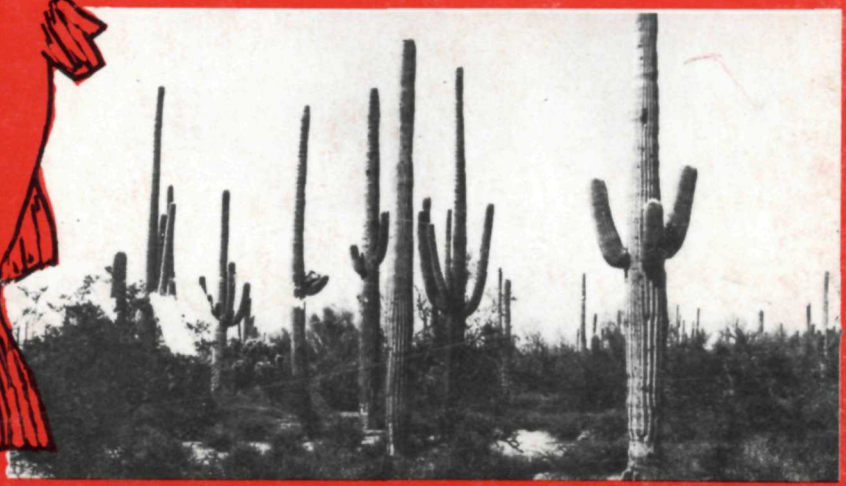
Research in the Parks



Research in the Parks

Transactions
of the National Park Centennial Symposium

Annual Meeting of the
American Association for the Advancement of Science
28 and 29 December 1971

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE SYMPOSIUM SERIES • NUMBER ONE • 1976

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Library of Congress Cataloging in Publication Data
Main entry under title:

Research in the parks.

(Proceedings series—National Park Service; no. 1)
Includes bibliographies and index.
1. National parks and reserves—United States—Congresses. 2. Natural history—United States—Congresses. I. Reid, Neil J. II. Series: United States. National Park Service. Proceedings series—National Park Service; no. 1.
SB482.A4R47 639'.9'0973 75–619179

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Foreword

The year 1972 marks the centennial of an idea-come-to-life in the form of the establishment of Yellowstone National Park. There can be no question but that the *idea* emerged, submerged, and re-emerged many times throughout recorded history—that a place, because it possesses such importance or grandeur, be set aside essentially as Nature created it for the use and enjoyment of a particular group of people. In this respect, Yellowstone was a culmination of evolving thought. Since Yellowstone's establishment, however, some 1200 or more national parks and equivalent natural area reserves have been established "for the people" throughout the world, in an ever-evolving concept that makes it increasingly possible for all people to partake in the magnificence of earth. In this latter respect, Yellowstone's establishment was a quantum leap toward a true earth culture.

The past 100 years have witnessed more than the establishment of natural area parks, of course. The technological advances in communication, transportation, and information processing that have emerged have been astounding—quite beyond the comprehension of the creators of Yellowstone in 1872. Technological advances and population increases have combined to bring trampling, pollution, smog, exotic plant and animal introductions, congestion, and a host of other immense problems to many national parks and natural areas. The goal of maintaining a national park in those ecological conditions that would now prevail were it not for the advent of modern technological society—i.e., in a "natural condition"—becomes possible only if modern science and technology are employed to counteract the problems wrought by technology and population increase.

Science was first employed in an organized way in the 1930s to combat the problems in national parks. That first effort possessed high ideals, high hopes, high quality, and high potential. The *fauna of the National Parks* series began at that time, attesting to the productivity of the fledgling group of scientists. Then, George Wright's death and later World War II brought a close to effective science in the national parks for over two decades.

The 1960s brought renewed alarm about the condition of national parks: long-established practices of extinguishing all wild fires; fighting naturally-occurring diseases, parasites, and insects; baiting large mammals into view for the visiting public—all produced an artificiality quite in opposition to the goal of naturalness. In the decade since, a great deal has been learned about methods and means of maintaining natural ecological systems, and these are now being applied as rapidly as possible to correct past misunderstandings and present use pressures.

The papers in this volume attest to the quality and sincerity of this most recent effort to utilize science and technology in the formulation of a management philosophy and in the development of management practices for the Nation's national parks. Yet, this effort is but a beginning of what must inevitably come to be.

Houghton, Michigan
March 1976

Robert M. Linn

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Another Look at Man, Nature, and National Parks

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Four years ago Frank Fraser Darling and Noel Eichhorn presented us with their thought-provoking publication entitled *Man and Nature in the National Parks* (Darling and Eichhorn 1969). I regret that Sir Frank cannot be here to address you once more on this same topic and give you the benefit of his further thoughts and experiences in this field. However, I will try to carry on in his footsteps, although his strides were long indeed.

In the foreword to the second edition of his publication, Fraser Darling noted that his words were not "new or unappreciated by the National Park Service" but rather that their value lay in the formulation of ideas that were ready to be expressed by the service. We know that many of the recommendations of Fraser Darling and Eichhorn have already become realities, and this symposium is an indication of the progress that has been made in the area of research. They said things that needed saying 4 years ago and still need repeating for, in most of the world, their words have not yet been heard.

I will attempt to extend the thinking expressed in *Man and Nature in the National Parks* to the parks of the world. In this effort I will also not be saying anything new or previously unappreciated but rather trying to reflect the thinking in International Union for Conservation of Nature (IUCN) and other international organizations concerned with similar problems.

