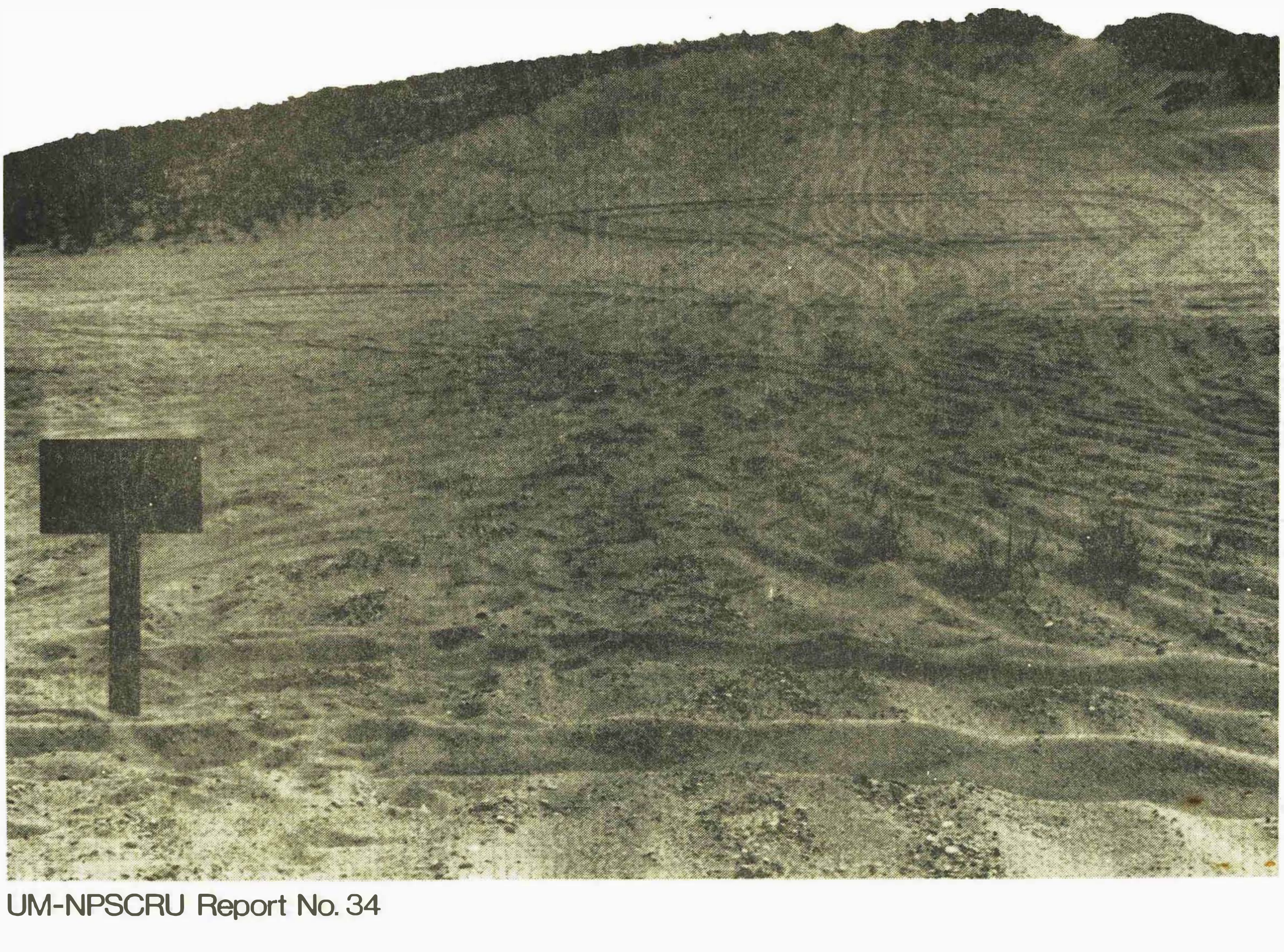
The Impact of Off-Road Vehicles on Coastal Ecosystems in Cape Cod National Seashore: An Overview

by Stephen P. Leatherman and Paul J. Godfrey



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THE IMPACT OF OFF-ROAD VEHICLES ON COASTAL ECOSYSTEMS IN CAPE COD NATIONAL SEASHORE: AN OVERVIEW

Final Report

Contract No. CX-1600-5-0001

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26. The Effect of Off-Road Vehicles on Least Terns and Other Shorebirds. Bradford G. Blodget.

27. The Preparation of an Off-Road Recreational Trail Map of the Province Lands, Cape Cod: Procedures, Observations, and Management Suggestions. Mark A. Benedict.

28. Effects of Off-Road Vehicles on the Infauna of Hatches Harbor, Cape Cod National Seashore. Nancy Wheeler.

29. The Ecological Effects of Off-Road Vehicles on the Beach/Backshore (Drift Line) Zone in Cape Cod National Seashore, Massachusetts. Robert Zaremba, Paul J. Godfrey, and Stephen P. Leatherman.

30. Effects of Off-Road Vehicles on the Sediments of Hatches Harbor, Cape Cod National Seashore, Massachusetts. James Hamilton.

31. An Investigation of the Effects of Vehicular Traffic on the Beach Face. Stephen P. Leatherman and Linda L. Long.

32. Effects of Off-Road Vehicles on Coastal Dune Vegetation in the Province Lands, Cape Cod National Seashore. John M.B. Brodhead and Paul J. Godfrey.

33. Effects of Off-Road Vehicles on Plants of a Northern Marsh, Final Report 1974-1977. John M.B. Brodhead and Paul J. Godfrey.

34. The Impact of Off-Road Vehicles on Coastal Ecosystems in Cape Cod National Seashore: An Overview. Stephen P. Leatherman and Paul J. Godfrey.

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

This final report summarizes the products of more than five years of research pertaining to the ecologic and geomorphic effects of off-road vehicles (ORVs) on coastal ecosystems. The impacts of ORVs were experimentally tested for the first time on the beaches, dunes, salt marshes, and tidal flats of Cape Cod National Seashore, Massachusetts. This research effort was undertaken by personnel of the National Park Service Cooperative Research Unit at the University of Massachusetts, Amherst. A bibliography on the effects of off-road vehicles on coastal ecosystems has also been included with this report as an appendix.

We have concluded that there is *no* "carrying capacity" for vehicular impact on coastal ecosystems. Even low-level impacts can result in severe environmental degradation. The most naturally unstable areas, such as the intertidal ocean beach, tend to be the least susceptible to damage. (However, this does not imply that there are no negative effects from ORV impact in this zone.) Dunes can be quickly devegetated by vehicular passage, resulting in blowouts and sand migration. Of all the ecosystems evaluated, the salt marshes and intertidal sand flats are the least tolerant of ORV impacts. This highly productive and complex system should be closed to all vehicles.

Specific recommendations for the areas studied are given below.

A. Beach

1. *ORV use should be restricted, whenever possible, to the outer ocean beach, seaward of the drift-line zone and expanding dune edge.* Such areas are subject to the greatest environmental change due to natural causes and are therefore less likely to be permanently damaged by ORV use. Also, if damage does occur, recovery would be most rapid in this area. However, other factors must also be considered with regard to use of the outer beach, such as conflicts with pedestrians, swimmers, foraging or resting shorebirds, and marine life in the sand beach.

2. *Prohibit driving in the upper backshore area, particularly in the areas of drift.* These drift lines are the precursors of new sand dunes on accreting beaches and can also moderate the rates of erosion when new vegetation is established at the base of a dune scarp.

3. *Close beaches that are so narrow as to force drivers to run along the very toe of the dunes at high tide.* Provide adequate bypass routes around such areas.

4. *Close beaches to vehicles during periods of exceptionally high tides, which force drivers to travel along the face of dunes or through shorebird nesting sites and embryonic dunes.* This can be an important safety measure, as well as protect the leading edge of the dunes and help to prevent damage to shorebird colonies. Access points to the beach should be closed at these times and posted accordingly.

