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PRELIMINARY ECOLOGICAL EVALUATION OF THE EFFECTS OF AIR CUSHION VEHICLE TESTS ON THE ARCTIC TUNDRA OF NORTHERN ALASKA

Warren Rickard

Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

September 1972

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SR 182

Special Report 182

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HANOVER, NEW HAMPSHIRE

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, NH 03755

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
PRELIMINARY ECOLOGICAL EVALUATION OF THE EFFECTS OF AIR CUSHION VEHICLE TESTS ON THE ARCTIC TUNDRA OF NORTHERN ALASKA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
Warren Rickard

6. REPORT DATE
September 1972

7a. TOTAL NO. OF PAGES
26

7b. NO. OF REFS
25

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c. ARPA Order 1615

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Special Report 182

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Advanced Research Projects Agency

13. ABSTRACT
Of prime concern in the Arctic is the need for an ~~nondestructive and~~ efficient means of transportation over both frozen and unfrozen arctic terrain. As part of the effort to develop such a means, the Advanced Research Projects Agency established a program to determine the potential for using an air cushion vehicle (ACV). Studies on the effects of ACV tests were conducted in two areas at Barrow, Alaska. One area was a drained lake bottom with a fairly homogeneous vegetation cover and soil type. The second area, much drier than the first, consisted of low-centered polygons composed of a wet tundra soil and a varying vegetation complex. The initial effects of the ACV tests in both areas were quite similar. The amount of litter decreased from 40-44% to 0-2% as the number of vehicle passes increased. The amount of standing dead vegetation decreased much less. Quantities of living vegetation remained fairly constant regardless of the number of vehicle passes, with clumps of mosses being torn loose in the low-centered polygon areas. The albedo also changed; this may become important over a long period with respect to the amount of solar radiation absorbed by the lighter and darker terrain surfaces.

14. KEY WORDS

Air cushion vehicle	Arctic tundra	Environmental tests
Ground effect machine	Northern Alaska	Solar radiation

DD FORM 1473, 1 NOV 65 — REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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ARPA ORDER 1615
BY
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HANOVER, NEW HAMPSHIRE

PREFACE

This report was prepared by Mr. Warren Rickard, Botanist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL).

The work was done under Advanced Research Projects Agency (ARPA) Order 1615.

The author acknowledges the support and cooperation of a number of individuals who contributed to the research. The Naval Arctic Research Laboratory (NARL) provided the logistics support necessary for completion of the work. Dr. J. Brown and Mr. P. Sellmann, USA CRREL, and Dr. M.C. Brewer, then Director of NARL, assisted in the research design and site selection. Specialist 5 V. Rockney, USA CRREL, supplied the thermocouple installations. Mr. D. Atwood, USA CRREL, made the aerial photographs.

Thanks are extended to the personnel from the Naval Ship Research and Development Center who coordinated research activities at Barrow and to the U.S. Coast Guard who expertly maneuvered the air cushion vehicle through the experimental procedures.

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PRELIMINARY ECOLOGICAL EVALUATION OF THE EFFECTS OF AIR CUSHION VEHICLE TESTS ON THE ARCTIC TUNDRA OF NORTHERN ALASKA

by

Warren Rickard

Introduction

One of the primary concerns in the Arctic is the development of a nondestructive and efficient transportation system over both frozen and unfrozen arctic terrain. Increasing emphasis has been placed on this subject since the discovery of large oil reserves on Alaska's North Slope.

During the period of early oil exploration, until 1969, surface travel to and from this area was by any means available. Many deeply entrenched scars serve as reminders of the travel that occurred during the past several decades with little regard for the unique, permafrost dominated terrain. Early inhabitants of arctic environments relied on travel by foot, animal skin boats, and dog sleds. Recent travelers in these areas have used low-ground-pressure wheeled and tracked vehicles, helicopters and airplanes.

Today off-road travel on the North Slope is restricted to winter operations, except for special low-ground-pressure vehicle travel allowed during the summer by permit from the State of Alaska.

The primary cause of concern for the development of an effective transportation system in arctic environments is the very close association that exists among the various biological and physical components of the arctic ecosystem. Largely because of low temperatures and short growing seasons arctic ecosystems are less capable of maintaining physical stability or of recovering from physical disturbance than midlatitude ecosystems. Consequently, if the plant layers and underlying peaty soils are modified, recovery to original conditions is slow or is often prevented by continuous or intermittent erosion. The damaged areas seldom return to their original conditions, as evidenced by tracks made 20 to 40 years ago that appear today as narrow bands across the landscape.

The necessity for travel over arctic terrain with minor surface disruptions applies to military as well as civilian populations. Thus, funded by the Advanced Research Projects Agency (ARPA), CRREL established a program to study the surface effect vehicle (SEV) as a mode of travel over tundra, ice and water. Before this program, air cushion vehicles had been briefly introduced into the Arctic, but as Courtial (1971) indicated, "Experience on how the SEV affects the tundra is limited and more work is needed in this field if ecologists and conservationists are to be convinced that the SEV is not another of man's inventions that will desecrate the surface."

The objective of this report is to present the results of an ecological evaluation of the effects of air cushion vehicle (ACV) operations on arctic terrain surfaces. The site for this program was near Barrow, Alaska (Fig. 1). Barrow was chosen because 1) terrain features in its vicinity are representative of the arctic coastal plain; 2) the SK-5 ACV, the same vehicle used in sea mobility studies, was available for use; and 3) logistic support was available from the Naval Arctic Research Laboratory.

