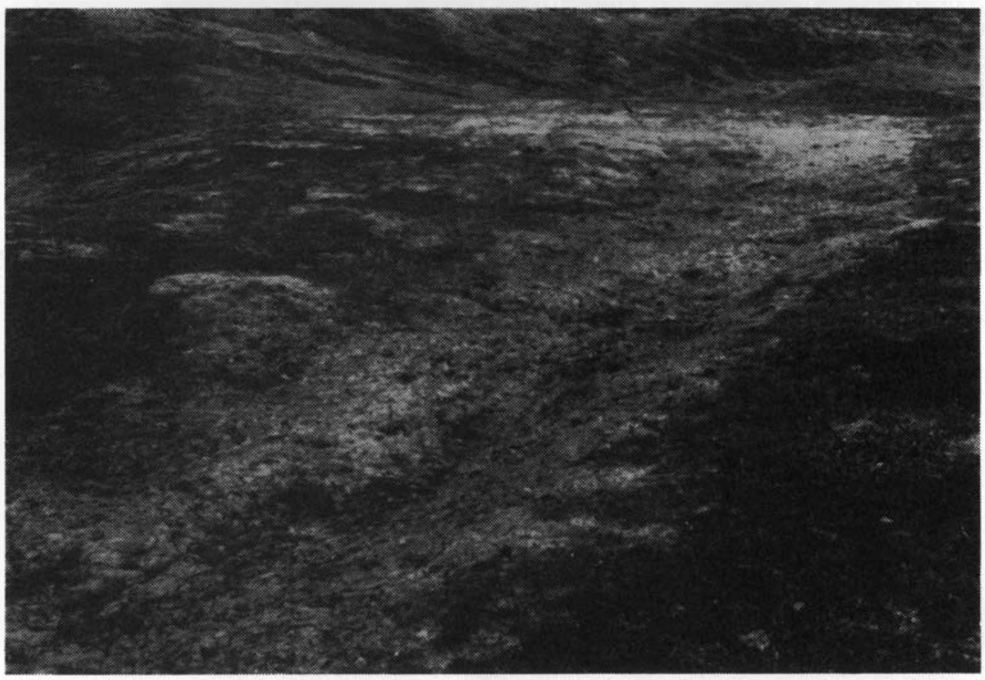

Fig. 18: Track classified as type 3, Colesdalen.

4. Less marked tracks with little vegetation in the most eroded zones.

Either: vegetation coverage of the surroundings between 40 and 70% and vegetation coverage of the most eroded zones between 10 and 20%,

or: vegetation coverage of the surroundings between 20 and 40% and vegetation coverage of the most eroded zones < 20%.

In both cases: impact severity index < 4.

Fig. 19: Track type 4, Endalen - Adventdalen intersection.

Remaining classes (5 - 6): *Tracks with significant vegetation in the most eroded zones.*

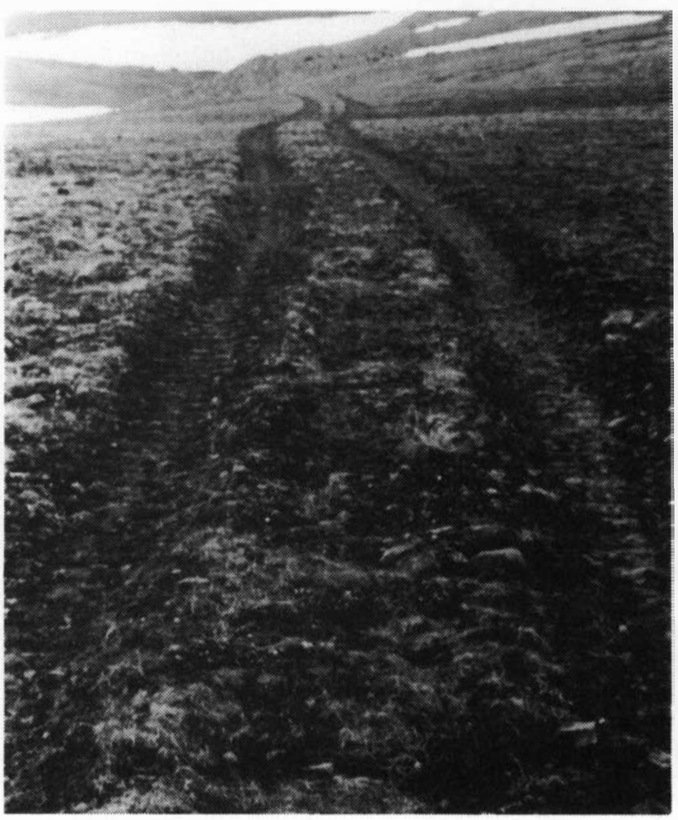

Fig. 20: Track type 5, Platåberget.