5. *Nesting areas of Least Terns and other colonial shorebirds must be protected by (a) fencing, (b) posted signs, (c) restriction of beach traffic to marked tracks, and (d) strict enforcement of leash laws for pets.* The shorebird (tern) management program, including the function of tern warden, in the Seashore is successful and should be continued. Interpretive signs should be placed at beach route entrances to (a) alert drivers to watch for active terneries, (b) explain briefly the life history of the Least Tern, and (c) request visitor cooperation in protecting the terns. Signs calling attention to the colonies themselves should be posted at least 100 feet on either side of a colony, and visitors urged not to approach any closer. Vehicles can pass by somewhat closer, but people leaving their vehicles will scare the birds and can lead to nesting failures. Dogs in particular must be kept from the nesting areas since the birds are much more alarmed by dogs than by people approaching on foot.

B. Dunes

1. *Prevent vehicle entry into previously closed dune regions.* Wherever possible, provide public transportation to inaccessible areas or allow only walk-in use.

2. *Where ORV access is necessary, tracks should be carefully planned to avoid the most sensitive areas.* These include:

a. drift lines and embryonic dune areas;
b. the leading edge of expanding dunes;
c. older, stable dune areas where drivers would be inclined to leave the tracks;
d. heathlands and hairgrass/lichen communities -- particularly beach heather (*Hudsonia*).

3. *Wooden ramps should be built and maintained over dune lines, providing beach access through the dune zone.* Such ramps are most critical where lowering of the dune line might lead to greater storm hazards for habitats or facilities behind the dune. New routes over dunes to the beach should not be allowed without adequate ramps that will protect the dune system.

4. *Dune routes should be oriented in such a way that prevailing winds cannot create blowouts.* Specifically, open trails should not face the prevailing winds. Properly placed borders of vegetation can help to prevent wind erosion.

5. *Dune routes should be designed to avoid sharp turns or climbs up steep grades.* Otherwise, drivers are likely to make new, unofficial trails that are easier for them to negotiate, which tend to increase the total area being impacted.

6. *Restrict traffic to marked routes with borders of cable or dense, impenetrable shrubs.* Such tracks should be established only after careful study to avoid or minimize environmental impact. Most trails should be permanently closed, and only those absolutely necessary should be retained.

7. *Vehicle trails must be controlled and maintained.* Deterioration of the track (especially washboarding) often spurs drivers to leave the established trails and impact surrounding vegetation.

8. *Close off deteriorated dune routes and institute management programs to repair the damage, especially where natural regrowth would be slow.* Most dune species can be readily transplanted, and thus vegetation can be restored.

9. *Close all sensitive habitats such as heathlands and shrublands.* Habitats with slow-growing species, that experience stress due to drought and lack of nutrients, are likely to be the most severely damaged and must be protected from vehicles.

10. *Institute public programs and displays that are aimed at educating the public to ORV damage.* The public needs to be made aware that "dune-busing" and "wheeling" are extremely damaging to dune systems, and severe penalties for such activities should be enacted. When given the reasons behind ORV regulations, most people will accept them.

11. *The concept of "no carrying capacity" should be emphasized when planning for ORV use.* A few vehicle passes through dune vegetation can create substantial problems, and once a trail is open for use, there is little difference between very light use (i.e., a few hundred passes) and very heavy use (thousands). For this reason, establishing a few, well-managed, "heavy-use" trails is preferable to many "low-use" trails.

12. *All ORV use of the high, migrating dunes in the Province Lands must be terminated until such time that the dunes can be stabilized and nondamaging routes created.* The present use patterns will keep the dunes unstable and migrating. If ORV trails through the high dunes area are necessary, they should be relocated and designed so as to prevent or at least minimize erosion.

13. *Whenever possible, ORV use should be restricted or eliminated entirely in the dunes and coastal habitats.* In general, ORV use in these areas is not compatible with the natural processes and adaptations of organisms to this environment.

C. Salt Marshes and Tidal Flats

1. *Close all salt marsh and tidal habitats to vehicle use.* The system is much too sensitive for such recreational purposes; it has no carrying capacity for vehicles. ORVs are a major stress to this environment, detrimental in all aspects, and it is clear that vehicles should be excluded from such environments. Once closed, the salt marsh/tidal flat system will begin to recover, but it must be patrolled and regulations enforced. Only a few illegal passes through protected areas will substantially set back recovery of vegetation.

2. *Prevent traffic from using the border zone between salt marshes and dunes.* Provision should be made for bypassing the marshes and flats by developing a series of carefully located upland trails.

3. *Establish a series of interpretive displays that show how vehicles damage marine resources.* Such information can help visitors understand why these areas must be closed.

INTRODUCTION

The impact of off-road vehicles on coastal ecosystems has recently become of much concern to land managers. Existing management plans have generally originated from intuitive feelings and casual observations, with hard data rarely available. Thus, the issues of ORV impact on the environment have frequently centered around emotional stands taken by opponents and proponents alike. It was in response to this need for basic data that the National Park Service Cooperative Research Unit at the University of Massachusetts, Amherst, was asked to undertake a multifaceted, multiyear, experimental analysis of off-road vehicle impacts in Cape Cod National Seashore. The project staff attempted to look at all critical aspects of the off-road vehicle problem, since little information was available to address the questions being raised. The initial design involved analysis of off-road vehicle impacts on beaches, dunes, salt marshes, and tidal flats, including their biota and physical characteristics. As far as we can determine, this multiyear effort represents the first experimental analysis of off-road vehicle impact in the coastal zone of the United States.

Various ecosystems susceptible to ORV traffic in the Province Lands of Cape Cod were impacted in a controlled fashion so that rates of deterioration and recovery might be measured. The two major study sites were Race Point beach and dunes, and Hatches Harbor salt marsh and tidal flats (Fig. 1). The following are short descriptions of the environments where experimental impacting was applied.

1. Sand Beach. The beach is an important site for nutrient recycling, drift-line deposition, development of new sand dunes, and a habitat for many animals, both interstitial microscopic species and macroscopic wildlife such as terns and other shorebirds. It is formed and shaped by waves and is thus the first defense against storm damage.

2. Dunes. The dune zone consists of two basic parts: newly formed foredunes and more matrue backdunes. Dunes catch and store sand blown from the beach and are dependent upon vegetation for stability and development. They are the natural barriers for backdune habitats against severe storm flooding. Dune vegetation can be divided into either grassland or woody communities, the latter being characteristic of more stabilized dunes. In our research, beach grass dunes (*Ammophila breviligulata*), which represent the first stages in