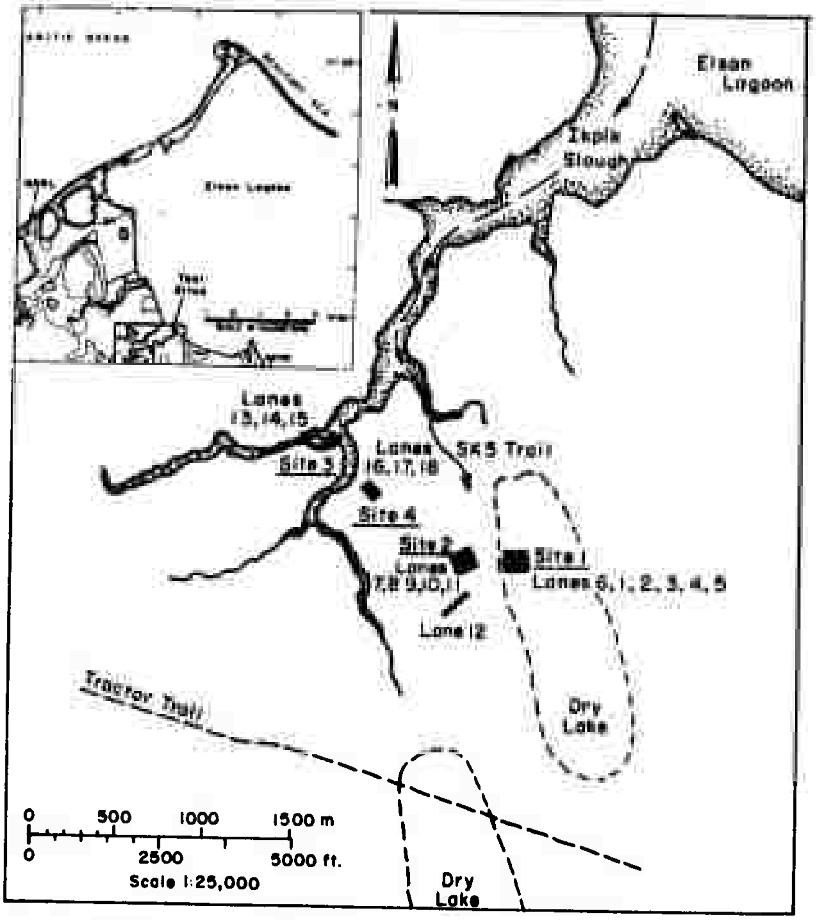


Figure 1. Location of test sites near Barrow, Alaska.

Vegetation and permafrost

In nature, a very close relationship exists between the vegetation and the environment in which it grows. A particular type of vegetation association develops in response to environmental conditions. A change in an environmental variable results in some response by the vegetation. These complex interrelationships, which form the foundation of ecology, are of particular importance in areas of permafrost. The vegetation and other biota of the biosphere act as the interface between the atmosphere and the soil or lithosphere. The term vegetation in this report refers to the entire plant canopy regardless of the species present (Fig. 2).

The plant canopy comprises living vegetation, standing dead vegetation (still attached at the rootstock), and litter (loose dead vegetation) arranged in various configurations above the terrain surface. This vegetative canopy changes the thermal regime at the terrain surface by intercepting the incoming solar radiation and modifying the energy exchange between the upper and lower boundaries of the canopy. Thus, the plant canopy is the leading component in the control of the microclimate at the plant/soil interface.

A study begun in 1946 by the Corps of Engineers (Linell 1960) to evaluate the effects of construction on warm permafrost produced an excellent example of what the result can be when the plant/soil balance is modified. After 10 years, permafrost under an area where the entire organic layer had been removed was 2 m below the ground surface, whereas permafrost beneath an undisturbed area was only 1 m below the surface.

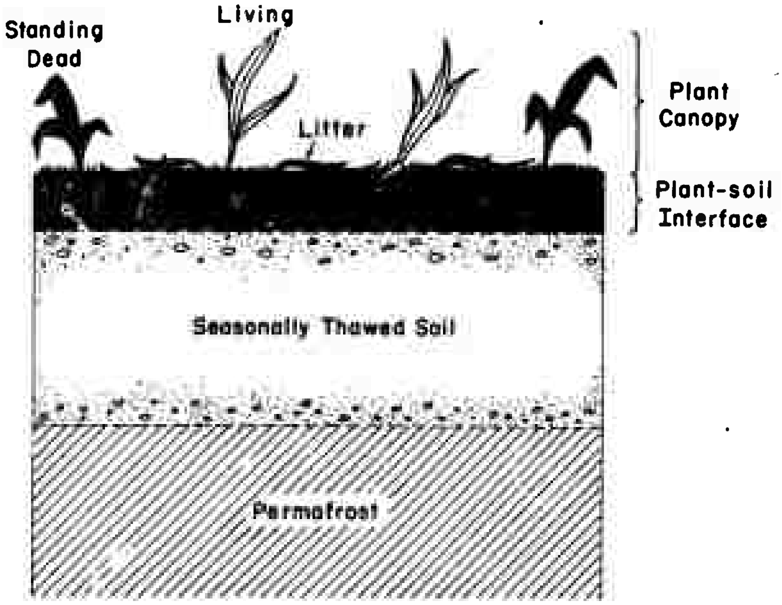


Figure 2. Diagram of components in arctic tundra.

Viereck (1965) presented an excellent natural example of the vegetation-substrate relationship. He found that ice lenses formed beneath white spruce trees as a result of the insulating effect of a thickened moss mat in summer. Each ice lens formed as a result of cooling of the soil in winter under the thin snow layer beneath the trees. Expansion of the silty clay formed the lens beneath the tree, raising the tree above the surrounding topography; any disturbance of the moss layer resulted in melting of the ice lens, followed by collapse of the ground and often death of the tree.

Recent reports of man-induced stresses on the delicate equilibrium of vegetative cover and permafrost are available (Brown et al. 1969, MacKay 1970, Ferrians et al. 1969, Haugen and Brown 1971). Disturbance of the peat layer often results in irreversible disturbances: formation of water-filled channels, headward erosion in vehicular tracks and along stream channels, drainage of lake basins, and slumping and cracking in building foundations and other structures. In tundra areas, the initial damage to vegetation may appear to be slight, but the resultant long-term effect on permafrost can be considerable.

In most arctic areas, some off-road movement of heavy equipment occurs during the winter months. At this time the ground surface is frozen and snow covered enough to support the weight of the equipment, thereby reducing physical abrasion on the ground surface. However, travel at this time can result in compression of the snow cover and surface vegetation. In the following years these areas appear as "green belts" stretching across the tundra (Brown and West 1970). If the surface vegetation is disturbed, thermokarst subsidence may result when the thaw season begins. This is exemplified by the presence of several subsidence areas along the winter road to the North Slope of Alaska.

Procedures

Four test sites were established in conjunction with engineering and other terrain test sites (Abele et al. 1972): two in July and two in August:

Site 1. Drained lake bottom where the vegetation and the active layer are relatively homogeneous and uniform. Soil moisture is high and representative of meadow and half-bog soils (Drew 1957). Dominant vegetation is *Carex* and *Eriophorum*. A series of five test lanes 100 ft long by 50 ft wide with five 70-ft control lanes was established. A sixth lane 300 ft long was used for monitoring the effect of vehicle hovering in one location for various periods of time. Figure 3a shows the plan view of this experimental design.