5. Marked tracks.

Vegetation coverage of the most eroded zones > 20% and impact severity index > 4.

6. Less-marked tracks.

Vegetation coverage of most eroded zones > 20% and impact severity index < 4.

Fig. 21: Track type 6, Trodalsmunninga, Colesdalen.

Interpretation of characteristics on images

The airphoto-based classification of tracks is based on subjective evaluations of the division criteria. Some aspects are discussed below.

Continuing erosion in tracks can be detected as visible water runoff at the time of airphoto registration. Track morphology may also be modified by running water. Connection to creeks/rivers or visible topographic expression (e.g. local depression, gully formation) often visualise erosion. Dark colour tones in track lines or in the whole trail are mostly interpreted as water drainage, although they may occur because of exposure of dark soils. Shallow ponds in the tracks are difficult to detect when vegetation grows in the depressions. Linear depressions caused by lowering of the permafrost table along trails may in severe cases be detected by stereoscopic observation of large scale (1:15,000) imagery.

During image-based determination of vegetation amount, it is possible to divide between areas where green vegetation gives a marked, areally continuous signal (yellow -/orange tone in the available imagery) and areas where this tone is absent or insignificant. The threshold value of 20% used in the classification system seems to correspond rather well with the minimum coverage for visually detectable green vegetation in the images.

Crustal lichens and dark or dead mosses are, as mentioned before, eliminated from vegetation coverage calculations from field data. These plants have spectral characteristics that are quite different from those of green vegetation. They often dominate on blocky ground and dry areas. Areas covered by dark lichens and mosses may also be interpreted as consisting of dark, unvegetated deposits or bedrock.

The depth dependent division (classes 2A and 2B) is included to separate between marked and less significant tracks in areas with insignificant vegetation coverage. Visible shadow effects and elevated track edges indicate deep tracks.

The division of the classes 3, 4, 5 and 6 is based on vegetation coverage in tracks and "impact severity". Common sources of classification errors are tone contrasts between tracks and surroundings due to other factors than vegetational differences and the influence of track width on the impression of wear.

Characteristic segments longer than 150 metres (equivalent to 1 cm on 1:15,000 images) have generally been classified separately, while shorter sections need to be very different from the adjoining track parts to be classified as belonging to an other class.

Calibration and testing

Track observation sites have been used for testing and adjustment of the classification system. These were randomly selected from relatively homogeneous track sections, chosen from the imagery. The points have been classified from descriptive field data. A comparison with classification of the same track segments from images has been carried out. Constants used for index calculations were set after some "trial and error". Vegetation coverage percentages have been estimated from analysis of 0.5 x 0.5 m squares, normally one inside each track line and one on each side outside these. Lack of representativity due to the nature of one-point sampling, especially for vegetation data, is the main weakness of the calibration method.

Table 1. Correspondence between airphoto based - and field data based classification of track localities.

	Class from field data:	1A	1B	2A	2B	3	4	5	6
Class from airphoto:	1A	4	----	----	----	1	----	----	----
	1B	----	----	----	----	----	----	----	----
	2A	----	----	----	----	----	----	----	----
	2B	----	----	----	1	1	----	----	----
	3	1	----	----	----	4	----	----	----
	4	----	----	----	----	----	----	1	4
	5	----	----	----	----	4	----	1	3
	6	----	----	----	----	----	----	2	21

Table 1 gives the result of the comparison between airphoto-based and field-data-based classifications of track localities. 31 of a total of 49 localities have been identically classified by both methods. The airphoto-based classification was done before the classification of field data. The risk of misclassification is particularly large between the classes 3 and 5 and between 4 and 5. Reasons for misclassification are listed in Table 2.

Table 2. Reasons for misclassifications during airphoto interpretation. Classification from field data is used as a reference.

Overestimation of vegetation coverage in tracks	5 loc.
Underestimation of vegetation coverage in tracks	4 loc.
Underestimation of "impact severity"	4 loc.
Generalisation during interpretation	3 loc.
Overestimation of "impact severity"	1 loc.
Continuing erosion not visible	1 loc.

Evaluation of image scales

A comparison between class track detection percentages was carried out in the area of Platåberget covered by image nr. 5557, scale 1:15000. The area was surveyed in the field, and all tracks were drawn on the image and classified. Where point observations were carried out, these were used as a calibration reference.