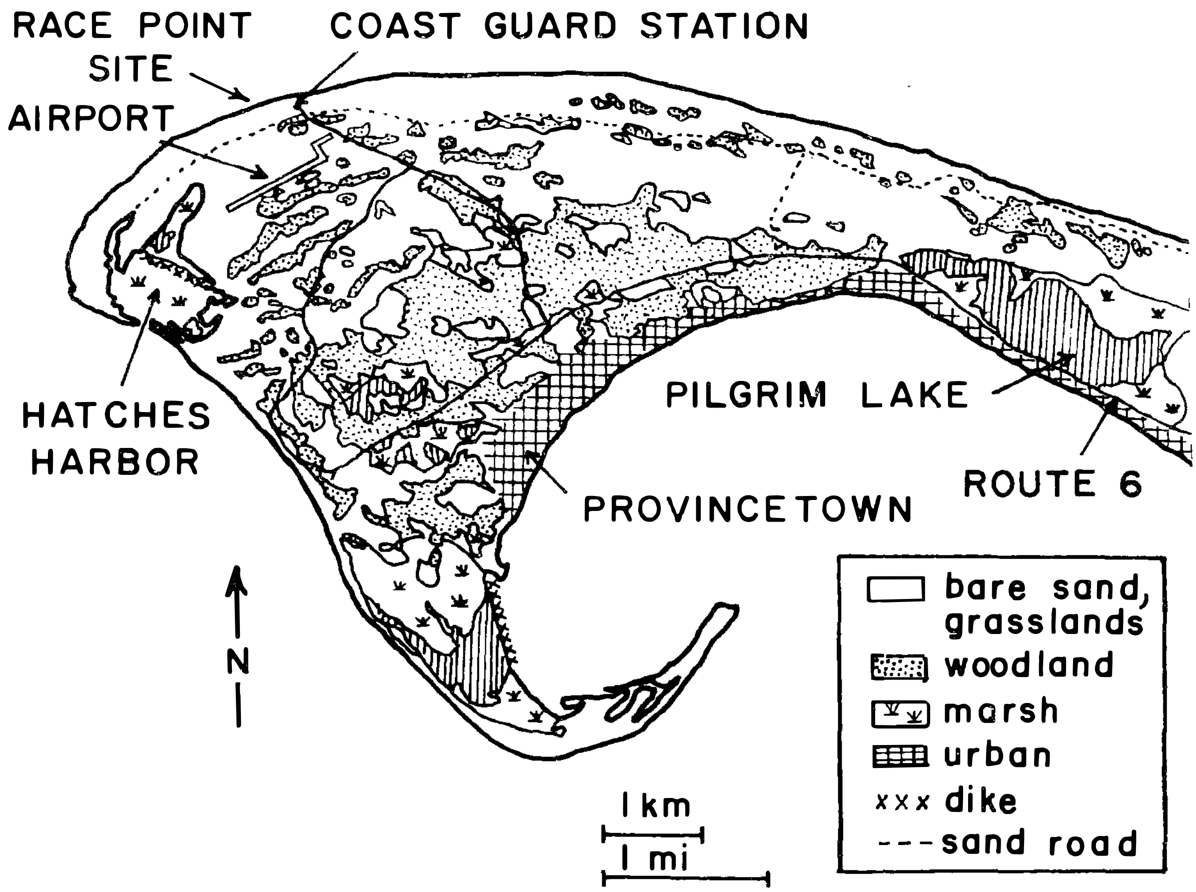

Fig. 1. ORV study sites (Race Point and Hatches Harbor) in the Province Lands, Cape Cod National Seashore.

dune succession, and the more stabilized bearberry *(Arctostaphylos uva-ursi)*, hairgrass *(Deschampia caespitosa)*, and heathlands *(Hudsonia tomentosa)* were experimentally impacted.

3. Salt Marshes and Sand Flats. Marshes are a major source of primary productivity for estuarine waters and form a barrier against erosion in the intertidal zone of bays and sounds. The two main parts of the intertidal salt marshes were impacted -- the high marsh *(Spartina patens)*, which is flooded only by spring tides, and the low marsh, dominated by *Spartina alterniflora*. The sand flats exposed at low tide are very important habitats for infauna, a number of which are commercially important species, such as the soft-shell clam *(Mya arenaria)*, clam worm *(Nereis virens)*, and bloodworms *(Glycera)*. It also serves as feeding grounds for migrating shorebirds.

BEACH BIOTA

Of the various ecosystems studied, the most naturally variable and therefore the most resistant to long-term vehicle impact appears to be the intertidal ocean beach. Attempts to determine the populations of meiofauna proved to be difficult, but those samples taken showed that very few organisms were present on this northern beach. Populations are highly variable and seem to exhibit no apparent effects from vehicle impact with the techniques used. Analyses of interstitial algae provided some indication of major groups present in the sand, but changes in populations as a result of driving over the sand could not be satisfactorily determined. Samples of sand were also cultured for bacterial studies, but high variability within the sample areas masked any correlations with vehicle damage. The continuous change from sand transport during tidal cycles, as well as annual and storm-induced beach cycles, made analysis of ORV impacts very difficult and of questionable reliability. Therefore, no definite conclusions could be drawn regarding long-term impact other than that natural changes appeared to overwhelm vehicle effects on this particular beach.

It should be noted that more detailed studies are needed, for both northern and southern beaches of the U.S., to clearly assess vehicle impacts on such ecosystems. Southerly beaches have larger populations and greater diversity of interstitial organisms, as well as more large infauna, such as ghost crabs, that can be directly affected by vehicle passage.

Impacts on the high beach or berm were more clear-cut than on the intertidal beach face. The high beach is very heavily impacted, being a relatively flat surface influenced only by the highest tides. It is here that drift accumulates, sea birds nest, and new dunes form along accreting beaches.

On some stretches of beach the most characteristic single trait of the backshore is massive, washboard ruts. Vehicle passage increases surface roughness, which can lead to greater beach variability and increased aeolian (windblown) transport of sand. It was also noted that vehicular passage breaks the (salt) crust, when present, which can initiate sand movement by the wind. With an offshore wind, this sand can be blown toward the ocean and lost to the longshore current system.

The most sensitive zone of the high beach is the drift-line zone, which consists chiefly of organic material deposited on the backshore during high spring tides or storms. Drift lines on northern beaches contain large quantities of marine algae, eelgrass, and marsh detritus. Bacteria and fungi quickly break down this organic matter, releasing nutrients into the sand and eventually back to the sea. The drift-line zone also contains fragments and seeds of dune plants and is therefore a significant site for new dune development on open sand. Regeneration of beach grass *(Ammophila)* on a bare sand beach is almost exclusively by growth of plant fragments washed from eroding dunes and redeposited on the beach as drift (Fig. 2). Once the plants are established, embryonic dunes can develop, provided they are not destroyed by storms or ORV impact.

The shearing and compressional effects of ORV passage extend to a depth of approximately 20 cm; the shear stresses of the turning wheels disaggregate the drift and break plant rhizomes (Fig. 3). The integrity of drift lines is destroyed by ORV traffic, as the material is scattered about the beach. Vehicle impact also decreases the rate of decay of organic material. Bacterial counts associated with the drift were normally very high but were markedly reduced when vehicles pulverized the organic deposits.

Vehicle traffic also crushes and kills seedlings of annuals and the young plants of perennials, such as *Ammophila*, which are associated with the drift. It was found that the effect of 100 passes of an ORV does not differ significantly from that of 10 passes; only a few passes are required to break up the deposit and kill all the vegetation. Thus, the major effect of vehicles on the high beach was on drift lines and developing dunes, with traffic severely limiting new dune formation.

The impact of ORVs on colonial beach-nesting seabirds, specifically Least Terns *(Sterna albifrons)*, and on transient populations of other migratory shorebirds was studied by Bradford Blodget (1978). Despite repeated claims over the past forty years that vehicles are having an adverse impact on the Least Tern population, counts on Outer Cape Cod during 1974-1977 were at least as high as for any period on record. With complete closure of nesting areas and wardening, hatchability of Least Tern eggs remains excellent, despite proximate ORV traffic and associated high levels of human disturbance. Without this positive management approach, the highly cryptic nests and young of beach-nesting seabirds, particularly terns, render them particularly vulnerable to disruption during the nesting season.

Fig. 2. American beach grass growing from rhizome fragments in a drift deposit have begun to form an embryonic dune.

Fig. 3. One vehicle pass can tear apart and scatter the drift-line deposit.

Controlled impacting experiments were also directed toward nesting birds. For each test, a vehicle was driven closer and closer to sitting birds to determine the flushing distance and the amount of time the birds spent in the air before returning to the nest. The results showed that birds can acclimate to vehicles passing very close to their nests, but would flush when persons or dogs approached. Vehicles could come twice as close to sitting birds before they would fly than could people on foot. When nesting colonies are protected by fences and drivers obey the rules, ORV impact on birds can be minimal, particularly where beaches are wide. In these situations, the greatest disturbance to the birds occurs when people stop their vehicles and walk over to the colony, or when they walk along the beach. Free-running pets that enter the colony can cause more harm than hundreds of vehicles passing around the exclosure.

The impact of vehicles is quite different when they run directly through a colony during nesting season. Forced by an exceptionally high tide, vehicles travel higher on the beach, and occasionally through colonies and along the dune toe. In other cases, entry may be of malicious intent, although such events were rather rare in our studies.

Where there are nesting sites on narrow beaches, direct confrontations between vehicles and birds are likely to result, and the birds will suffer accordingly. Drivers passing directly through a colony (either accidentally or intentionally) will run over eggs and chicks. However, as long as birds have room to nest and are protected, and as long as drivers have space to pass by the colonies, the two uses of the beach can coexist.

DUNE ENVIRONMENTS

The effects of vehicles on dunes depends on what portion of the dune is impacted (Fig. 4). Where American beach grass *(Ammophila)* is expanding directly onto the beach, fewer than 50 passes can stop seaward growth and development of the foredune system. This low-level impact is enough to set back *Ammophila* expansion by a full year.