The national park idea, as such, had its origins in the United States over 100 years ago. The first national park to be protected by the Federal Government was Yellowstone, which now approaches its centennial celebration. Yosemite Valley, of course, preceded it, but it was administered initially as a state park. The idea of natural reserves was not new a century ago, but the national park concept, as it was formu-

lated in America, had a vitality and appeal that caused it to be adopted by other countries. Today there are over 1200 protected areas around the world that are somewhat similar to the American idea of a national park (IUCN/ICNP 1971). I say "somewhat similar" since the American national parks are not the same as those of other countries, and the confusion in terminology and purpose is one of the themes to which this paper is addressed.

What is a national park? All of us have ideas based on experience in the United States and perhaps a few other countries. But if we look at the world spectrum, our ideas may be shaken. I will refer first to some of the definitions and considerations provided for IUCN by Jean-Paul Harroy (IUCN/ICNP 1971). The first is that accepted by IUCN in its General Assembly in New Delhi in 1969.

A national park is or should be: (1) a relatively large area; (2) where one or several ecosystems are not materially altered by human exploitation and occupation; (3) where plant and animal species, geomorphological sites, and habitats are of special scientific, educational, and recreational interest or which contains a natural landscape of great beauty; (4) where the highest competent authority of the country has taken steps to prevent or eliminate as soon as possible exploitation or occupation in the whole area and to enforce effectively the respect of ecological, geomorphological, or esthetic features which have led to its establishment; and (5) where visitors are allowed to enter, under special conditions, for inspirational, educational, cultural, and recreational purposes.

Furthermore, we find that governments are requested not to designate as national parks: (1) scientific reserves which can be entered only by special permission; (2) a natural reserve managed by a private institution or a lower authority without some type of recognition and control by the highest competent authority of the country; (3) a special reserve—fauna or flora, game, bird, geological, forest; and (4) an inhabited and exploited area where landscape planning and measures taken for the development of tourism have led to the setting up of "recreation areas" where public outdoor recreation takes priority over the conservation of ecosystems (nature park, Naturpark, parc naturel regional).

Next we find further restrictions, including: (1) a statutory basis giving sufficiently strict protection; (2) a certain minimum size; and (3) adequate staffing and an adequate budget for maintenance and protection.

Further, we note that the London Convention of 1933 and the Washington Convention of 1940 specifically rule out "hunting, killing or capturing of fauna" and "destruction or collection of flora" except

under "direction and control of park authorities." Exploitation for commercial profit is forbidden.

Unfortunately, if we take these criteria and attempt to apply them strictly even to the *United Nations List of National Parks and Equivalent Reserves*, we find that their strict application would rule out many of the world's most famous national parks (IUCN/ICNP 1971).

Thus the United States parks would not necessarily qualify since, among other things, they permit the "killing and capturing" of fauna by the general public without the clear direction and control of park authorities. I refer of course to the killing of fish which as a biologist I must insist are animals and part of the fauna. Fishing may indeed be as Fraser Darling and Eichhorn have described it: "one of those outworn privileges in a national park." I would not necessarily put it in that category, but reserve the right to view it as the equivalent of hunting.

Germany has no national parks that fit these criteria. Even France's best, La Vanoise, must be ruled out because of hunting and agricultural privileges which persist. The famous Zaire parks, which were treated in the past as strict nature reserves, would not have qualified because of this. Australia's parks are not national, but state, and one could quibble over this since the rules may vary from state to state. None of Great Britain's national parks as such will qualify since they are used for a variety of purposes including settlements and agriculture.

I believe in some ways the term national park has become too overladen with emotional connotations and national legal definitions. It is not a useful term to work with. Rather, I would prefer to ask "what are we trying to accomplish?" Thus we can try to get away from some of those difficult to analyze phrases such as "parks are for people" and also avoid some of the scars left by past battles. In consequence, I would leave the definition of national parks untouched, perhaps as representing a goal toward which nations may strive, and talk instead about reserves.

Why do we want to set aside areas of land and provide them with protection in a certain state? There are several goals that need to be examined. Thus, we may seek: (1) to protect natural communities and wild species; (2) to protect outstanding natural landscapes, scenic wonders, and geological formations; (3) to preserve certain man-made structures or formerly occupied sites, and their settings, for their anthropological, archeological, or historical interest; (4) to maintain landscapes of unusual charm or value created by man particularly in view of the disappearance of those ways of life responsible for their creation; and (5) to provide opportunities for people to develop an understanding of the values of the above and to enjoy outdoor recreation in natural surroundings.

CLASS I: NATURAL RESERVES

These are general goals, but some of the more specific reasons for protection need stressing. Thus, under the heading of protection of natural communities and wild species there are scientific and esthetic values to be derived from: (a) the preservation of ecosystems in conditions unmodified by man to the fullest extent that this is possible. Such ecosystems need to be allowed to progress through natural succession including increases and die-offs of animal populations and the loss of certain vegetation. Wildfires, storms, diseases, insect plagues, and the like would need to be allowed to operate unchecked; (b) the preservation of various ecosystems or animal species that require disturbance and management for their perpetuation, as, for example, open pine savannas or successional forms of wildlife. These may require cutting, mowing, grazing, burning, water table manipulation, reduction or introduction of animals, etc., for their perpetuation; and (c) certain rare or endangered species of plants or animals likely to disappear without intensive protective or management measures including the removal of competitors or predators, and the creation of more desirable habitats. Under the heading related to people and recreation, there are special requirements for: (a) wilderness enjoyment, which requires the absence of large numbers of other people and of obvious signs of human interference with the landscape; (b) enjoyment of natural scenery, vegetation, and animal life in an outdoor setting by people unwilling or unable to undertake arduous wilderness travel, and (c) the need to provide outdoor centers for mass recreation including skiing and other winter sports, water sports of various kinds, feeding and transporting people in the areas selected for these activities.