Site 2. Well drained low-centered polygons (Fig. 3b). This area is composed of wet tundra soil predominately covered by a *Dupontia-Carex-Eriophorum* complex as described by Drew et al. (1958). Three test lanes 150 ft long and 50 ft wide with three 70-ft control lanes were again oriented in an approximately north-south direction. The lanes were made 150 ft because of heterogeneity of the terrain and vegetation types. A lane for 25 vehicle passes was lengthened to 200 ft to encompass more polygons for detailed observations. A separate lane was used for observing various intervals of vehicle hovering in one location.

Site 3. Land-shoreline site located in the soil/water interface to allow observation of vehicle interaction with shoreline features. Figure 3c outlines the circular pattern used to evaluate movement over large expanses of water, then onto land, and across narrow stream channels.

Site 4. Well drained high-centered polygon area (Fig. 3d). Three test lanes 100 ft long and 50 ft wide were established in polygons with centers 2.5 to 3.5 ft high.

The most extensive evaluations of ecological parameters were made at sites 1 and 2. Here basal area measurements of vegetation and species composition were determined by using a randomly spaced 0.1-m^2 quadrat. These values were determined before and after passage of the vehicle. Five soil moisture measurements were taken in each lane and the samples were divided into two vertical subsamples: the upper 0-5 cm, and the remainder of the sample.

Depth of thaw measurements were made at 1-m intervals by probing with a graduated $^3/_8$-in. rod through the active layer until the frost table was reached. Attempts were made to determine surface temperatures but because of inclement weather it was felt the data were not reliable so they are not reported. Four thermocouple strings were placed at various depths at site 2: 1) in the 25-vehicle-pass lane in the polygon center and in the polygon trough, and 2) in the adjoining control lane again in the polygon center and in the polygon trough. The data obtained were used in conjunction with other Barrow soils and vegetation data for soil thermal computations (Nakano and Brown 1972).

At sites 3 and 4, observations were basically qualitative. Extensive photographic coverage was made of these tests and will be included in another report (Abele et al. 1972).

Results and discussion

Vegetation. Results of the vegetation observations at sites 1 and 2 are presented in Table I. Values for the control lane are averages of data from 40 quadrats and values from each test lane are averages of data from 10 quadrats.

Each site was covered by a carpet of assorted moss species. Above the moss mat the plant canopy was divided into six categories as seen in Table I. The sedge category included *Eriophorum* and *Carex* species. Other vascular species were placed in the broadleaf group as they were rather insignificant in the overall species content. The term "open area" signifies that no vegetation or litter can be found directly above a certain percentage of the surface.

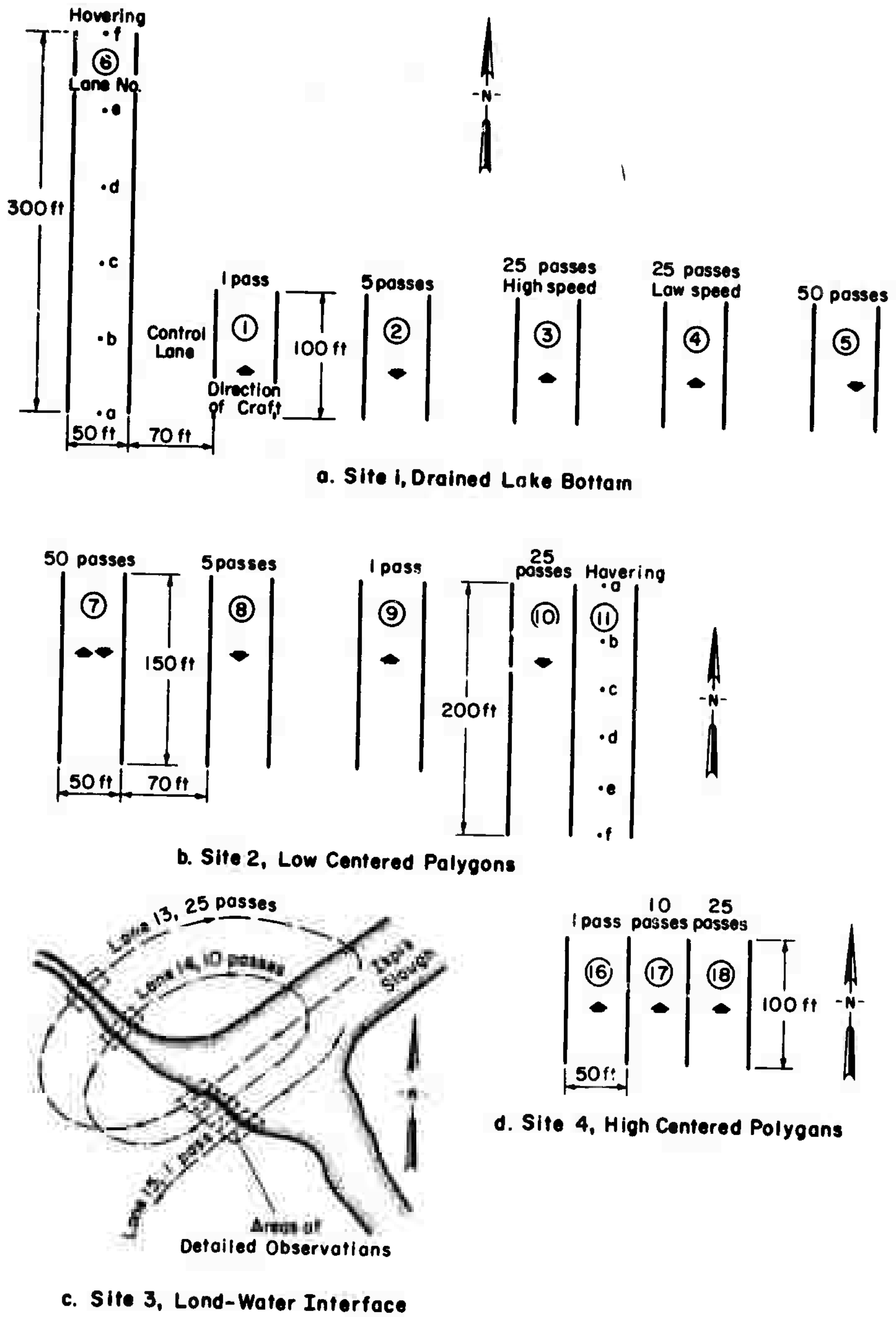


Figure 3. Diagram of lanes in the four test sites.

Litter and standing dead. As has been emphasized, the amounts of litter and standing dead vegetation are very important in determining the insulating quality of the organic mat. If the litter or standing dead vegetation becomes dislodged, the thermal regime at the air/soil interface is altered. Depths of soil thaw also reflect the changes resulting from manipulation of the surface cover.