John M. B. Brodhead and Paul J. Godfrey (1979) found that a healthy *Ammophila* community could grow seaward onto the beach at a rate of 1 to 2 m each growing season, with daily rates of 2 cm under optimal conditions. Driving along the front of an advancing *Ammophila* community will effectively stop new growth. Continuous ORV impact along a foredune front can induce or accelerate erosion and dune scarping. Such traffic will also prevent the healing of erosion scarps by interfering with the natural tendency of *Ammophila* to invade and colonize open sand.

Growth of *Ammophila* rhizomes occurs at the juncture between wet and dry sand, normally 15-20 cm beneath the surface. Rhizomes grow rapidly along this boundary, sending up shoots through the drier sand to the surface and roots down into the moist sand below the boundary. The effect of wheel disturbance is to mix up the sand, thus breaking the critical boundary between wet and dry sand, which results in a loss of moisture from the deeper zones. Off-road vehicle traffic also breaks rhizomes at this boundary as well as changes the moisture regime. Only 100 vehicle passes are sufficient to break all underground rhizomes; most are churned up to the surface where they soon dessicate and die. The tolerance of *Ammophila* rhizomes to vehicle impacts is very low and only a few passes have a severe effect.

Rhizomes of *Ammophila* will grow rapidly once protected and revegetate disturbed areas. Thus, where dune growth is necessary for the health of the strand, such as the front of dune lines, ORV traffic must be restricted. Without protection, vehicle traffic will prevent expansion of the dune community since *Ammophila* rhizomes are not capable of growing deep enough to avoid ORV impacts.

The effects of experimental ORV impacts on *Ammophila* vegetation along a straight section of track showed that relatively low levels of impact (less than 175 passes) were sufficient to create maximum damage to the plants (Fig. 5). The experimental data clearly indicate that the first passes of a vehicle across the dune grass community are the most critical and damaging. In this sense, *Ammophila* vegetation does not have a "carrying capacity" for vehicles. There is

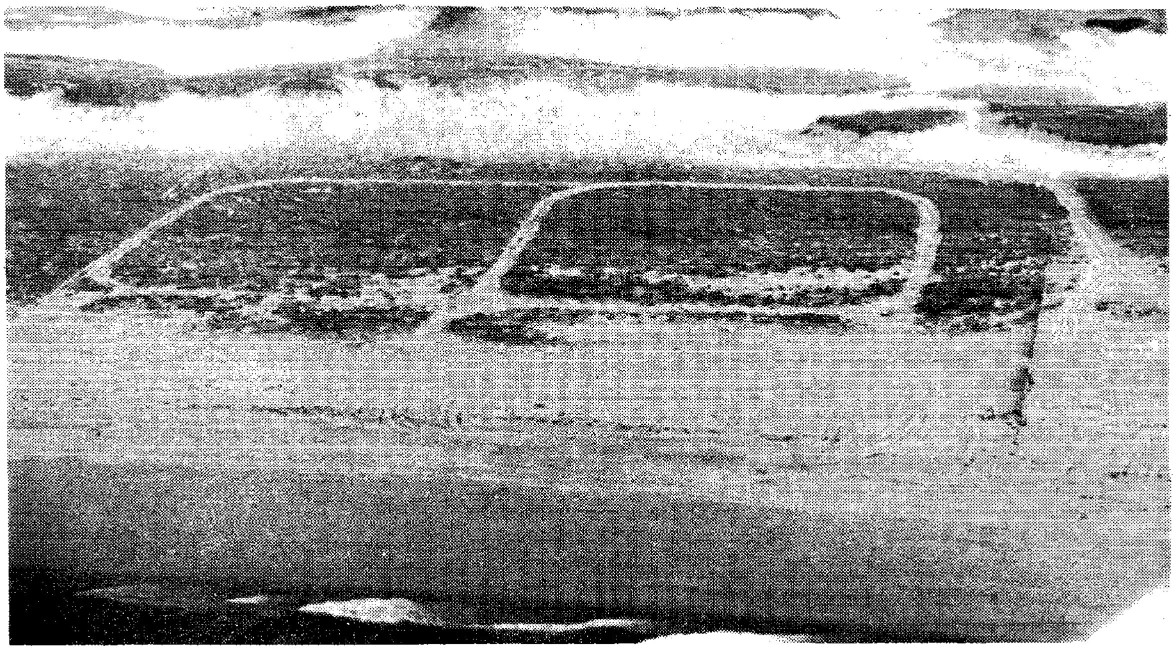

Fig. 4. The experimental impacting on the beach and dunes was conducted as a figure-eight track, commonly called "Race Point racetrack." This picture shows the impact on different portions of the dune (foredune vs. backdune).

Fig. 5. Rhizomes of beach grass are pushed up to the surface by the churning wheels, where they dry out and die. The foredune was experimentally impacted with 525 passes in 1974.

also no intrinsic difference between tolerance of *Ammophila* plants on the foredune and backdune; all sites are affected to nearly the same degree. An open track will soon result from repeated passes of vehicles, and an established ORV dune track can be considered as a rather permanent feature.

Studies showed that there were no differences in recovery rates between sites that received heavy impacts (675 passes) and those that received moderate impact (270 passes). Thus, the rate of recovery following relatively few vehicle passes is about the same as after heavy impacts. Once started, a vehicle track will remain open and bare with minimal use.

When off-road vehicle impacts are stopped, the *Ammophila* dune community begins recovery almost immediately, particularly if the final passes occur before the end of the growing season. Since plants damaged by ORV stress have usually been killed (they are broken away from underground rhizomes, carried to the surface, crushed, and dessicated), recovery is through new growth into the disturbed track from adjacent, undamaged stands of vegetation.

Recolonization proceeds according to the overall vigor of the vegetation. Near the beach and in the foredune, where growing conditions are most favorable, complete recovery can occur within four years following impact of 675 vehicle passes. Recovery on the backdune, where growing conditions are less favorable, takes much longer. After four years of protection, experimental ORV tracks are still visible in this study plot. Other studies have shown that ORV tracks in backdune areas are clearly visible even after eight years of protection. Thus, ORV effects are longest lasting farthest from the source of new sand that promotes optimal growth of *Ammophila*. Natural regrowth can be set back easily by passage of a few vehicles. Management actions (fencing and replanting) are necessary to rehabilitate badly damaged sites.

Off-road vehicle use has resulted in vegetative denudation and consequent lowering of portions of the stabilized Province Land dunes (Fig. 6). The physical forces applied to the sand by climbing or descending wheels result in a downward transport of sand. Over a period of time, the profile may be significantly lowered in those areas where numerous vehicles traverse the dune.

Sand tracer studies were used to quantify the volume of sand displaced downslope (due to propulsion) by vehicles. Dune-slope angle and tire pressure were the two most significant variables influencing downslope sediment displacement. On an 8-degree slope, approximately 2000 cm^3 (range from 1400 to 3600 cm^3) of sand would be transported by a single vehicle that approaches perpendicular to the slope. As the angle of approach was varied toward being more parallel to the slope contours, the amount of sediment displacement decreased to less than 1000 cm^3.