Virtually all of the above goals and their special requirements are being pursued throughout the world in areas designated as national parks or by some equivalent term. I believe they are all appropriate to such areas, and much would be lost if we discouraged such goals and uses. However, confusion and controversy have derived from failure to designate the purposes for which each area has been set aside.

As a means for reaching some solution to a classification of national parks and equivalent reserves, I would like to propose two general categories: (a) natural reserves and (b) cultural reserves; and to examine their purposes and the implications of management directed toward these purposes.

These are areas of national importance having as their primary purpose the protection of nature. The natural features to be protected may include geological or geomorphological features; landscapes of special interest which combine physiographical and vegetational aspects; natural communities made up primarily of indigenous species of plants and

animals; or various combinations of these. The areas selected may be outstanding in beauty or scientific interest or they may be equally representative of natural ecosystems that are, or once were, widespread. A reserve in this class may include one or more of each of the following categories:

I.A. This is an area set aside for its scientific, esthetic, or ecological values, with the latter considered to include the contribution it may make to the stability of productivity of other areas such as in a strictly protected watershed reserve. Such an area is to be maintained in an unmodified condition, or one approaching as closely as possible to this as can be achieved. Such areas should be allowed to develop without human interference even where this may involve their modification by naturally occurring fires, insect plagues, or diseases.

Use of such reserves needs to be severely restricted. Scientific study would be encouraged but it, along with any other use, must be compatible with maintaining the area in an undisturbed state. Any use for scientific, educational, or recreational purposes would necessarily require approval by the reserve administration in pursuance with the recommendations of a scientific, advisory committee.

I.B. This is an area set aside to protect a species, biotic community, or a physical feature of the environment, usually where these are of a rare or endangered category requiring specific management measures for their perpetuation. The vegetation, animal life, or terrain in such an area may be managed and modified to afford maximum encouragement or protection to the features of particular concern, including removal of competing vegetation or animal life. Use of such an area for scientific or other purposes will depend on the requirements for protection decided upon by an appropriate advisory body, and may be more or less restricted than in *I.A.*, and subject to the same approval.

I.C. This is an area set aside to provide a limited amount of recreation within a natural setting in which the visible interference of man is held to a minimum. Protection of wild nature remains the primary purpose, with recreation secondary to this requirement. However, development of hiking trails, primitive campgrounds, marked waterways, cross-country ski routes, and similar minor modifications is appropriate to such an area. Suppression of fires, disease outbreaks, or insect plagues, where this is recommended by appropriate advisory authorities, would be permitted in such an area. In general, however, the development of roads, firebreaks, buildings or elaborate campgrounds, and similar modifications of the wilderness character of the area are inappropriate.

Use by the public of motorized transportation or recreational equipment would not be permitted. Such equipment may be used by administrative personnel when this is deemed essential. Limitations on public use to prevent excessive numbers of people from visiting the area at the same time are appropriate.

I.D. An area set aside to protect natural environments that may require active modification and management for their perpetuation, and that are made available for appropriate public use. In general, limited development of roads, trails, campgrounds, lodges, and other visitor facilities consistent with the protection of the natural features of the area would be permitted. Small areas may be devoted to intensive development to accommodate tourism, intensive outdoor recreational facilities (e.g., for winter or water sports), or the installations required for the administration and management of the reserves where it is not feasible to locate these outside the reserve. In such reserves activities of a wide range may be permitted insofar as they are consistent with maintaining the natural features that the reserve serves to protect. Under the direction of the reserve authorities and with appropriate scientific advice, these may include cutting, moving, burning, or other removal of vegetation, or its grazing by domestic animals and the killing, trapping, or removal of animal life. These activities may either be carried out by the park authorities or by the public under appropriate supervision.

CLASS II: CULTURAL RESERVES

Areas of national importance having as their primary purpose the protection, from development or destructive alteration, of sites modified by man that are considered to have anthropological, archeological, or historical importance, high esthetic value, or other cultural or scientific importance. These may include various agricultural, pastoral, or other landscapes modified by man, with the exotic or domesticated species appropriate to them. They may also include sites surrounding and including buildings or other structures, villages, towns, or cities. Activities encouraged or permitted in these areas are those appropriate to maintaining their natural or man-made features. Viewing or visitation by the public will normally be encouraged under special safeguards for the areas concerned. Where appropriate, farming, pastoral activities, or other occupancy of the protected sites will be carried out, but changes in land use or other alteration in the nature and character of the area would normally not be permitted.

These reserves may be variously classified—obviously Mesa Verde National Park, The Lake District National Park of the United Kingdom, and Angkor in Cambodia cannot all fit in one category—however, I will not attempt to do so at this time.

GENERAL CONSIDERATIONS

The size of any reserve shall be appropriate to the preservation of its natural or cultural features. To protect certain cultural or geological features only a small area may be required. For other purposes, such as the protection of far-ranging animals or representative areas of highly variable vegetation, areas need to include many thousands of square miles.

The ownership of the land within the reserve need not be specified. It is essential, however, that the tenure of the reserve be guaranteed for the longest possible time through appropriate legal measures and that the reserve be managed and administered by a competent agency in accordance with its specified objectives.

Staffing and budgetary requirements for reserves will vary with conditions. An *I.A.* reserve in a remote area may require no permanent staff and could be managed at little or no expense, although this would be an exceptional condition. Heavily visited *I.D.* reserves will require large numbers of managerial personnel and a high budget for administration and management.