Table I. Vegetation observations at sites 1 and 2.
Values are percentages of cover.

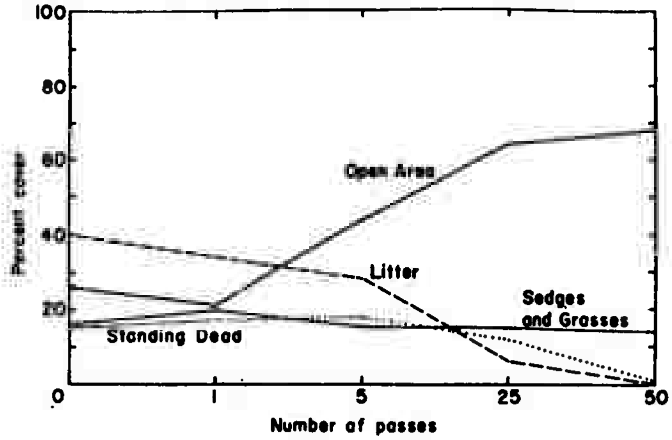
Pass lanes	Moss	Open area	Sedge	Broadleaf	Standing dead	Litter	Lichen	Bare
				Site 1				
Control	100	26	16	1.9	15	40	1.3	0
1	100	21	21	3	17	34	4.7	0
5	100	45	16	0.9	19	18	0.2	0
25	100	64	16	0.3	12	5.6	0	0
50	100	68	14	0.3	1	0	0	0
				Site 2				
Control	100	22	14	5.6	8.5	48	3.7	0
1	100	38	6.9	3.7	8.4	33	3.7	0
5	99	44	16	2.6	15	21	3.1	0.7
25	97	66	17	2.9	9.2	4.9	2	3.4
50	91	70	19	0	7.9	2.0	0	29

Researchers involved in the U.S. Tundra Biome portion of the International Biological Program (IBP) established various treatment plots at the Barrow IBP site. One manipulation was the removal of living plants, loose litter, and standing dead material above the moss mat; this resulted in an increase in soil thaw from 26 cm in a control plot to 31 cm in the treatment plot.

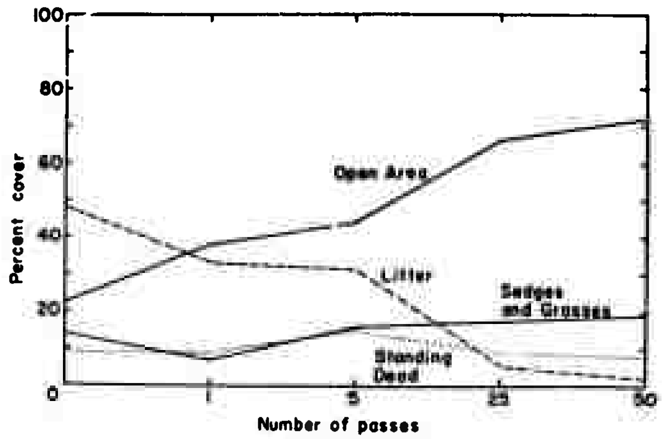
In the present study litter accounted for 40% of the ground cover at site 1. Figure 4 shows that the removal of litter by the ACV was proportional to the number of passes over an area. After 50 passes no litter remained in site 1 and only 3 to 4% remained in site 2. Following 5 passes of the vehicle (Fig. 4), the amount of standing dead vegetation began to decline steadily. As the components of the canopy were being removed by repeated passes, the amount of open area was increased substantially to about 70%. Figures 5-9 give overall views of each lane in site 1 following the designated number of passes over it. Changes at individual locations in site 1 were photographed (Fig. 10-12) before, during and after 25 vehicle passes at high speed; the sequence of removal is apparent in the photographs. The primary cause for removal was contact of the vehicle's skirt with the vegetation. During the first passes, the skirt appeared to loosen the various canopy components and subsequent vehicle traffic over the area removed the loose material by blowing it away.

The various canopy components removed from the trafficked lanes were deposited in other locations. Loosened fragments of moss and vegetation were blown about by air escaping from the ACV (Fig. 13 and 14). A row of the removed material was deposited adjacent to the 25- and 50-pass lanes, site 2 (Fig. 15 and 16).

The accumulation of organic material also alters the microclimate at the surface. In a controlled experiment by IBP personnel (Brown and West 1970), the addition of 100 g/m² of litter (equivalent to one season's plant growth) to a test plot reduced soil thaw 2 cm in the first thaw season. In a second plot, where 250 g/m² of litter was added, soil thaw was reduced 5 cm in the same period. These differences in thaw may seem minor; however, minor disruptions in the natural thawing process may result in accelerated thaw and erosion (Brown et al. 1969, McKay 1970).



a. *Site 1.*



b. *Site 2.*

Figure 4. Effects of ACV on plant canopy.

Figure 5. View of lane 1, site 1, following 1 pass.

Figure 6. View of lane 2, site 1, following 5 passes.

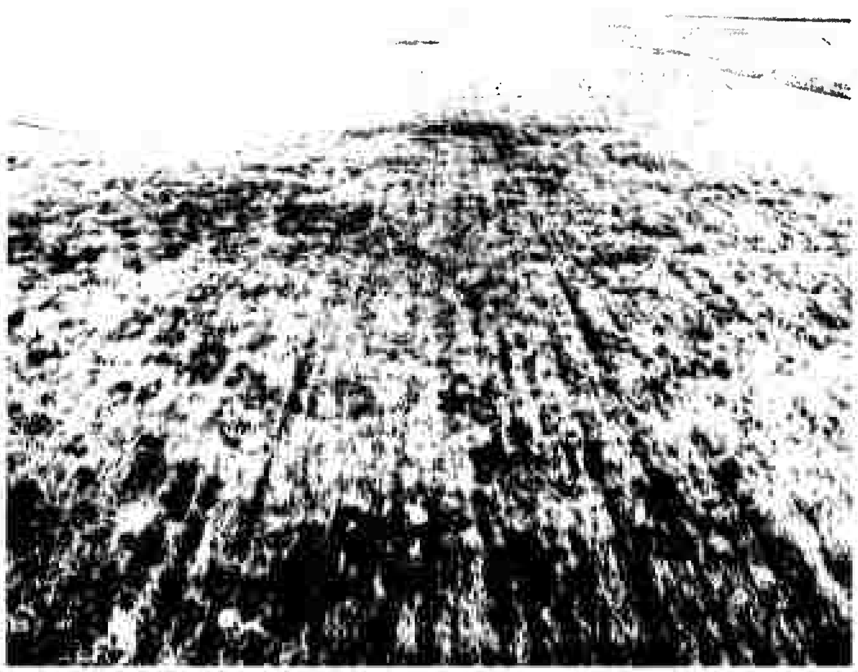


Figure 7. Overall view of lane 3, site 1, following 25 passes at high speed.