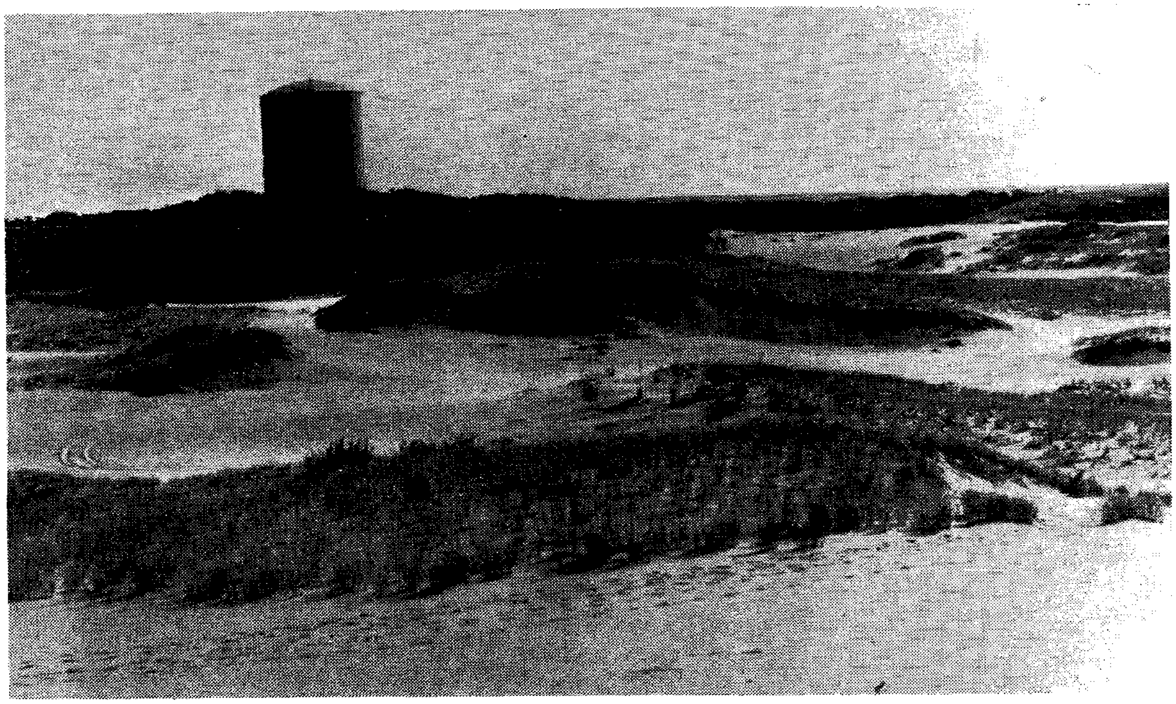

Fig. 6. Vehicular traffic can quickly kill the stabilizing beach grass. The devegetated sand can then be blown away by the wind, resulting in sharp notches in and truncation of the Province Lands dunes.

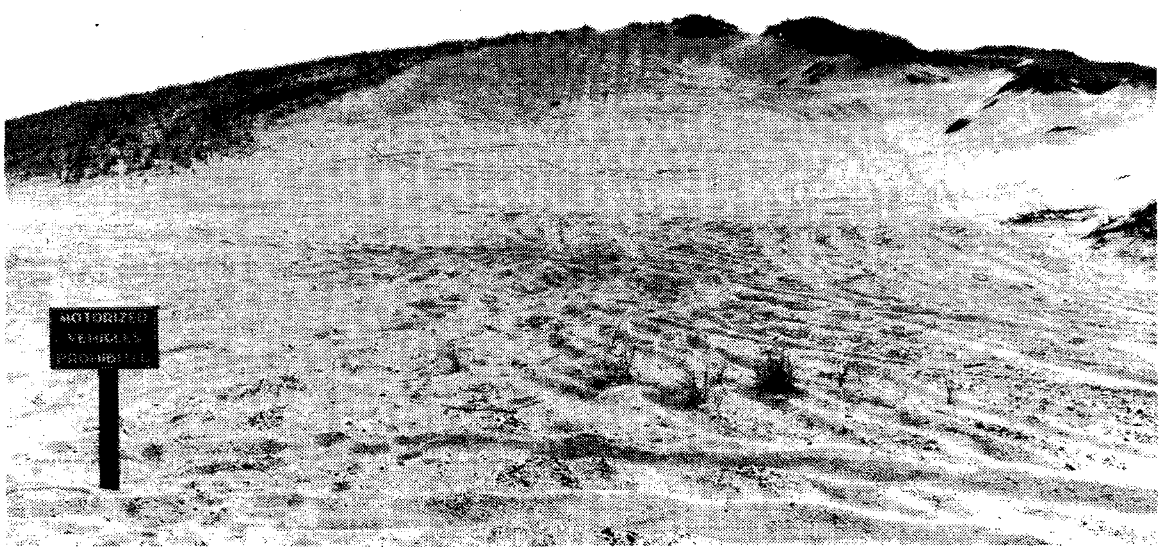

Fig. 7. Dune busting can result in blowouts and dune migration. It takes only a few drivers, ignoring regulations, to inflict severe damage.

In order to minimize direct sand transport by the churning wheels, it is preferable to orient trails parallel or diagonal to dune contours rather than perpendicular. Tracks should not be established along the direction of prevailing winds, which are from the northwest in the Province Lands. When vegetation shelters a bare ORV track from strong winds, loss of sand is kept to a minimum. However, bare tracks exposed to strong winds will develop into blowouts, increasing erosional problems. The orientation of planned or illegal dune tracks is therefore quite important to the future of the dune field. Open tracks on dune slopes exposed to the prevailing winds should be closed to traffic and revegetated, or ramps should be built to prevent blowouts from developing.

The physical changes and loss of plant cover caused by vehicles on dunes can lead to instability and promote dune migration. In addition to and more important than direct sand displacement, vehicular passage precludes re-establishment of plant communities. These areas remain open to wind erosion, which allows blowouts to develop. The dunes will then become unstable and begin to migrate unless controlled. Many open dune slopes and migrating sands, now very much in evidence throughout the Province Lands, owe their present condition, if not their origin, to the continued use by off-road vehicles, especially the illegal and occasional dune-busters (Fig. 7). Unvegetated sand dunes will continue migrating across stable areas as long as traffic is permitted across the crest and high-angled slopes.

Tests made on other types of stabilized dune vegetation showed that no one species has a greater capacity to withstand ORV impacts than another. Plant communities, dominated by *Arctostaphylos uva-ursi* (bearberry), *Deschampsia caespitosa/Cladonia* (hairgrass/lichen), and *Hudsonia tomentosa* (beach heather), commonly develop on stabilized dunes and are subject to ORV damage. Each vegetation type broke down at approximately the same rate when compared to *Ammophila* dune vegetation; the first few passes (50 or so) were sufficient to create maximum damage.

Rates of plant recovery, however, were different, and the various communities can be ranked according to regrowth capacity. *Arctostaphylos* and *Deschampsia* vegetation showed moderately fast recovery; the communities were returning to preimpact levels within four years. *Arctostaphylos* showed the most rapid recovery since its hard, woody, creeping stems were not severely damaged by the level of impact experimentally applied (Fig. 8). Thus, new stems could be produced in a relatively short time, but the tire tracks in the sand are still evident. These tests were made on level surfaces, and similar damage on slopes would likely have led to long-lasting erosional problems.

The most sensitive community, in terms of recovery time, was *Hudsonia*. Due to its growth habit -- short, dense, and shrublike -- *Hudsonia* vegetation was quickly destroyed by ORV impact. Since the

Fig. 8. The aboveground stems of the woody bearberry plant were not entirely broken after 300 passes. The community was able to recover after several years, but severe erosion can result in areas of steep slopes.

Fig. 9. *Hudsonia* (beach heather) has experienced very little recovery after three years, as shown by this photograph.

plant does not spread readily by underground rhizomes or aboveground creeping stolons, much more time is required for revegetation, which is accomplished primarily by seedlings in the tracks. After four years of monitoring, ORV tracks in the *Hudsonia* (heathland) community were clearly visible and largely bare (Fig. 9). Such damage, particularly on easily erodible sand, can lead to blowouts, since the area remains open for long periods of time. It is therefore imperative that all off-road vehicle traffic through heathland communities of *Hudsonia* be prohibited.

Sensitivity of dune vegetation to ORV impact can be described by recovery rates, but not in terms of "carrying capacity." There is no carrying capacity of dune vegetation for off-road vehicles. Low levels of impact create maximum damage. Thus, once a track is created, it will remain open as long as vehicles, even in low numbers, use the track. However, vegetation on dunes recovers at different rates, as mentioned above. Such recovery depends on the species involved and the environmental conditions of the locality. The most stable sites, and those with natural stresses such as drought and low nutrient levels, take the longest time to recover. More dynamic sites, with inputs of new sand, nutrients, and moisture, tend to recover more rapidly. The various plant communities tested on the Race Point dunes were ranked from the standpoint of recovery rates:

Ammophila foredune	(most rapid)
Ammophila backdune	↓
Arctostaphylos heath	
Deschampsia/Cladonia grassland	
Hudsonia heath	(least rapid)

In summary, off-road vehicles have substantial effects on dune vegetation, which can lead to degradation of the dune system. Maximum damage to vegetation results during the first few passes of a vehicle. Dune vegetation has a low threshold of tolerance, and only 100 passes are sufficient to cause severe degradation. Given protection, however, the vegetation on dunes will recover, but at varying rates, depending on the species and environmental conditions. Vehicle use must be controlled and managed to avoid ever-growing damage to dunes and dune vegetation. Continuous use of open dune regions by vehicles, particularly those that stray from marked trails, result in dune erosion and migration.