Areas not considered as suitable for designation in the foregoing categories include those primarily developed for outdoor recreation in which nature conservation is secondary. Those used primarily for the production of renewable resources, including production forests, rangelands managed primarily for livestock grazing, areas intensively managed to increase water yield, areas managed intensively for the production of wildlife or fish to satisfy demands for commercial or recreational hunting or fishing, areas used or to be used primarily for mineral or fuel exploitation, agriculture, residential, commercial, transportation, or industrial purposes, are all not suitable to be designated as natural or cultural reserves.

Obviously, any or all of the foregoing categories of reserves may be designated as a national park or equivalent reserve, and in many parts of the world they are so designated. Larger national parks may include several or all of these categories, but it is important that each of their boundaries be marked and the purpose of each area clearly specified to avoid confusion in regard to their use or management.

In this presentation I hope I have been responsive to questions raised by Fraser Darling and Eichhorn. You may recall that they progressed from the general question of "what is a national park for?" to the specific question of "what is this national park for?". I believe, as they did, that by addressing oneself to the question of the purpose for which an area is to be protected we avoid the immediate issue of the uses of the area. By this approach, uses to be permitted are those consistent with the purpose. Certain uses may well be ruled out for traditional,

emotional, or sentimental reasons, for convenience of administration, or for protection of the visiting public. Public hunting is an example. However, we should be clear of our grounds. There is no basis for ruling out public hunting, under proper control, on the grounds of protecting common animal species that occur in widespread natural communities.

I have attempted to recognize those realities of life revealed in the *United Nations List of National Parks and Equivalent Reserves*. Thus, for example, the national parks of Great Britain fall into the Class II of the cultural reserves, whereas the national nature reserves belong in various categories of Class I natural reserves. France's national game reserves, in which hunting is permitted, would fall in the category *I.D.* The *Naturschutzpark* and *Naturschutzgebiete* of Germany would similarly be placed in *I.D.* or would combine *I.D.* with Class II.

United States national parks represent, often within a single park, a wide range of conditions from de facto *I.A.* to the more general *I.D.*, or in many instances to Class II cultural reserves. Many other areas in the United States, however, need to be considered as equivalent to national parks. Among these are the Adirondacks Forest Preserve of New York or the very large Anza Borrego Desert State Park of California. Wilderness areas in national forests or under other administration fall clearly into *I.C.* Many national wildlife refuges will belong in *I.B.* I do not suggest that these all be termed "national parks" but only that they are clearly "equivalent reserves."

Although it may seem that many strange horses have come through the barn door labeled "national park or equivalent reserve," I propose that the responsibility for administering the various categories of natural and cultural reserves for the primary purpose of protection of nature or of cultural sites places a heavy burden on national park authorities. The questions of how to perpetuate a species, community, or landscape are not easily answered and many activities now permitted in the national parks of America are probably not consistent with the protection of nature or other values in the areas where they take place. It is clear that the research to reconcile management and use with the goals and purposes of the area concerned needs to be increased. Other chapters in this book indicate quite clearly that progress is being made even beyond the question of "what is this national park for?" to the greater specificity of "how do we protect this species?," "how do we maintain this natural community?" or "what use is appropriate to this area?" I express the hope that when the answers to these questions have been provided by research, they will be applied as quickly as possible to the management of national parks.

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Research on Ungulates in Northern Yellowstone National Park

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The northern winter range of Yellowstone National Park contains about 204,000 acres, supports six species of native ungulates with their complement of predators and scavengers, and is, in short, an ecological gem unmatched for this assemblage of species. Current research is designed to test hypotheses which relate to ungulate habitat relationships, biotic succession, and ecological homeostasis. Special emphasis has been placed upon the elk (*Cervus canadensis*) as the most abundant ungulate and because of the history of concern and controversy surrounding this species. I present here a review of the research approach and some preliminary results.

The primary purpose of Yellowstone National Park, as a natural area, is to maintain a representative ecosystem in as near pristine conditions as possible. Management of the park ecosystem generally involves preventing or compensating for modern man's altering of natural ecological relations. Criteria for management of a national park must therefore differ from criteria for other uses of land. The mission-oriented research in parks often involves documenting pristine conditions and processes, determining the completeness of park ecosystems, and developing management procedures to maintain or restore the ecosystem (Houston 1971a).

This is a fair description of the studies being conducted on the northern winter range and research hypotheses have been developed to guide problem definition and analysis. The major concern in posing hypotheses was that they be capable of being tested and rejected, and I have not always used a formal null form (Ghent 1966). Stating hypotheses capable of unequivocal support or rejection is a problem in ecology, and I suspect that those being used to guide this research program could generate lively discussions on the basis for rejection, the

separation of causes from effects, the possibility of circular arguments, etc. Some of the hypotheses lend themselves to experiment; others must be tested using the method of successive approximations described by Poore (1962). Many of the hypotheses being tested are based upon results from other studies of ungulates that have been conducted in parks of the Rocky Mountain area since 1962. These have recently been reviewed by Cole (1971a).

HYPOTHESES CONCERNING HERBIVORES

The "northern range" extends down the elevational gradients of the Yellowstone and Lamar rivers from about 8500 to 5000 ft. The range within the park is contiguous with additional acreage on the Gallatin National Forest, making an overall total that approaches a quarter-million acres. Winter distribution and densities of ungulates along this elevational gradient are fluid, and appear to be influenced by severity of environmental conditions, population size, and various behavioral interactions. Although some ungulates occur on the area as year-long residents, highest densities occur during November-April periods.