The comparison formed a base for determination of detection percentages, which were calculated as classwise summed lengths of detected tracks, divided by the corresponding field registered totals. The airphoto registrations took place

after the field survey, and fewer of the less marked tracks (classes 2B and 6) would have been detected without field knowledge.
Detection percentages are given in table 3.

Table 3: Detection percentages of different track types using different image scales.

	Track type:	1A	2B	3	4	5	6	Tot.
Scale:	1:15000:	100	59	100	100	100	60	63
	1:50000:	100	23	100	94	69	20	27

Information in 1:50000-scale images has been compared with the helicopter track registrations on Edgeøya done by Iversen (1989). Oblique photos were taken and tracks were drawn on maps, making them easy to locate. Only a few segments could be detected, although locations were known, and some of the identified sections would not have been recognised as tracks if additional information had not been available. This contributes to the conclusion that 1:50,000-scale imagery is not suited for track mapping.
The detection percentages using 1:15,000-scale images are satisfactory for all classes. All severe tracks were seen, and the field survey confirmed that the tracks which were not detected during image interpretation were either narrow and revegetated or situated in areas invulnerable to terrain wear.

INFLUENCE ON VEGETATION

Species observations

Vegetation analysis on observation sites was carried out by botanist cand scient Anita Myrmæl, who worked as field assistant for the project. Five 0.5 x 0.5 m square analysis plots were chosen on each sample point. One reference square was placed on each side of the track, each five metres from its lateral limits. One square was placed in the middle of both main depressions and one midway between these (Fig. 9).

Plant species were registered, and plant-sociological vegetation types of the localities were determined. The coverage of each species was given according to a 5% scale. Plants represented only by few specimen were given 1% as coverage value. In difficult cases, group designations were used (e.g. *Hepaticae* sp.). Crustal lichens of quantitative significance are placed in groups using colour as the criterion.

Names of higher plants follow Rønning (1979), mosses Hallingbäck & Holmåsen (1985) and lichens Krog, Østhagen & Tønsberg (1980). Hans Haavardsholm

Blom, NINA (Norwegian Institute of Nature Research) contributed during species determination.

Species vulnerability classification

To classify species according to their fragility to disturbances or pioneering abilities, observations from worn zone - and reference squares were compared. Vegetation coverage percentage differences were calculated for each species. Observations were grouped in four categories:

1. Coverage in the tracks > 90% of coverage in the surroundings.

2. Coverage in the tracks 50 - 90% of coverage in the surroundings.

3. Coverage in the tracks 10 - 50% of coverage in the surroundings.

4. Coverage in the tracks < 10% of coverage in the surroundings.

For classification of species, a "pioneering and resistance index" was calculated by weighting observations in each of the categories and dividing on the total number as follows:

$$\text{Index} = \frac{(\Sigma\text{obs. cat.1} \times 3) + (\Sigma\text{obs. cat.2} \times 2) + (\Sigma\text{obs. cat.3} \times 1)}{\Sigma\text{obs. tot.}}$$

It is not possible to determine from the data whether the occurrence of plant species in the tracks indicates that plants have been resistant to the wear imposed or if they have established after driving took place with absolute certainty. It is therefore case-specific whether existence in tracks should be attributed to resistance or to pioneering abilities. However, occurrences in heavily worn tracks might indicate revegetation. Remaining vegetation in less trafficked localities might, on the other hand, comprise the more resistant species. Therefore, a division of localities into "worn" and "moderately worn" was made. These were divided by use of the vegetation wear components of the severity index. In most cases, the division was corresponding to classes 1, 3 and 4 and 2b, 5 and 6, respectively. Classification was performed separately for the two groups. Common species in the "worn" track category may be regarded as pioneers, while species commonly occurring in the less worn tracks may be the more resistant to driving-imposed wear.

A further subdivision into environmental types (e.g. dry/wet) could have been performed to illustrate environment-specific species characteristics. This was, however, not done, because a further division of the data set would have lead to significantly greater uncertainties.

In Table 5 and 6, plant species with four or more registrations in respective track groups were divided in four classes dependent on occurrence in tracks. The categories are defined as follows:

1. Track vegetating. Strong tendency (index value 2 - 3).

2. Track vegetating. Weak tendency (index value 1.5 - 2).

3. Absence in tracks. Weak tendency (index value 1 - 1.5).

4. Absence in tracks. Strong tendency (index value 0 - 1).

For some species, the number of registrations in each category is too low to be included in Tables 5 and 6. Species or groups of species with less than 4 observations in each category (worn/moderately worn tracks) but 4 or more in total are given in Table 4. They are classified by calculation of a common index for both locality groups. A high degree of classification uncertainty must be expected.