SALT MARSHES AND TIDAL FLATS

Hatches Harbor, the salt marsh and tidal flat study site, is a small, young estuary in the Province Lands that has experienced heavy recreational usage. The impacts from ORVs are visually obvious: barren tracks of compacted sediments cut through both tidal flats and vegetated salt marsh regions. Some Provincetown citizens, who formerly harvested soft-shell clams and sea worms in Hatches Harbor, maintain that the present depauperate conditions are directly related to ORV activity. Many ORV enthusiasts, however, refuse to consider that their vehicles do damage to any aspect of the local environment, but depletion of the floral and faunal resources is apparent.

Of all the ecosystems studied so far, Brodhead and Godfrey (1979) found that the intertidal salt marshes and sand flats are the most severely affected by vehicle impacts. This environment harbors a variety of marine and coastal organisms and supplies the primary productivity to the estuarine and nearshore marine food webs. The complex food webs leading to the great diversity of marine life are dependent on the proper functioning of the intertidal ecosystem, and vehicles can significantly affect the intertidal area not only at the species level, but at the systems level as well, threatening its very survival. Dune environments are also seriously affected by ORVs, but the complexity of those habitats does not compare with the intertidal zone of marshes and flats. Thus, dunes are more easily managed and repaired than intertidal areas.

The *Ammophila* dune/*Spartina patens* marsh edge is very susceptible to impact because it marks the easiest and generally safest ORV route in the area, but vehicles destroy this all-important buffer zone. The resulting bare tracks lead to disruption of both the marsh edge and the adjacent dunes.

Sand eroded from the dunes by wave and wind action is deposited on the marsh surface. Continual sand movement threatens both the dune system due to erosion and the marsh by increasing its elevation. This study has shown that open sand tracks around the periphery of the salt marsh are definitely the result of off-road vehicle traffic, and even very low levels of traffic can maintain barren strips in the marsh indefinitely. Access to this area and all further traffic in this zone should be eliminated.

ORV impacts in the high salt marsh (dominated by *Spartina patens)* are also substantial, but this zone is not extensively used for driving. Less than 200 passes killed the standing biomass, and three seasons were required for recovery. Repeated traffic across the high marsh quickly results in barren tracks (Fig. 10). Where experimental tracks were created through the high marsh, tide water began to flow back and forth through the track and erosion of the surface began. Low-level impacts on the high marsh initiated the formation of open sand channels similar to those already in existence at Hatches Harbor. As the channels erode, the surface is cut down, often below the survival level of high marsh species, thus preventing early recovery. Rapid water movement through such channels prevents establishment of other salt marsh species. Sand channels closed for three seasons showed no signs of revegetation, except where tidal currents are weak or slowed by artificial barriers. Where repair of tracks across the high marsh is desired, management actions will be needed, such as planting the site with appropriate species. In any case, all traffic should be restricted from the high marsh.

One of the most seriously affected regions in the intertidal environment is the upper sand flats, which provide the surface on which new salt marshes form. Although some extent of flats is natural, the extensive sand flats around the periphery of Hatches Harbor were definitely maintained by ORV traffic. Once protected from such impacts, the sand flats were quickly colonized by low salt marsh species, in particular *Salicornia* spp. (Fig. 11). Invasion by *Spartina alterniflora* took longer but was nevertheless underway in a relatively short time. From these exclosure experiments, it became clear that the present level of vehicle use on certain sections of the flats was preventing the natural development of salt marshes.

Once this vegetation is established, however, only a very few passes of a vehicle can cause maximum damage. Tests showed that 25 passes throughout a 3 m wide area are enough to kill all existing plants by crushing. ORV traffic on these flats also packs the substrate to create a kind of pavement, which is sufficient to prevent the establishment of some plants.

Nancy Wheeler (1979) found that ORV traffic on the naturally open flats has also affected the survival of marine infauna, including worms, clams, and other mollusks. Counts of marine animals in transects across driven and nondriven sections showed marked reductions in driven zones. The much-reduced density of amphipods in a driven area, as compared with a non-driven one, implies that "normal" ORV activity does deplete population numbers and might be sufficient to eliminate this species in impacted areas.

Marine worms were also greatly affected by low levels of ORV impact. After applying 50 passes per day during a 20-day test, the polychaete (clam worm) populations were totally decimated. This

Fig. 10. Sand channels cut through the high marsh by vehicles allow for rapid movement of sand landward, accelerating the rate of infilling of Hatches Harbor.

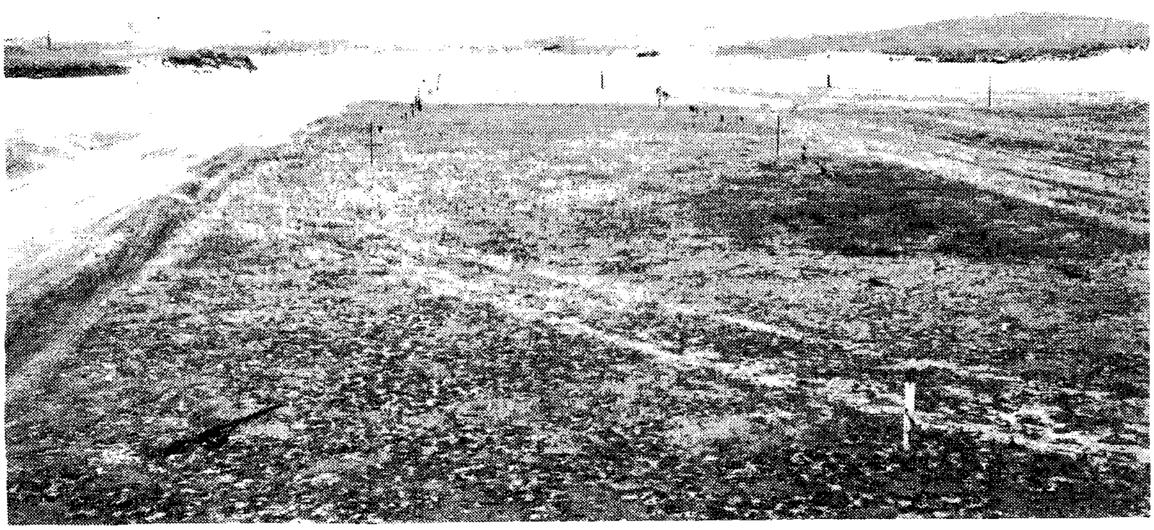

Fig. 11. A large exclosure was placed on one portion of the open, intertidal sand flats. Within three seasons the fenced area was well on its way toward becoming a normal marsh.

result is not surprising since they are soft-bodied organisms and are therefore particularly susceptible to physical compression. As with other invertebrates, spawning adults and metamorphosing young should be even more vulnerable to ORV traffic than nonreproducing adults. Depletion of numbers of polychaetes might discourage shorebirds and fish from feeding in the area, and decrease the amount of organic material supplied to the food web as detritus.

Experimental tests were made on the survival of the soft-shell clam (*Mya arenaria)* under relatively low levels of vehicle impact. The soft-shell clam has historically been an important economic resource on Cape Cod, but this species has undergone dramatic declines in recent years at Hatches Harbor and other areas subject to human disturbance. Popular opinion placed the blame for this decline on green crabs and moon snails rather than human causes of over-shellfishing and ORV traffic.

The 20-day period of impacting marked clams *(Mya)*, 50 times per day, resulted in total decimation of experimental animals and established that the clam population in Hatches Harbor could easily be depleted by vehicular traffic. Clams were killed by the crushing of their relatively soft shells, as well as by modification of the environment. Vehicles compacted the substrate to a pavementlike (macadam) surface, interfering with normal exchange of sea water with the sediments and creating anaerobic conditions in the substrate. It also prevented clams from extending their siphons to the surface to obtain food and water at high tide; such restriction eventually results in death to filter-feeding organisms such as clams.