An analysis of census data obtained from 1929-61 led to the hypothesis that the northern elk herd might be divided into a "migratory segment" that wintered in the lower portions of the Yellowstone River drainage both inside and outside of the park, and a "resident segment" that stays within the upper portions of the Yellowstone and Lamar river drainages (Fig. 1) even during severe winters (Cole 1969). The division between segments is tentative, but present studies suggest that 3000-4000 elk may occur in the postulated resident segment (Table 1). Research designed to test the hypothesis that the resident segment occurs on "ecologically complete habitat" and will be "naturally regulated" was initiated in 1968 when the periodic artificial regulation (involving trapping and shooting) was terminated. Natural regulation of ungulate populations has been defined as regulation of numbers without human influence (Cole 1971a). The actual mechanisms involved in natural regulation are difficult to document, but appear to be primarily due to the effects of density-influenced intraspecific competition for winter forage and the partially density-independent effects of severe weather on mortality and natality. Ecologically complete habitat for elk appears to consist of complexes of physiographic sites with interspersions of vegetation types that provide contingencies to obtain forage and maintain relatively stable populations in variable and periodically harsh environments (Cole 1971a).

The hypothesis for the natural regulation of elk will be evaluated by analyses of accumulated data on rates of natality and mortality, sex and age structures, historical records, and by conducting regular distribution

TABLE 1. Research hypotheses being tested on herbivores, carnivores, and vegetation on the northern winter range of Yellowstone National Park.

Hypotheses:	Methods of evaluation:	Basis for rejection:
HERBIVORES		
I. Upper Yellowstone winter range is ecologically complete habitat (ECH) for a resident segment of 3–4000 naturally regulated elk.	1. Historical records.	1. An elk population eruption.
	2. Census and distribution counts.	2. Retrogressive plant succession.
	3. Analysis of sex and age structures and of natality and mortality.	3. Trends toward competitive exclusion among population of sympatric herbivores.
A. Density dependent homeostatic mechanisms will result in natality + immigration = mortality + emigration.		
II. Lower Yellowstone winter range will support a migratory segment of 3–5000 elk that can be managed by public hunting conducted outside park boundaries.	1–3 above.	4. Artificial concentrations of elk along the boundary within the park resulting in one or more of 1–3 above.
	4. Evaluation of a variable quota hunting system.	
A. Management by hunting will not cause artificial concentrations of elk within the park.		
III. Natural regulation and management of segments of the northern elk will not result in competitive exclusion of sympatric herbivores because of interspecific competition.	1–3 above.	5. Trends toward competitive exclusion of sympatric ungulates as a result of 1, 2, or 4 above.

TABLE 1. Research hypotheses being tested on herbivores, carnivores, and vegetation on the northern winter range of Yellowstone National Park.—Continued

Hypotheses:	Methods of evaluation:	Basis for rejection:
A. Sympatric herbivores will be naturally regulated—i.e., artificial regulation of populations will be unnecessary.		6. Population eruptions among sympatric herbivores.
CARNIVORES		
IV. Densities of predators and scavengers will increase in response to increasing food supplies from having a naturally regulated elk population.	1. Monitor sightings and sign of predators and scavengers.	1. No measurable population reponses among carnivores.
	2. Historical records.	2. Failure to demonstrate dampening or extension of intervals between population fluctuations.
V. Predation is an assisting but nonessential adjunct to the regulation of ungulate population size.	3. Analysis of predator-prey relationships.	
PLANT COMMUNITIES AND HABITAT RELATIONSHIPS:		
VI. Vegetation on the winter range does not depart from natural conditions, or departures have not resulted from grazing by native ungulates (boundary line area excepted).	1. Analysis of historical photos.	1. Photos or measurements showing retrogressive plant succession—i.e., "range deterioration."
	2. Measurements of density, condition, and composition of vegetation.	

Hypotheses:	Methods of evaluation:	Basis for rejection:
A. Native free-ranging ungulates on ECH do not have a capacity to progressively deplete food supplies that ultimately determine their own densities.	3. Studies of ungulate habitat use.	
1. Low densities of herbaceous vegetation on limited ridgetop sites represent naturally occurring "zootic climax" vegetation.	1–3 above.	2. Enlargement of such sites and retrogressive succession.
2. Replacement of willow and aspen communities do not represent retrogressive succession.	1–3 above.	3. Documented evidence of retrogressive succession.
	4. Comparison of successional changes within Yellowstone NP to changes in outside areas.	
B. Natural fires were a major influence in development of vegetation and changes in vegetation reflect change in fire frequency.	5. Historical photos.	4. Failure to obtain predicted vegetative change as a result of allowing natural fires to burn.
	6. Analysis of fire-scarred trees.	
	7. Allow natural fires to burn.	
C. Climatic changes have occurred and have influenced changes in vegetation.	8. Analysis of neoglacial stades.	
	9. Analysis of weather records, including dendroclimatology.	5. Failure to demonstrate changes in precipitation and temperature.
	10. Analysis of vegetation measurements.	