Figure 8. Lane 4, site 1, after 25 passes at low speed. Numerous lemming burrows are present in the foreground.

Figure 9. Lane 5, site 1, after 50 passes.

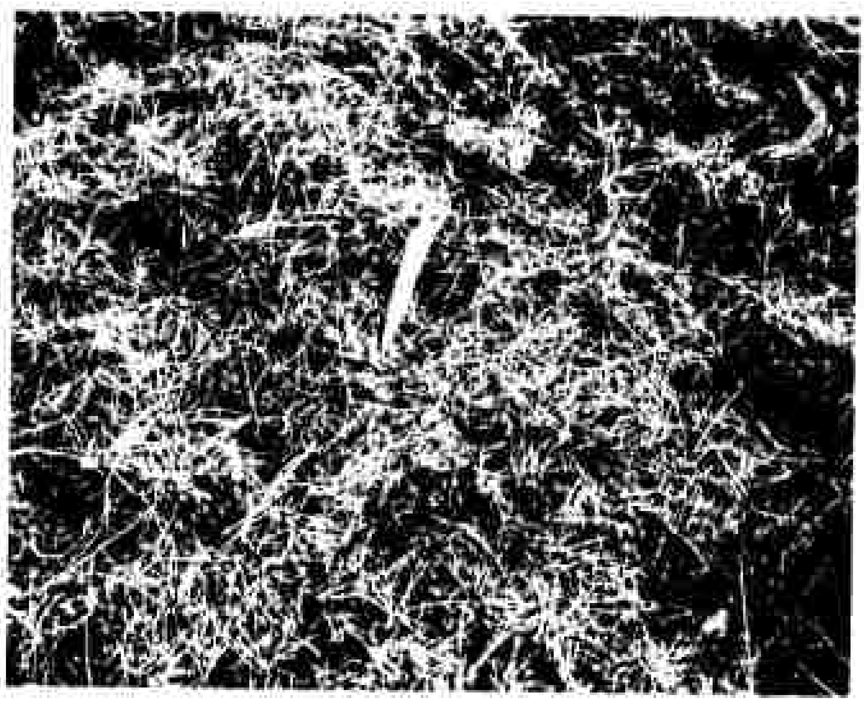


Figure 10. Photo point a, lane 3, site 1, before traffic by vehicle.

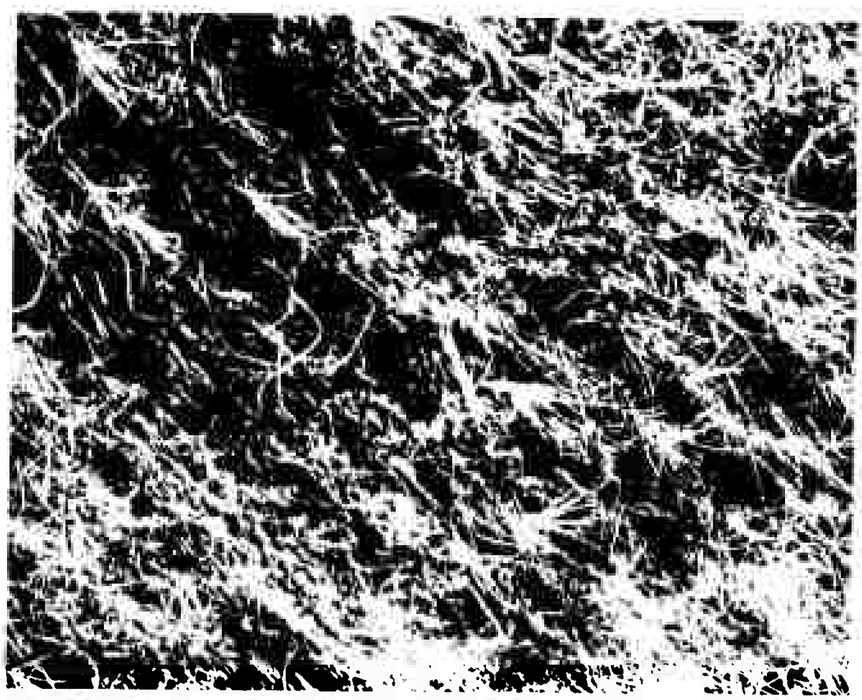


Figure 11. Photo point a, lane 3, after 5 passes, with litter removed.

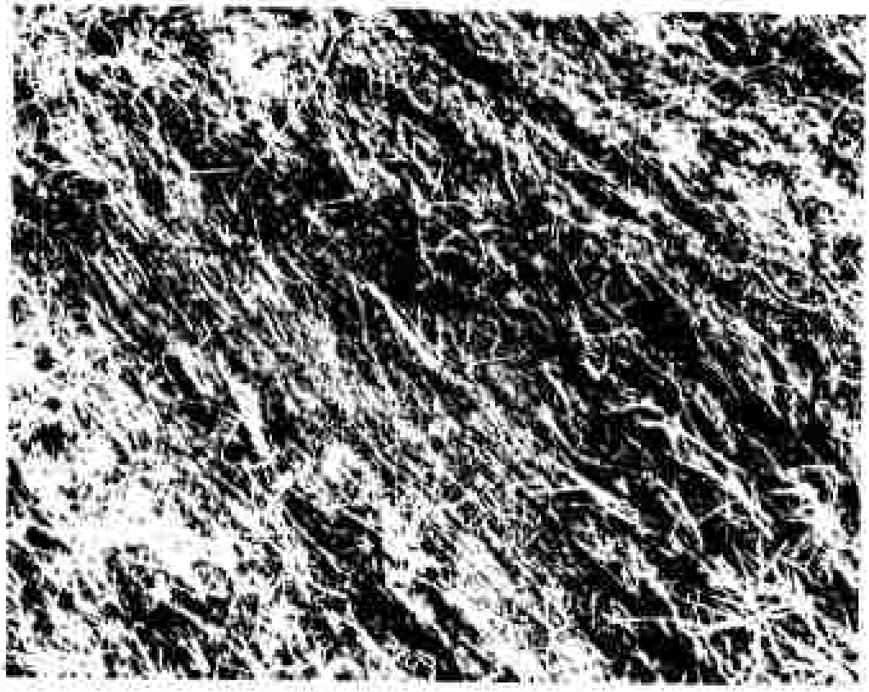


Figure 12. Photo point a, lane 3, after 25 passes, with all standing dead and litter removed. Remaining vegetation is matted into the surface.