All soft-shell clams in the path of ORV traffic are adversely affected. Continued impact reduces the likelihood of reproduction by preventing colonization of the shellfish spat and reducing the breeding population. Low levels of ORV activity were found to affect growth rates of *Mya* in all size and age classes alike. Nonreproductive-size clams experienced slowed growth and remained in small, vulnerable size classes for an extended period, reducing production (biomass) and the probability of their survival to adult size. Finally, since large clams under the stress of even low levels of ORV activity would have correspondingly less energy available for growth or reproduction, spawning may be reduced in adults.

The results of this study imply that ORV activity in the intertidal zone has adverse effects not only at the species level, but at the systems level as well. Any natural system that has been disturbed by man may lose important species, food-web complexity, and much of its aesthetic and recreational appeal. Continued ORV disturbance can create biologically unproductive as well as aesthetically unappealing, barren areas. The amount of damage that has been incurred already is difficult to estimate, but there can be little doubt that important populations have been severely depleted.

Considering the importance of the intertidal environment and the tendency for drivers to cross these flats, it is imperative they they be protected from ORV traffic. This region has very high use and is the most badly damaged by vehicles in terms of its biological potential. No traffic should be allowed in these areas.

Although the low salt marsh of *Spartina alterniflora* is rarely impacted, destruction by a vehicle can be very severe and long lasting. Only one pass of a vehicle is sufficient to create ruts in the marsh peat that will persist for quite a long time (Fig. 12); the marsh surface can be depressed by 10 cm or more. Thus, the major effect of traffic through marsh peat is to create deep ruts in the soft organic substrate. Only 90 passes of a Jeep were possible in the experimental impacts because compaction of the peat created an impassable quagmire (Fig. 13). The vegetation in the tracks was totally destroyed, creating a series of depressions in the peat. These undrained depressions accumulated and retained salt water during each high tide. As evaporation proceeded, the salt content increased and reached levels that were too high for plants to tolerate. Artificial pannes precluded reinvasion by marsh plants and provided habitat for salt marsh mosquito larvae. The creation of these vehicle-induced depressions in the low marsh thus altered the environment to the detriment of the marsh system. The length of time such ruts will remain is not known; they were clearly evident after four years.

Since there is little tendency for people to drive on the low salt marsh, ORV traffic is not a major problem at present. Nevertheless, all ORV use in or near the low marsh community should be prohibited. For management, preventing access to the dune/marsh transition zone and sand flats will also protect the low marsh.

There are two primary geomorphic changes caused by off-road vehicles in Hatches Harbor. As previously mentioned, vehicular passageways through the marsh can become sand channels, which will result in accelerated infilling. Vehicles also destroy the embryonic dunes on the sand spit, which increases the amount of overwash and further enhances the rate of sedimentation.

Sand and pebbles are brought into Hatches Harbor as overwash deposits during storm events. Vehicles can greatly increase the amount of overwash by destroying the developing dune vegetation on the protective sand spit. These overwash deposits are subject to transport by tidal action; this sediment can then be pumped landward through the sand channels by the flood-dominant flow.

Experimental evidence indicates that the open sand channels in Hatches Harbor are at least maintained by vehicles, if not created by them. The narrow sand channels are probably artifacts of earlier ORV impact; the edges of these channels are too sharp and straight to truly suggest natural formation. Once the marsh peat has been destroyed and

Fig. 12. One pass through the low marsh can result in deep ruts due to compression of the peat. Since there is little to no rebound, vehicle scars can remain intact for decades.

Fig. 13. The low marsh (*Spartina alterniflora*) was reduced to a quagmire and became impassable after only 90 passes.

a low area produced, tidal currents naturally flow through and maintain these channels. Sand transport studies showed a net movement of sand into the Harbor and up the channels that surround the marshes and sand flats. This implies that sand will continually enter the region at increased rates as long as vehicles keep the channels open.

Thus, ORV traffic can increase the amount of open sandy areas and rate of movement and hence quicken the infilling of Hatches Harbor by creating new sand channels through marshy areas. On the other hand, salt marsh vegetation enhances sedimentation by slowing the water flow, and ORV disruption of these grasses would tend to thwart siltation. The net impact of ORV disturbance on salt marsh vegetation by creating open sandy areas would still be to increase the infilling of Hatches Harbor because of the large flood dominance of sediment transport. Channels through the marsh should be closed to vehicle use since they create long-lasting problems.

Off-road vehicle traffic on sand flats, exposed at elevations below the low marsh, is rare because of the difficulty of driving on soft, usually wet sand and mud. However, should such use increase, it could create substantial problems for the animals that live in this area and the sea birds that feed on these flats at low tide. Although heavy traffic is unlikely, such areas should be closed, at least for the safety of visitors unfamiliar with the tides.

In summary, it was found that only a few passes of a vehicle in the salt marsh/tidal flat area were sufficient to cause maximum damage. The amount of controlled impacting was much less than normally experienced by the environment on a typical summer day. *Salicornia* plants were destroyed with only 1 to 5 passes; *Spartina alterniflora* by 90 or less; and *Spartina patens* by less than 200. With protection, recovery begins almost immediately. Full colonization of a barren flat by *Salicornia* occurs in two years, with *Spartina alterniflora* increasing significantly in that period as well. The low marsh of *Spartina alterniflora* was severely affected by ORV impact, which produced deep ruts in the peat substrate. The ruts remained after four years, but vegetative recovery was nearly total in that time. The high marsh of *Spartina patens* showed the least ability to recover following total destruction; it may require decades of protection for normal conditions to return. We estimate that given complete protection, the Hatches Harbor area will recover from ORV impacts within 5 to 10 years.

ORV use of salt marshes, intertidal flats, and the marsh/dune border is a severe environmental impact that warrants a complete ban on vehicles in such areas. This environment cannot tolerate even light use by vehicles and therefore should be completely protected. Appropriate interpretation programs should be instituted to educate the public as to the need for protecting the intertidal environment, and the damaging effects that vehicles have in such habitats.

Specifically, we recommend that Hatches Harbor, and all similar regions, be permanently closed to vehicles of all kinds. Traffic through marshes and across tidal flats is unnecessary and can be eliminated with little effect on visitors. This closure should include all access routes to the intertidal zone, particularly the marsh/dune border. Greater enforcement of regulations will undoubtedly be required due to the difficulties in physically closing this sensitive habitat. Bypass routes may be located in the uplands beyond the intertidal areas, but care will be needed to ensure minimal damage in those areas as well.

CONCLUSIONS

Several general conclusions can be drawn from this research. It appears that as environmental stability of certain portions of the coastal ecosystem increases, their sensitivity to ORV stress also increases. Thus, more stable parts are more likely to be damaged by vehicle impacts. Those environments that undergo the greatest physical changes, such as the intertidal ocean beach, appear to have the greatest tolerance to vehicles. Although vegetation is adapted to the severe physical stresses of moving sand, high winds, salt spray, and dessication, they cannot tolerate continuous, mechanized pressures. The rapidly growing beach grass *(Ammophila)* recovers quickly after impacts, where conditions are favorable. However, this vegetation can be totally destroyed by even low-level, continuous ORV pressure.

At least until further research shows otherwise, the best place for vehicles to travel is the open intertidal beach, as long as this traffic does not interfere with nesting areas, embryonic dune regions, or zones with major populations of marine animals. Other than the beach, the only place for vehicles to travel, where environmental impact can be kept to a minimum, is through the dunes along specifically marked and well-maintained trails with a minimum of steep grades or sharp turns. Sand transport down dune slopes can become a problem when heavy traffic is allowed to follow the same paths for a long period; dune areas can be lowered and also rendered more unstable by indiscriminate traffic. When such trails must be closed, revegetation can be promoted by fertilization or planting projects.

Those upland sites that have been stable for some time and support heathland or low shrub vegetation are the most easily damaged. *Hudsonia* (beach heather) vegetation was particularly susceptible to impact and took the longest time to recover. Every attempt should be made to prevent vehicle travel across these communities.

Intertidal salt marshes and sand flats are also very sensitive to vehicle damage. Traffic in the low marsh will create deep, long-lasting ruts, leading to man-made pannes. On the high marsh, excessive traffic will damage the vegetation and also lead to open flats and sand channels. The problem is especially acute at the borders of the high marsh and dunes. All salt marshes should be closed to vehicle traffic.