TABLE 1. Research hypotheses being tested on herbivores, carnivores, and vegetation on the northern winter range of Yellowstone National Park.—Continued

Hypotheses:	Methods of evaluation:	Basis for rejection:
VII. Vegetation within 1–3 miles of the north boundary does not depart from natural conditions, or departures have not resulted from the grazing of native ungulates.	11. Historical photos. 12. Analysis of historical human uses of the area. 13. Analysis of climate, fire history, and soils. 14. Studies of past and present patterns of habitat use by ungulates. 15. Comparisons of successional changes with areas outside the park.	6. See text.
A. Reduction in dense stands of big sagebrush represented retrogressive succession.		
B. Reduction in big sagebrush represented accelerated primary succession.		
C. Presence of big sagebrush represented retrogressive succession and its reduction represents a return to pristine conditions.		
VIII. Vegetation on spring, summer, and fall ranges does not depart from natural conditions.	16. Analysis of records and photos. 17. Studies of seasonal habitat use by ungulates.	7. Documented evidence for retrogressive plant succession.

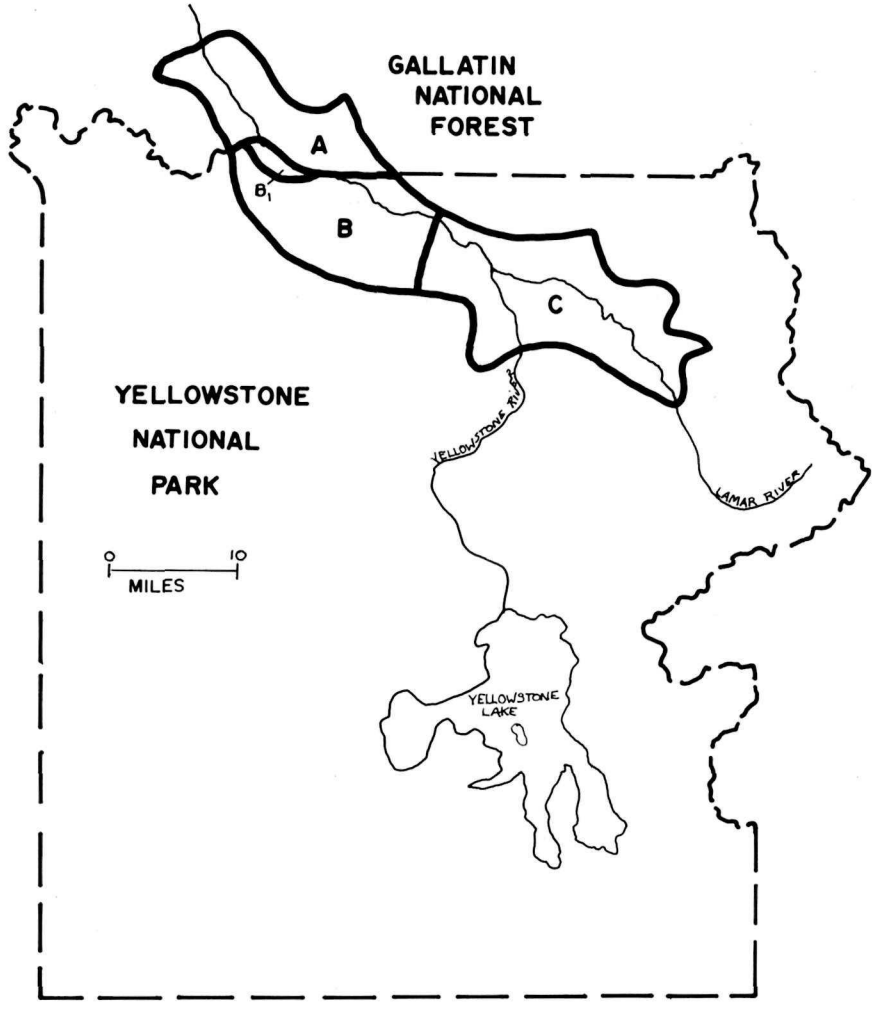

Fig. 1. Map of Yellowstone Park showing the northern winter range divided into postulated areas for resident elk segment (C) and migratory segments inside (B) and outside (A) the park. Area B_1 is the "boundary line area" described in text.

and census counts. The basis for rejecting the hypothesis would be departures from natural conditions in interspecies homeostasis which resulted from an elk population eruption (Caughley 1970), retrogressive plant succession, or trends toward competitive exclusion among populations of sympatric native herbivores.

As shown in Table 1, the use of historical records and photographs is an important means of evaluating departures from natural conditions. A major project has been to assemble and interpret this reference information. Yellowstone has a wealth of historical information, most of which has not been used in this manner (M. Meagher, pers. comm.). It has become apparent that, without this background framework, any assessment of problem situations can be little more than personal judgments which may vary with the training and experience of individuals.

As part of this project I have reviewed over 200 publications, reports, etc., in an attempt to provide historical perspective on numbers and distribution of the northern elk herd. Narrative accounts from 1877 support the concept of the postulated resident segment for the northern herd. This review has not supported the reports of a population eruption and crash in the early decades of this century which seem to be entrenched in the literature of the northern herd. The reported population eruption appears to have resulted in part from changing the definition of the northern herd, and from the methods employed in early censuses and in calculations of increase rates. The northern herd has variously included elk wintering on the Gallatin, Madison, Firehole, and Shoshone rivers, in addition to those on the Yellowstone and Lamar rivers (the current definition). This apparently has not been previously recognized. The population crash appears to have been suggested in an administrative report as an explanation for the discrepancy between counts and calculations, and has subsequently been accepted as factual (Houston 1971b).