Table 4. Track vegetating tendencies for species groups with few observations.

Species	Category	Number of obs.
Higher plants:		
Saxifraga nivalis	2 (moderately vegetating)	5
Papaver dahlianum	2 (moderately vegetating)	4
Cassiope tetragona	4 (strongly absent)	5
Mosses:		
Calliergon stramineum	1 (strongly vegetating)	5
Pogonatum dentatum	2 (moderately vegetating)	5
Racomitrium sp.	3 (moderately absent)	5
Racomitrium lanuginosum	4 (strongly absent)	4
Lichens:		
Cetraria nivalis	2 (strongly vegetating)	4
Thamnolia vermicularis	4 (strongly absent)	4

Table 5: Species by species track vegetating tendencies, strongly worn tracks.

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1. Plant species / groups with strong track vegetating tendencies.

Higher plants:

Phippsia algida	*Saxifraga cernua*	*Poa sp.*
Saxifraga hyperborea	*Cerastium arcticum*	

Mosses:

Pohlia nutans	*Psilopilum laevigatum*	*Drepanocladus uncinatus*
Calliergon sarmentosum	*Bryum sp.*	*Pohlia sp.*

Lichens:

none

2.Plant species / groups with weak track vegetating tendencies.

Higher plants:

Cerastium regelii	*Luzula arctica*	*Poa arctica*
Cardamine bellidifolia	*Equisetum arvense*	

Mosses:

Dicranum sp.	*Aulacomnium turgidum*	*Tomenthypnum nitens*

Livermosses:

Ptilidium ciliare

Lichens:

none

3. Plant species / groups with absence in tracks. Weak tendencies.

Higher plants:

Polygonum viviparum	*Luzula confusa*	*Pedicularis hirsuta*
Alopecurus alpinus	*Draba sp.*	

Mosses:

Hylocomium splendens	*Drepanocladus sp.*	*Conostomum tetragonum*

Livermosses:

Hepaticae sp.

Lichens:

Cetraria islandica

4. Plant species / groups with absence in tracks. Strong tendencies.

Higher plants:

Stellaria crassipes	*Luzula sp.*	*Ranunculus sulphureus*
Salix polaris		

Mosses:

Polytricum sp	*Dicranoweisia crispula*	*Onchophorus wahlenbergii*

Lichens:

Sphaerophorus globosus	*Crustal lichen, white*	*Crustal lichen, dark*
Cladonia arbuscula	*Stereocaulon sp.*	*Cetraria delisei*
Peltigera canina	*Cladonia sp.*	*Peltigera apthosa*
Peltigera rufescens	*Psoroma hypnorum*	

Table 6. Species by species track vegetating tendencies, less worn tracks.

1. Plant species / groups with strong track vegetating tendencies.

Higher plants:		
Dupontia sp.	*Poa arctica*	*Luzula sp.*
Polygonum viviparum	*Equisetum arvense*	
Mosses:		
Psilopilum laevigatum	*Pohlia sp.*	*Bryum sp.*
Drepanocladus sp.	*Polytricum sp.*	*Drepanocladus uncinatus*
Hylocomium splendens	*Aulacomnium turgidum*	*Dicranoweisia crispula*
Livermosses:		
Anthelia juratzkana	*Hepaticae sp.*	
Lichens:		
Peltigera canina		

2. Plant species / groups with weak track vegetating tendencies.

Higher plants:		
Luzula confusa	*Luzula arctica*	*Alopecurus alpinus*
Cardamine bellidifolia		
Mosses:		
none		
Lichens:		
Crustal lichen , dark	*Peltigera apthosa*	*Sphaerophorus globosus*

3. Plant species / groups with absence in tracks. Weak tendencies.

Higher plants:		
Salix polaris	*Stellaria crassipes*	*Pedicularis hirsuta*
Mosses:		
Dicranum sp.	*Conostomum tetragonum*	*Tomenthypnum nitens*
Livermosses:		
Ptilidium ciliare		
Lichens:		
Crustal lichen, white	*Psoroma hypnorum*	*Peltigera rufescens*
Cladonia sp.	*Cetraria islandica*	*Stereocaulon sp.*
Nephroma sp.		