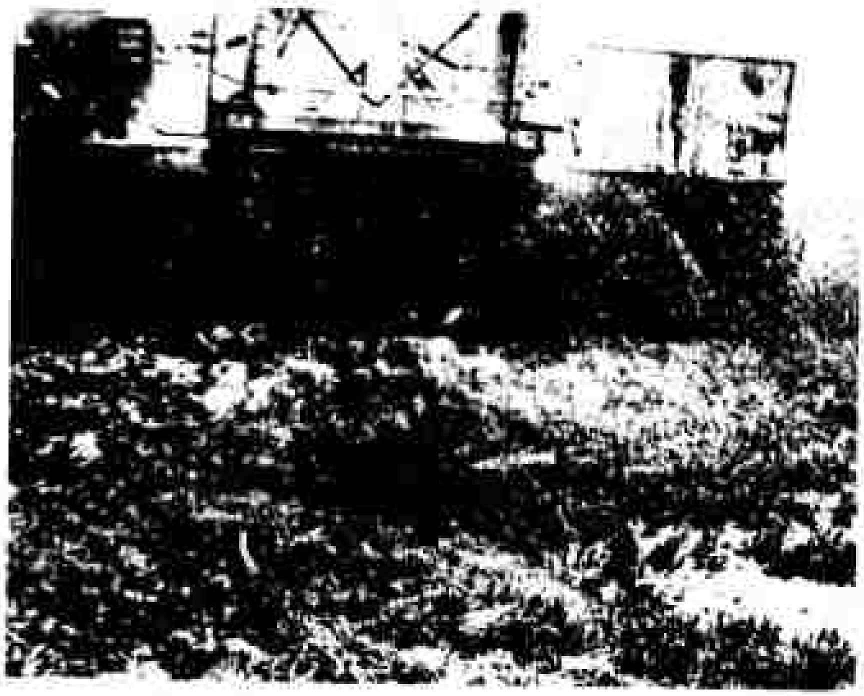


Figure 13. Blowing material at rear of the ACV.

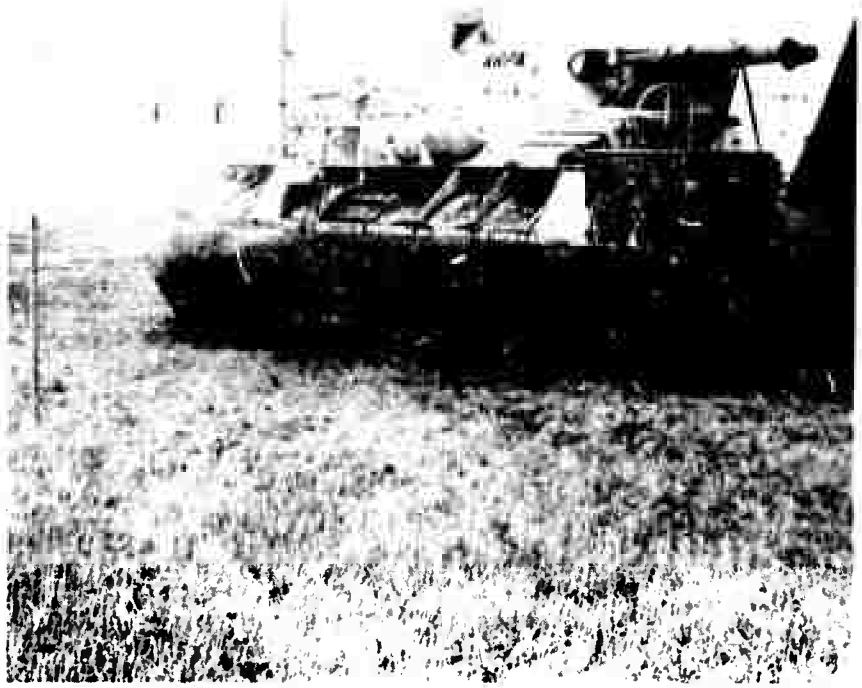


Figure 14. Loose organic being blown about by air escaping along sides of the ACV.

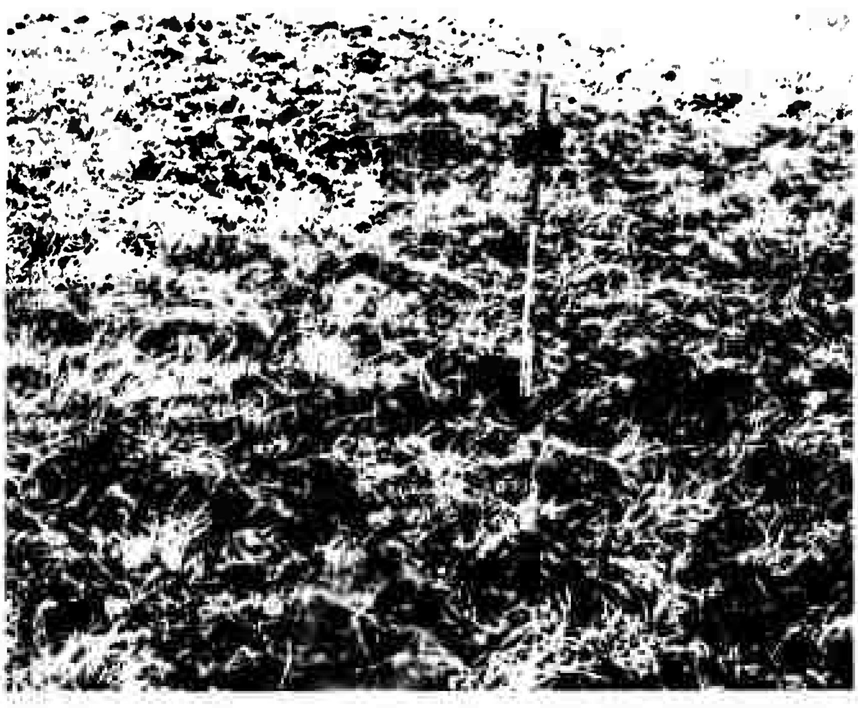


Figure 15. Loosened portions of organic mat scattered over the surface adjacent to lane 10, site 2, following 25 passes.

Figure 16. A ridge of organic 12 to 15 cm high adjacent to lane 7, site 2, following 50 passes.