Historically, some portion of the migratory segment of the northern herd has moved beyond park boundaries during severe winters, which suggests that the lower range within the park does not represent an ecologically complete habitat. These elk are periodically available to be managed by public hunting conducted outside park boundaries. Present management objectives will test the hypothesis that it is possible to maintain the migratory segment in a 3000-5000 animal range by using public hunting, and that hunting will not result in conditioned avoidance behavior among elk, which in turn would cause unnatural concentrations within the park. The proposed variable quota hunting system, where allowable removals can fluctuate annually from 0 to 2500 elk, depending upon fall herd sizes and the numbers migrating outside park boundaries, has been described in detail elsewhere (Cole 1969).

Elk occur sympatrically on the northern range with populations of

mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), pronghorn (*Antilocapra americana*), bison (*Bison bison*), and a variety of smaller herbivores. The hypothesis concerning sympatric herbivores will test the concepts that the natural regulation or effects from hunting the different segments of the elk population will not result in competitive exclusion because of interspecific competition, and that populations of herbivores associated with elk will also be naturally regulated.

The entire northern elk herd probably numbered less than 4500 at the termination of artificial reductions in 1967-68. Calculations suggest that 8500-9000 elk should occur in the 1971 fall herd. The elk population is approaching levels where these hypotheses will be tested, but it would be premature to reject, modify, or claim support for them from ongoing field studies. Tentative support for several hypotheses has been provided from historical records.

HYPOTHESES CONCERNING CARNIVORES

Herbivores of the northern range support a complement of predators and scavengers which include the grizzly bear (*Ursus arctos*), black bear (*U. americanus*), cougar (*Felis concolor*), gray wolf (*Canis lupus*), coyote (*C. latrans*), wolverine (*Gulo luscus*), raven (*Corvus corax*), golden eagle (*Aquila chrysaetos*), and bald eagle (*Haliaeetus leucocephalus*). Except for the historic presence of a low-density population of aboriginal man, this predator-scavenger fauna appears to be largely intact, although gray wolves, cougars, and wolverines occur at very low densities. The hypothesis that predator-scavenger populations will increase in response to increased food supplies as a result of having naturally regulated elk will be evaluated by monitoring sightings and signs (Cole 1971b). A continuing analysis of predator-prey relationships (including rates of predation and scavenging, prey selection, etc.) will be used to evaluate the hypothesis that in a variably harsh environment such as Yellowstone's, predation functions as an assisting but nonessential adjunct to the regulation of ungulate population sizes. The latter is an example of an hypothesis that will be difficult to clearly support or reject. Both hypotheses must be qualified to the extent that population responses among avian scavengers such as eagles and perhaps for the cougar and gray wolf will depend upon the protection these species receive when they move beyond park boundaries.

HYPOTHESES CONCERNING PLANT COMMUNITIES AND HABITAT RELATIONSHIPS

The vegetation on the winter range is primarily a steppe composed of a variety of grassland types, which is intermixed with scattered

coniferous forests. A fundamental hypothesis is that the density, composition, and successional trends of vegetation on the range do not depart from natural conditions, or that departures have not resulted from grazing by native ungulates (Table 1). (I omit the area adjacent to the north boundary from consideration here for reasons discussed below.) The corollary under study is that native ungulates on ecologically complete habitat do not have a capacity to progressively deplete food supplies that ultimately determine their own densities. Stated more specifically, no unnatural effects upon vegetation will result from the natural regulation of the resident segment of the elk population. Support for these hypotheses has been provided by rephotographing over 100 historical photos of the range. This in turn led to the development of subsidiary hypotheses that are more specific and which deal with vegetative conditions or changes that have been of major concern in the maintenance of the park ecosystem. A consideration of written historical records indicated that photos taken from 1871 to the late 1880s provide our best approximation of the pristine conditions. Ungulate populations would have been at pristine levels in the early 1870s; some may have been reduced through hide hunting by the mid-1880s.

A consideration of historical photos (Fig. 2), vegetation measurements, and studies of ungulate habitat use led to the hypothesis that low densities of herbaceous vegetation on certain ridgetop sites represent naturally occurring "zootic climax" vegetation, and do not illustrate retrogressive plant succession. After some preliminary descriptive sampling, I mapped in detail the distribution of those plant communities showing 60% or more bare ground. About 5900 acres were in this condition, and about 1100 of these acres were considered to be overwhelmingly the result of peculiar topoedaphic conditions. The remaining 4800 acres are considered to represent some combination of natural "zootic climax" vegetation and perhaps retrogressed disclimax vegetation adjacent to the north boundary. Given that the area of zootic sites might be underestimated by 25% (because of failure to locate them all), there may be 6000 acres of this vegetation that has been previously considered "overgrazed" and in "poor condition" when the usual range criteria are applied. This represents 3% of the winter range and the historic photos show the presence of these areas 100 years ago. I suggest that the condition of this vegetation does not reflect range deterioration (boundary line area possibly excepted). This represents a fundamental difference from interpretations made in the past.

Space precludes a complete discussion concerning the hypothesis that replacement of willow (*Salix* spp.) and aspen (*Populus tremuloides*) communities on the winter range does not represent retrogressive succession, but instead indicates types of natural primary and secondary