4. Plant species / groups with absence in tracks. Strong tendencies.

Higher plants:
none
Mosses:
none
Lichens:
Cladonia arbuscula

Table 7 gives the track vegetating tendencies for the different main plant categories. From the table it is clear that lichens are much more fragile to impacts than higher plants and mosses.

Table 7: Track vegetating abilities of different plant groups.

Percentage of observations, cat:		1	2	3	4
Plant group:	Higher plants, marked tracks:	42.6	4.0	6.3	47.2
	Mosses, marked tracks::	43.0	5.0	10.9	41.2
	Liver mosses, marked tracks:	33.3	12.5	0	54.2
	Lichens, marked tracks:	13.1	6.6	1.6	78.7
	Higher plants, less marked tracks:	56.7	10.2	7.0	26.3
	Mosses, less marked tracks:	61.1	8.9	5.7	24.2
	Liver mosses, less marked tracks:	57.7	7.7	7.7	26.9
	Lichens, less marked tracks:	39.2	10.8	2.5	47.5

TERRAIN VULNERABILITY

Vulnerability classification

Valuable studies in this field have been carried out by Leif Sørbel and co-workers at the Department of Physical Geography, University of Oslo (Sørbel 1987; Sørbel, et.al.1990; Sollid & Sørbel 1991). A vulnerability classification system has been defined with the following classes:

1. Invulnerable areas. Examples are active alluvial plains, fans and tidal shores.

2. Moderately vulnerable areas. Dry, well–drained areas with a discontinuous vegetation cover.

3. Vulnerable areas. Characterised by continuous vegetation cover, often fine–grained material and relatively high ground moisture.

4. Very vulnerable areas. Wear easily causes further erosion. Areas are characterised by fine material, moisture saturation and continuous, thick vegetation cover, often combined with inclination and proximity to drainage ways.

5. Areas of conservational value. Localities which contain biotopes, landforms or other features which are found to be particularly valuable and therefore should be protected from disturbances.

The division of the first four classes is determined by probable effects of terrain driving as a function of geotechnical characteristics and vegetation cover of the different terrain types. The last class covers areas which, by biological or geoscientific reasons, should be protected. The system is not intended to provide a complete geoscientific and biological vulnerability outline. Influences on the living conditions of birds and mammals are not discussed in this context.

Material type-determined vulnerability and possible geomorphological effects of driving are the main division criteria of the system. Differences in revegetation possibilities on different surface types are not mentioned specifically. Because the degree of revegetation strongly affects the observed significance and duration of impacts, it must be regarded an important vulnerability factor. The possibility of revegetation should therefore be a weighted terrain-type specific factor in the classification system. Future modification of the system should pay concern to duration of changes in the vegetation cover in addition to topographic and erosional effects.

The above–mentioned system forms the basis for the discussion which follows. Modifications are not suggested. On the other hand, cases are illustrated where terrain type class correspondence should be discussed, observed significance and predictions about duration of possible impacts taken in concern.

Class 1

Two main terrain types are associated with this class: continually, fast changing areas and areas with very stable ground conditions. Lack of green vegetation is a common characteristic.

Lichen-covered stony ground represents a debatable case. Apparent tracks may be the result of repeated passages in block-dominated, frost sorted material, even though green vegetation is practically absent (Fig. 22). From a geotechnical viewpoint, this terrain type may be considered almost invulnerable. Effective drainage and stability prevent further erosion, and a significant lowering of the permafrost table is improbable. In spite of this, tracks are apparent and lasting impacts. The removal of lichens, breakage of stones and reduction of surface texture due to compression visualise tracks and make them easily detectable on aerial images. Due to small soil activity and late re-establishment of lichens, tracks will be visible for a long time. The topographic expression of the track will depend on stone size and inclination.

It is suggested that stony (not totally block-dominated) ground with high lichen coverage and possible occurrence of fine material patches is associated with class 2, while homogeneous block fields, stony fields which are snow–covered during much of the summer season and areas of exposed bedrock belong to class 1. Limitation determination from aerial imagery is based on texture and (grey) tone criteria.

Fig. 22: Track made by bulldozer in 1953 on Platåberget in stony material with lichen cover.

Class 2

In the specifications of this class, it is mentioned that tracks may be "lasting, but not significant". Areas with thin, discontinuous vegetation and coarse material are mentioned as typical. Variations in vegetation cover, material composition and moisture give variations within the class.

Vegetated slopes in weathering material with limited moisture and a high stone content belong to this class. Higher moisture and smaller grain sizes validate the use of class 3 or 4.