Sand flats are important precursors of new salt marshes. Where vehicles are allowed to travel, marsh expansion onto the flats will be inhibited. Those open areas beyond the limit of salt marshes are improtant habitats for marine infauna, particularly worms, clams, and other mollusks. Vehicle traffic, even at relatively low levels, compacts the substrate into a pavementlike surface and reduces survival of infauna. Tire pressure on the sand surface can also directly kill the animals living in the sediment, especially soft-bodied creatures and soft-shell clams. Sand flats, along with marshes, are therefore especially sensitive to vehicle damage and should be completely protected.

Nesting sea birds can coexist with vehicles on a beach as long as the vehicles stay outside marked nesting areas. Birds are more likely to fly off their nest when people or pets approach on foot. Vehicles passing directly through nesting areas obviously destroy nests and chicks, but this has been less of a problem than pedestrian traffic. Birds will acclimate to the passage of ORVs and remain on their nests as long as people stay in their vehicles. Feeding shorebirds can be affected when vehicles pass through their feeding sites, especially at times of high tide. In general, birds can tolerate human use, either in nesting areas or feeding zones on the beach or sand flats, as long as disturbance is kept to a minimum.

The best way to avoid vehicle problems is to prevent their entry into previously closed regions. Wherever possible, provide public transportation to inaccessible areas. A series of interpretive displays should be used to show how vehicles damage the environment. Such information can help visitors understand why certain areas should be closed or controlled. The public is much more likely to support such actions when they understand they are in their best interest.

The best general management approach is to maintain a conservative program regarding vehicle use. Management plans should be based on sound scientific information whenever possible. When such data are lacking, the ORV plan should err, if it must, on the conservative side. Maintaining the critical balance between public use of coastal recreation areas and protection of the resources requires that all sections of the interested public be involved. This is a very difficult task, but one that can be accomplished with the help of basic data and public understanding of that information.

It is also important that scientific data be gathered individually for each region. Applying information acquired on the northern beaches of Cape Cod to all coastal areas is fraught with hazard. Although some broad generalizations might be made, it is essential that each region be examined in detail for proper tailoring of the management program.

APPENDIX A

LIST OF PRODUCTS RESULTING FROM CONTRACT
NPS-CX-1600-5-0001

I. Technical Reports (UM-NPSCRU)

6. *Ecological effects of off-road vehicles in Cape Cod National Seashore, Massachusetts, preliminary report*. P.J. Godfrey, J. Brodhead, H. Walker, J. Gilligan, and A. Davis. 1975.

7. *A preliminary report on the geomorphic effects of off-road vehicles on coastal sytsems*, A.W. Niedoroda and R. Limeburner. 1975.

17. *Geomorphological effects of ORVs on coastal systems of Cape Cod, Massachusetts*. A.W. Niedoroda. 1975.

18. *The ecological effects of off-road vehicles in Cape Cod National Seashore, Massachusetts (Phase II)*. P.J. Godfrey, J. Brodhead, J. DiMaio, J. Gilligan, D. Reynolds, B. Blodget, and N. Wheeler. 1975.

26. *The effect of off-road vehicles on least terns and other shorebirds*. Bradford G. Blodget. 1978.

27. *The preparation of an off-road recreational trail map of the Province Lands, Cape Cod: Procedures, observations, and management suggestions*. Mark A. Benedict. 1978.

28. *Effects of off-road vehicles on the infauna of Hatches Harbor, Cape Cod National Seashore*. Nancy Wheeler. 1979.

29. *The ecological effects of off-road vehicles on the beach/backshore drift line zone in Cape Cod National Seashore, Massachusetts*. Robert Zaremba, Paul J. Godfrey, and Stephen P. Leatherman.

30. *Effects of off-road vehicles on the sediments of Hatches Harbor, Cape Cod National Seashore, Massachusetts*. James Hamilton. 1979.

31. *An Investigation of the effects of vehicular traffic on the beach face*. Stephen P. Leatherman and Linda L. Long. 1978.

32. *Effects of off-road vehicles on coastal dune vegetation in the Province Lands, Cape Cod National Seashore, Massachusetts*. John M.B. Brodhead and Paul J. Godfrey. 1979.

33. *Effects of off-road vehicles on plants of a northern marsh, final report, 1974-1977.* John M.B. Brodhead and Paul J. Godfrey. 1979.

34. *The impact of off-road vehicles on coastal ecosystems in Cape Cod National Seashore: An Overview.* Stephen P. Leatherman and Paul J. Godfrey. 1979.

II. Journal Articles and Conference Proceedings

1. Brodhead, J.M.B., and P.J. Godfrey. 1977. Off-road vehicle impact in Cape Cod National Seashore: Disruption and recovery of dune vegetation, *Intern. J. of Biometeor.* 21:299-306.

2. Godfrey, P.J. 1976. Recreational impact on shorelines -- research and management. In Proceedings of Conference on Recreational Pressures in an Urbanizing Coastal Environment, Hyannis.

3. Godfrey, P.J., S.P. Leatherman, and P.A. Buckley. 1978. Impact of off-road vehicles on coastal ecosystems. In Proceedings of the Symposium in Technical, Environmental, Socioeconomic and Regulatory Aspects of the Coastal Zone, San Francisco, pp. 581-600. 1978.

4. Leatherman, S.P. Effects of off-road vehicles on the geomorphology of dunes in Cape Cod National Seashore. In proceedings of the First Conference on Scientific Research in the National Parks, New Orleans, pp. 1119-1124.

III. Academic

1. M.S. Degree in Forestry and Wildlife Management: Bradford G. Blodget, "The effect of off-road vehicles on Least Terns and other shorebirds," 1977.

2. M.S. Degree in Zoology (Marine Sciences): Nancy R. Wheeler, "Off-road vehicle (ORV) effects of representative infauna and a comparison of predator-induced mortality by *Polinices duplicatus* and ORV activity on *Mya arenaria* at Hatches Harbor, Provincetown, Massachusetts," 1978.

3. .S. Degree in Geology: James A. Hamilton, "The Sedimentation of Hatches Harbor, Cape Cod, Massachusetts," 1978.

4. Ph.D. Degree in Botany: John M.B. Brodhead, "The role of *Spartina patens* as a pioneer species in the development of salt marsh ecosystems in Hatches Harbor, Cape Cod National Seashore, Massachusetts," 1979.

APPENDIX B: PROJECT STAFF

The following is a list of the staff who contributed significantly to this project, their fields of expertise and years of service.

Principal Investigators

S. Leatherman	Coastal geology, Environmental sciences	1976-1979
P. Godfrey	Coastal ecology	1974-1976
A. Niedoroda	Coastal geology	1974-1975

Research Associates

J. Brodhead	Botany	1974-1978
B. Blodget	Wildlife	1974-1977
N. Wheeler	Zoology	1975-1977
R. Zaremba	Botany	1976-1978
J. Hamilton	Geology	1975-1977
M. Benedict	Botany	1976-1977

Research Assistants

H. Walker	Biology	1974-1975
D. Reynolds	Biology	1974-1975
R. Limeburner	Geology	1974-1975
J. Gilligan	Microbiology	1974-1976
J. Di Maio	Botany	1974-1976
D. Elmer	Botany	1974-1975
W. Carey	Geology	1975-1976

Research Assistants (Continued)

T. Clough	Wildlife	1974-1975
L. Long	Geology	1976
J. Beskenis	Limnology	1974-1975
M. Kottas	Botany	1976
A. Davis	Botany	1974
P. Johnson	Geology	1974
E. Jones	Botany	1976
D. Smith	Wildlife	1976
M. Yates	Biology	1976

Office Staff

D. Owen	Editor	1977-1979
H. Swartz	Editor	1976-1977
B. Fullington	Editor	1974-1975
S. Klingener	Admin. Asst.	1974-1978
R. Nathhorst	Coordinator	1974-1976
S. Swartz	Technician	1974-1976

APPENDIX C: BIBLIOGRAPHY ON THE EFFECTS OF OFF-ROAD VEHICLES ON COASTAL ECOSYSTEMS

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