In site 2, where small ponds are prevalent, the blowing litter may cover the entire pond surface, as seen in Figures 17 and 18. The magnitude of alteration to the habitats within the ponds has not been evaluated. But it can reliably be assumed that covering the pond surfaces modifies the temperatures within the ponds. Since many small animals, especially lemmings, depend on litter and standing dead vegetation for cover, the removal of these materials undoubtedly alters their habitats.

The only other reported ACV tests in the Arctic were made near Tuktoyaktuk, NWT, by the Canadian Department of Transportation. Qualitative observations obtained from these tests lead to the assumption that the terrain was not significantly altered by the tests. Of interest in this discussion are the results from these trials concerning the influence of the ACV on vegetation (Colby 1969).

> After ten passes over the track there was little evidence of vehicle passage except some decapitated lupins and leaves off the willows. After twenty passes the track began to be discernible and after fifty it could be clearly followed. In the first terrain class the willows were largely defoliated and practically no flowers remained; some erosion had taken place on protruding tussocks. In the second class there was perceptible erosion of the tips of tussocks, and polygons and many tussocks had been knocked over and in some cases bowled along like tumble-weed. The third class showed no damage but was visible by color difference, probably because the craft had blown away the dead grasses. Even the worst erosion was quite superficial compared with that produced by wheeled or tracked vehicles. Whether it will have any real or permanent effect on the tundra will not be known for some time.

Temperature. Directly related to increased litter or percentage of vegetation cover is the soil temperature. Tyrtikov (1959) found that the mean monthly temperature 15 to 40 cm below the vege-

Figure 17. Small pond in control area adjacent to lane 10.

Figure 18. The same pond after 25 passes in adjacent lane.

tation was 5 to 15°C lower and the depth of thaw was 1.5 to 3 times less than in areas where no vegetation was present. In discussing litter he concluded, "It often retards the warming (thawing) of the soil more than a living vegetation cover." Tyrtikov (1957), in studying the effect of peat removal on thawing rates in a spruce-lichen community, reported a temperature of 10.3°C 15 cm below the surface in an area where peat had been removed and 3°C in the undisturbed control plot.

Kallio and Rieger (1969) and Linell (1960) reported increased temperatures and degradation of permafrost in areas cleared of vegetation. Tikhomirov (1959) observed that with an air temperature of 10 to 15°C the temperature of the vegetative cover was 20 to 25°C and the temperature of the soil at a depth of 10 to 20 cm was 2 to 3°C. Brown (1963), in discussions of temperatures at a uniform depth in various vegetation areas, reported a general decrease in temperature with increased peat thickness. A detailed integration of all factors concerned with the heat exchange between permafrost and atmosphere was presented by Balobaev (1964).

Currently, temperature measurements of canopy and soil temperatures as related to soil thaw from the Barrow IBP site have been incorporated into a sensitive thaw-temperature prediction model by Nakano and Brown (1972). The primary inputs into these computations are the ground surface temperature and soil properties. Miller and Tieszen (1972) have described a plant growth model for this arctic tundra. These two models are currently being combined and field research in 1972 will provide data to validate a model of ACV-disturbed canopy.

Albedo. Qualitative observations concerning the impact of vehicles on the tundra are essentially based on the ability of the observers to differentiate between the color of vegetation before and after a vehicle passes over an area (Burt 1970a, b; Colby 1969). In essence, what they are observing is a change in the albedo or the reflective quality of the surface cover. The reflective quality of a particular vegetation type is quite important to the overall thermal balance of the tundra thermal system because the radiant energy that is not reflected is absorbed as heat and becomes available for heating and thawing of the soil. Benninghoff (1963) concluded that vegetation has a definite effect on the energy flux between the atmosphere and lithosphere, but pointed out the necessity for further observations of reflectivity values. Brown (1963) presented albedo data of five different vegetation groups, from 6.2% for a spruce bog to 13.5% for treeless lichen-covered surfaces.

Tables presented by McFadden and Ragotzkie (1967) contain albedo values for various regions of central Canada. In their study, reflectivities determined from aircraft were: 10.8% for a tundra surface with unfrozen lakes and no snow, and 14.8% for a tundra surface with no lakes and no snow. Albedos from Siberia reported by Dolgin (1970) were: for shrub and moss tundra, 17%; for peat and tussocky tundra, 19%; and for lichen tundra, 15%. A number of reflectivity measurements were made of different surfaces at the Barrow IBP site (Brown and West 1970). Here it was found that reflectivities of natural dry ground vegetation (24%) and wet ground (16%) were reduced to as low as 10% by various kinds of surface manipulations. The impact of the ACV on albedo and on surface temperatures requires further investigation.

During the recent Barrow tests it was apparent that the direction of travel over the lanes was important. The distinctness of the lanes depended upon one's position in relation to the direction of the ACV traversal. If the vehicle was moving north to south and the land was observed from the south the lane was more distinct or darker than if it was observed from the north. The lighter appearance was caused by the reorientation of vegetation and litter which revealed the lighter underside of the living vegetation.

Of the aerial photos of the lanes (Fig. 19-23), Figure 19 demonstrates this phenomenon quite well. The 5-vehicle-pass lane (lane 2, site 1) in the drained lake bottom is more distinct than are the two 25-vehicle-pass lanes (lanes 3 and 4). The 5-vehicle-pass lane was traversed north to

Figure 19. Aerial view of lanes 1, 2, 3, 4 and 5, site 1.

Figure 20. Aerial view of lanes 3, 4 and 5, site 1, in lake bottom. Many older tracked vehicle trails can be seen crisscrossing the area.

Figure 21. Aerial view of lane 7, site 2, after 50 passes. Lane 8 (5 passes) can also be seen.

Figure 22. Overall aerial view of lanes in site 2.

Figure 23. Another aerial view of test lanes in site 2.

south and the two 25-vehicle-pass lanes were traversed south to north. This possibly insignificant factor will become more important in the future because of the orientation of the lanes with the incoming solar radiation. Here the 5-vehicle-pass lane appears darker from a southerly direction than do the two 25-vehicle-pass lanes; thus more heat may be absorbed, resulting in increased soil thaw. In this case more heat may be absorbed because when the sun is in the south solar radiation is greatest.