Tracks made on somewhat vegetated alluvial plains may be marked and lasting. Effective drainage in the coarse material and packing in track lines cause lack of moisture and hardening of the surface. Revegetation takes place slowly, and in spite of stable ground conditions and little chance of further erosion, tracks are lasting impacts. Vegetated, inactive alluvial plains in coarse material normally belong to class 2. Duration and appearance of impacts is largely determined by moisture availability. Wear marks will be lasting features in dry areas.

On dry ridges, removal of vegetation may start wind erosion. This causes lasting and significant marks and exposed localities should therefore be included in class 3.

Fig. 23: Track in coarse river material in Colesdalen, deposited before 1965.

Class 3

Mentioned features are continuous (thick) vegetation cover, dominance of fine material and relatively high moisture content. Removal of vegetation will cause a significant lowering of the permafrost surface, and a marked depression along the track may develop. The correspondence of some geomorphologically determined terrain types with this class is discussed below.

Surface morphology and topographical position provide information about material type and moisture content. Different types of patterned ground are only formed when fine material and segregated ice in the upper soil are present. In areas with high vegetation coverage and relatively homogeneous material, frost soil activity (heave/sorting) is highest when the moisture content is somewhat below saturation level. Given the facts that surface morphology largely is governed by material type and moisture and that these are important vulnerability criteria, it is clear that small-scale landforms are a very useful source of information for vulnerability mapping. The 1:15,000 images are well suited for retrieval of morphological information.

Hummocks cover extensive areas of high moisture, fine material and thick, insulating vegetation cover, preferably dominated by turf mosses. Where tracks made by few or single passages were seen in such terrain types, damages were to a high degree repaired by soil activity. The hummock pattern was often almost re-established, and small vegetational differences and depressions were the only remaining marks. Where a larger number of passages had taken place, parallel pathways had normally been used (Fig. 27). The vegetation cover was not significantly disturbed, and this indicates high resistance to wear. On the other hand, it is assumed that implications of removal of vegetation would have been the same as in other terrain types with high moisture content and fine

material. Therefore, hummocky ground should probably be classified as vulnerable.
Areas with more or less vegetation-free sorted circles or wind-eroded hummocks/frost boils have a discontinuous, less insulating vegetation cover than hummocky ground. In existing tracks, revegetation typically takes place in wet, poorly drained depressions. Where the ice content is locally high (e.g. where tracks cross ice wedges), a depression with a water pond is often made. Vulnerability categorisation of such terrain types is dependent on topography, moisture and soil type, and these terrain types often represent cases of doubt between class 2 and 3.

On dry, exposed heath crests, wind erosion may cause widening of tracks if vegetation has been initially eroded (Fig. 24). Moisture, stability and grain size composition indicate low vulnerability. Despite this, wind erosion may give lasting, growing wounds. Association with class 3 is therefore valid.

Inactive alluvial plains dominated by fine-grained deposits and characterised by a thick vegetation cover normally belong to class 3. Wetland characteristics validates the use of class 4.

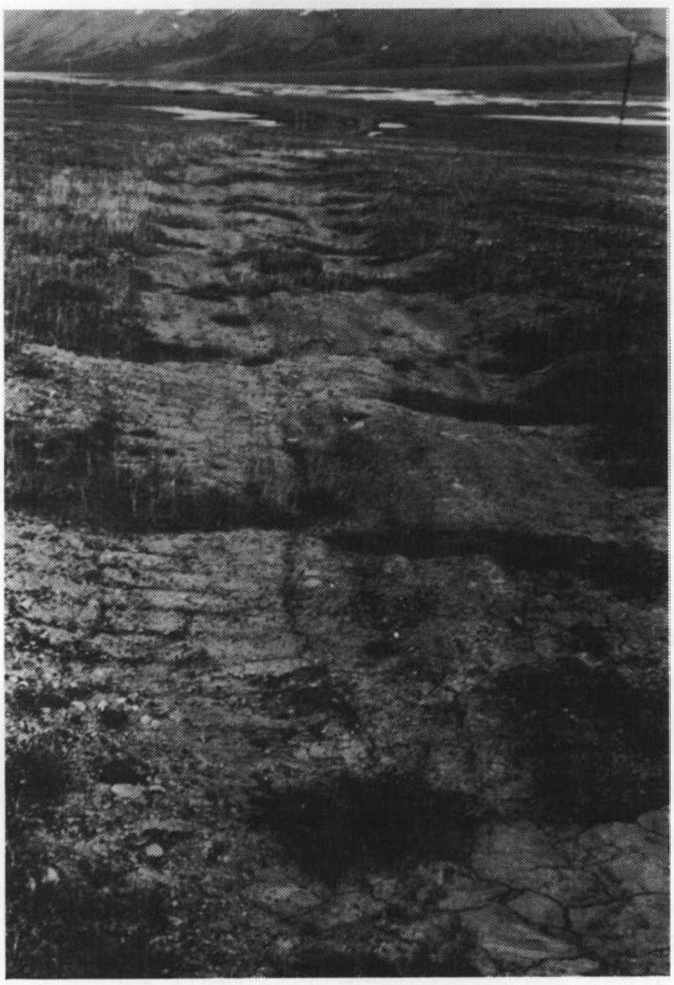

Fig. 24: Track across a gently sloping ridge with wind-erosional scars, Adventdalen. The track was in use until 1958.

Tracks made by few or single passages in moist, fine-grained material sometimes show strong vegetation vigorousness in depressions (fig. 25). Moisture conditions and material type indicate high vulnerability and the morphological effect of tracks is clear. Vegetation growth reduces the impression of the impact, even though species composition differs from the surroundings. Imposed wear and locational characteristics will determine further development.

Fig. 25: Track with vegetation vigorousness effect, Adventdalen.

Class 4

In terrain types of this class, tracks have to be self-enhancing. The areas are in many respects similar to class 3-areas. Water saturation or runoff cause water accumulation or erosion (Fig. 26). Inclination and proximity to drainage ways or instable slopes cause erosion or slumping due to instability caused by permafrost melting.

Wetlands, slopes with water-saturated soils and surface runoff, gelifluction slopes and moist depressions belong to this class.

Many of the track sections where continuing erosion was detectable on aerial images were situated in slopes in close proximity to rivers or creeks. Tracks in moist, sloping tundra also often seemed to be affected, and this impression was confirmed during the field period.

Class 5

It has not been an aim of this project to evaluate areas in a natural protection context. Criteria for use of this class is therefore not discussed.

Track characteristics and vulnerability

In this report, descriptive track classification is distinguished from terrain type classification and use of vulnerability classes. Track classification is meant to give a situation description, while vulnerability classification provides a base for evaluation of consequences of planned and performed activities.

Fig. 26: Tracks deposited by use of parallel passages in intermediately moist tundra with active frost soil, Reindalen.

The development and appearance of existing tracks is, on the other hand, an important vulnerability indicator. The amount of driving must be known before comparisons can be made. Uncertainty exists, as illustrated above, regarding vulnerability for some terrain types, because the amount of use of observed tracks is unknown. Moist tundra areas have often been crossed by use of parallel passages (Fig. 26), and it is difficult to predict the consequences of the use of a regular trail when these are not seen.

INFORMATION RETRIEVAL FROM AERIAL IMAGERY

Extraction of information about terrain impacts from aerial images have been discussed above. Additionally, a wide range of geophysiographical information can be extracted from false-colour large scale infrared imagery. The S90 infrared-composite aerial image series provide new thematic mapping possibilities on Svalbard.

The images are registered in the spectral region 525 - 900 nm. Information from the infrared part of this range (700 - 900 nm) gives information about vegetation extent and quantity. The following interpretational indicators are important for vegetation mapping and classification:

- Colour tone. Vegetation is generally visualised in red-orange colour tones with deviations towards brown or green. Colour tone, intensity and saturation are useful information sources for vegetation type and density information.

- Topographical position. If relations between the extent of different vegetation types and topography are known, this is a very important factor. The position in relation to moisture sources (e.g. snow patches) and exposition are determining factors for vegetation growth.

- Texture determined by relationships between vegetated and unvegetated features. Texture is for example created by differential wind exposition or by the geometry and arrangement of frost sorted surface features. It may be used as a vegetation indicator if relationships between surface forms and plant societies can be established.

Moist, dense moss tundra is particularly easy to distinguish in the images, with a deep red-orange tone and a characteristic lowland position. Grass-dominated tundra, mainly associated with relatively moist terrain, normally gives light yellow-orange tones and may be confused with parts of the moss tundra and some types of dry tundra vegetation. Topographic information may be utilised to avoid this. *Cassiope tetragona*- and *Salix Polaris*- dominated tundra types are often characterised by darker tones than the surroundings. Large amounts of dead mosses give a significant effect of dark grey tones.