Speed. ACV speed over the terrain surface is another important consideration. To determine the amount of disruption caused by the SK-5 at various speeds a comparison was made between the effects of 25 passes of the vehicle at high speed (30 to 40 mph) and those of 25 passes at low speed (10 mph). Views of both tests lanes showed that the 25 passes at high speed left the surface much darker than the 25 passes at low speed. The differences between the two lanes can be seen in Figures 7 and 8. The high-speed lane (lane 3, site 1) exposed a large quantity of decaying organic material, resulting in a much darker surface. The importance of this variance in surface albedo will become evident in the future. The variance may be caused by changes in the airflow characteristics of the ACV as its speed increases. At high-speed there appears to be more skirt drag, as indicated by the streaks through the high-speed lane; the streaks are not as prominent in the low-speed lane.

In the lanes over which the vehicle made 25 and 50 passes at high speed, the remaining vegetation was thoroughly matted into the very wet surface (average 5-cm moisture was 1200%). A visit to the site made four weeks later (August) showed that the majority of the vegetation was still depressed into the surface. Little living sedges and grasses had been removed or cut by the vehicle's skirt. Other vascular plants as well as lichens were completely removed after 50 ACV passes.

Animal habitats. To obtain additional data on the effects of the ACV on avian habitats a zoologist working on a U.S. IBP Tundra Biome project was invited to observe vehicle tests on low-centered polygons. The data and discussion of these observations are given in Appendix A. Results from these observations indicate that very young birds (1 to 3 days old) are subject to mortality from air cushion vehicle overflights, but that larger, older chicks may withstand the effects of the overflights. Bird nests located in raised areas are subject to destruction after one pass of an air cushion vehicle. Nests in lower protected areas are destroyed after a few passes of an air cushion vehicle.

Conclusions

Currently efforts are being made to assess the long-term impact of various vehicles on the arctic terrain. The air cushion vehicle is thought to be one of the most efficient methods of transportation on this terrain in existence. The quantitative evaluation of this vehicle's potential impact on the sensitive vegetation-permafrost relationships is presently under investigation. Ongoing research indicates that the main contribution by the ACV to the physical disruption of the terrain is contact between the vehicle's skirt and the terrain surface, with exhaust air blowing the loosened plant and soil material away from the path of the vehicle.

In summary, future research efforts will call for continuing close scrutiny of past test sites and the establishment of new and more detailed test sites for monitoring specific aspects of various air pressures associated with larger ACV's. Data will be interfaced with computer programs involved in determining soil thaw resulting from changes in plant canopy.

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APPENDIX A: EFFECTS OF ACV ON AVIAN HABITATS

by

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Methods

Mockups of 6 nests representing 3 species of shorebirds were placed in locations and habitats typical of those for each species, and in the path of the experimental air cushion vehicle route on 20 July 1971. With one exception, the nests each contained 2 real eggs, a dummy egg of plaster (heavier than normal), and a paraffin-coated dummy egg (of normal weight) tethered to the bottom of the nest by a 15-cm string. The paraffin eggs thus could be blown only a certain distance out of the nests; they then could be retrieved and examined for impressions resulting from any contact with the skirt of the ACV. The excepted nest contained 3 real eggs of a golden plover and was placed in a typically exposed position atop a high-centered polygon where it was reasonably expected to be obliterated by one pass of the vehicle's skirt. Two nests were placed just lateral to the expected line of transit described by the windward vehicle skirt to assess the effect of lateral winds generated by the vehicle.

Each nest was examined following the 1st, 2nd, 5th, 10th and 25th overflight for egg breakage and displacement. Skirt nicks were counted on the surfaces of the paraffin eggs after the 25th run.

In addition, 3 banded red phalarope (*Phalaropus fulicarius*) chicks, each weighing 7 g (at 1 day old) and one red phalarope weighing 15 g (at about 5 days old) were placed in the route of the vehicle. Their viability was assessed after 1 pass of the vehicle over them.

Finally, a brown lemming (*Lemmus trimucronatus*), which survived 1 overflight, was caught and examined, then subjected to a second overflight and observed from a distance.

Results

The results of nest and egg experiments are summarized in Table AI. Of the three chicks subjected to overflights, the two younger ones died after several minutes of appearing healthy following the exposure. Both birds showed signs of a massive hematoma in the neck region, as if their circulatory systems had received massive shocks. These symptoms were confirmed by necropsy the evening of the experiment, although the exact cause is unknown. The 5-day-old chick and the lemming were not apparently bothered by the passing of the vehicle, as the chick was seen behaving normally nearby in the company of the brooding adult for an hour after the experiment.

Summary and conclusions

1. Well-concealed nests of shorebirds, such as dunlins, and pectoral sandpipers, have a good chance of surviving a single direct overflight by an air cushion vehicle.

2. Less well concealed nests, such as those of golden plovers and baird's sandpipers, are subject to destruction by a single overflight.

3. Well-concealed nests are subject to destruction beginning with a second overflight, and none can be expected to survive repeated passes.

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Table AI. Summary of nest characteristics and experimental results of ACV overflights.

Nest no.	*Species*	*Nest location*	*Nest character*	*Vegetation*	*1st*	*2nd*	*5th*	*10th*	*25th*	*Vehicle skirt hits*
1	Pectoral sandpiper (*Calidris melanotos*)	Central	Concealed	10 to 20-cm grass	OK	½ broken	Dest			2
2	Pectoral sandpiper (*Calidris melanotos*)	Lateral	Concealed	10 to 20-cm grass	OK	OK	OK	OK	OK	0
3	Pectoral sandpiper (*Calidris melanotos*)	Central	Concealed	10 to 20-cm grass	OK	½ broken	Dest			1
4	Pectoral sandpiper (*Calidris melanotos*)	Lateral	Concealed	10 to 20-cm grass	OK	OK	Blown out			1 (?)
5	Baird's sandpiper (*Calidris bairdii*)	Central	Open	Mossy polygon top	½	2/2 blown out				1
6	Golden plover (*Pluvialis dominica*)	Central	Open	Mossy polygon top	2/3	3/3 smashed				3

4. Most damage arises from fan wash and perhaps flying litter, while a small proportion (1-10% in well-concealed nests) arises from contact of nests with vehicle skirt.

5. Vehicle skirt contact is most destructive of exposed nests in irregular terrain.

6. There is little danger of destruction of eggs only a few feet upwind of the vehicle's route, although nothing can be said of nests immediately downwind of the vehicle route.

7. Very small chicks are subject to mortality from hovercraft overflights, but larger chicks may withstand these effects better.

8. Full-grown lemmings could not be shown to be subject to vehicle injury, under the conditions observed.

9. It is probably important to consider the effect of horizontal airflow under the vehicle in predicting the vehicle's effects on nests and chicks, and not to be misled by the small increment in atmospheric pressure generated by the vehicle.