For vegetation mapping in other parts of the Arctic–Scandinavian zone, image texture created by plant height is an important criterion. In Svalbard, all plants are too low to allow detection of height variation on images.

Extensive fieldwork is, in spite of the information content in the images, necessary during vegetation mapping. The imagery is mainly used for generalisation from point samples and area limitation determination.

The images (1:15,000) are suitable for detailed geomorphological mapping. Information about mass movement and frost-sorting features is important in a vulnerability context. Surface morphology gives, as stated above, information about soil type, ice content and distribution, moisture and stability. The combination of the large-scale geomorphological overview and the enhanced vegetation information content in the IR images is particularly interesting.

A combination of vegetation information and geomorphological information will provide a good foundation for soil type determination. Moisture and drainage conditions are likewise illustrated by small-scale morphology, colour tone and density variations in vegetated areas, colour tone variations in vegetation free unconsolidated material and topography.

TERRAIN DATA ORGANISATION AND - PRESENTATION

GIS provides extensive potential in vulnerability mapping and consequential analysis contexts. Combined display of different data sources and some kinds of analysis are made possible. Following are four examples of the use of GIS for area use conflict illustration are mentioned in the following:

1. Use of overlaying graphic polygons from multiple data layers. Thematic information is classified, and data are combined or "overlaid" for presentation and visual analysis. Areas given a high "conflict score", one or more factors taken in concern, are easily outlined. The technique is particularly useful for studies of covariations between factors.

2. Use of a "potential model". A numerical weighting of single physiographic factors is performed and weights are given polygon-delimited areas. When factors are combined, the "conflict score" is summed up area–wise. In this way, a simple display of terrain use conflicts or conservation values is provided. Quantification and weighting of factors are major problems. The method is therefore not suitable in every context. Use of quantitative measures may give the false impression that terrain use conflicts are measurable figures that can be evaluated just by taking a few factors into consideration.

3. Use of buffer zones. Around graphical elements (points and lines, repre– senting e.g. rivers and bird nest areas), buffer zones with a user defined extent corresponding to conflict areas can be defined. Examples are erosional zones along rivers and zones where noise and disturbances should be avoided around bird or mammal habitats. Buffer zones can easily be superimposed onto representations of other thematic data.

4. Combination of maps and area statistics. Tabular data are available within the GIS system for processing and display. Area statistics can be listed in tables or shown in diagrams combined with the map plot. In this way, large amounts of data can be coupled to the visualised map features.

GIS-based representations will seldom give approximately complete overviews of conflicts between area use and conservation. Relative weighting and quantification of factors as well as model assumptions, data quality and completeness impose important limitations. The advantage of GIS in such contexts is the close coupling between storage and presentation of thematic data and the possibilities for overview illustrations. Use of GIS does not eliminate or perhaps not even reduce the need for field surveys, but it must be regarded as an organisational and visualisation tool. At the moment, lack of digital map data is the most limiting factor for the build-up of a management–directed geographical database on Svalbard.

SUGGESTED FUTURE WORK

New industrial activities which conflict with conservational intentions are being, and will continue to be, planned. Increased disturbances due to tourism must also be expected. The need for the monitoring of changes in the natural environment which are more or less caused by human activity was one of the motivating factors for the 1990 airphoto-acquisition. Utilisation of these and other remote sensing data is of major importance for future monitoring. Therefore, studies of the thematic information content in these images and their suitability for different environmental monitoring tasks should be carried out.

Studies should also be directed towards use of GIS for different terrain analysis purposes. The potentials and limitations of different GIS-based approaches in management and monitoring contexts should be investigated.

Highly skilled personnel with a great deal of field knowledge and experience are required for terrain vulnerability mapping. A further development of the classification system should lead to more precise definitions of vulnerability classes.

Better knowledge about the vulnerability of different terrain types requires studies of erosion-determining factors. Soil thickness, texture and distribution of the clay fraction on different mineral types are among the soil factors that may influence stability and resistance to wear. For a determination of the importance of these factors, joint studies of soil characteristics and vulnerability must be carried out. GIS may be a suitable data organisation tool for vulnerability investigations where many factors are to be taken into account.

For future monitoring and track development studies, inclusion of data about the time of track formation, especially in areas affected by Soviet activities, should be carried out.

This project has provided information about the extent and characteristics of vehicular tracks at the time of airphoto acquisition. These data should be included in a systematised database covering different topics with relevance to environmental monitoring on Svalbard. New studies should be carried out when new imagery or other useful remote sensing data appear to provide information about naturally or human-induced changes taking place.

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