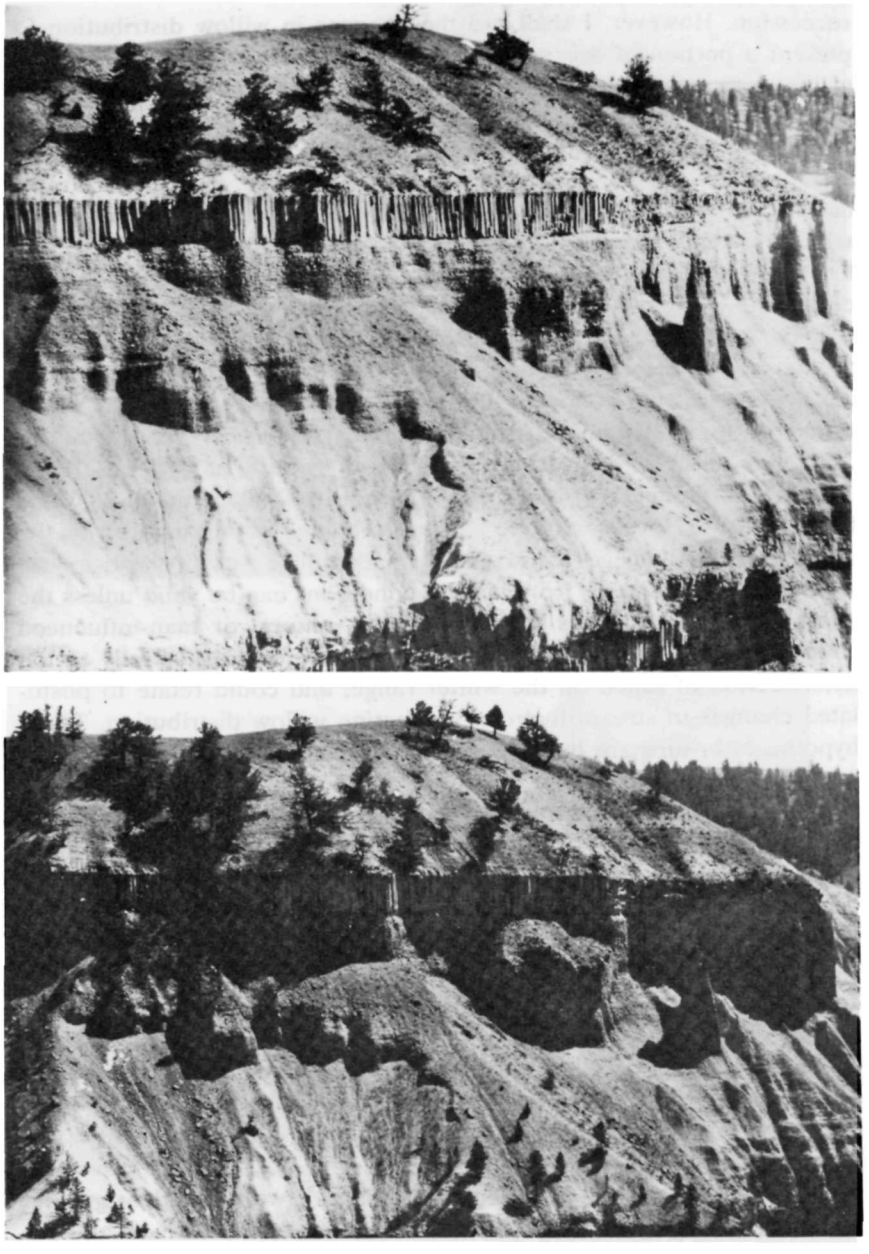

Fig. 2. Northern winter range along Yellowstone River. The westfacing ridgetop receives heavy use by bighorn sheep and elk, shows little change in patterns of herbaceous vegetation after about 86 years, and is considered to be largely a "zootic climax" vegetation. *Upper photo by* J. P. Iddings circa 1885 (USGS No. 142), *lower*. D. B. Houston 1971.

succession. However, I shall use the changes in willow distribution to present a portion of this argument. Photographic evidence shows that willow communities have declined on limited areas of the winter range during the past century. However, willow has also declined on areas outside the winter range (Fig. 3) and in areas well outside the park. Willow has also persisted on, and appears to have colonized, pioneer substrates on the northern range in the presence of wintering ungulates. These observations support the hypothesis that changes in the distribution of willow represent primary plant succession which reflect some fundamental changes in hydrology and alluviation on streams.

Major vegetative changes illustrated in historical photos (Fig. 4) led to the hypothesis that natural fires have been a major influence in development of vegetation on the winter range. Evidence for past fires is abundant, and a series of fire-scarred trees were cut to investigate fire frequency. Individual fires have been dated as early as 1525, and best estimates of frequency suggested mean intervals of about 20-25 years between fires (Houston 1973). This has provided strong support for the hypothesis, and I suggest that few interpretations of range trends or assessments of departures from natural conditions can be valid unless the influence of natural fires is considered. A natural or man-influenced change in fire frequency has probably contributed substantially to the deterioration of aspen on the winter range, and could relate to postulated changes in stream hydrology affecting willow distribution. These hypotheses in turn are being subjected to further testing by again permitting natural fires to burn.

A preliminary review also suggests the possibility of climatic changes dating from the Gannett Peak stage of neoglaciation (Benedict 1968; Porter and Denton 1967) that must be considered in interpretations of vegetative changes.

The range along the present north boundary of the park is an arid steppe with an annual precipitation of about 11 inches. The 11,000 acres (5% of the range) within 1-3 miles of the boundary provide winter habitat for elk, mule deer, pronghorn, and bighorn sheep. The condition of the vegetation on this area also nearly defies interpretation because of the various human uses that have occurred in the past. Much of this area was not within the original boundaries of Yellowstone National Park but was added in 1932. A partial list of past human influences would include developments such as homesteads with attendent grazing by domestic livestock, a townsite of several hundred people, a military rifle range, a racetrack and golf course, a fence along the original park boundary, feedgrounds for native ungulates, and accidental or deliberate introductions of exotic plants. Additionally, soils on portions of the area were derived from an unusual bentonitic parent material

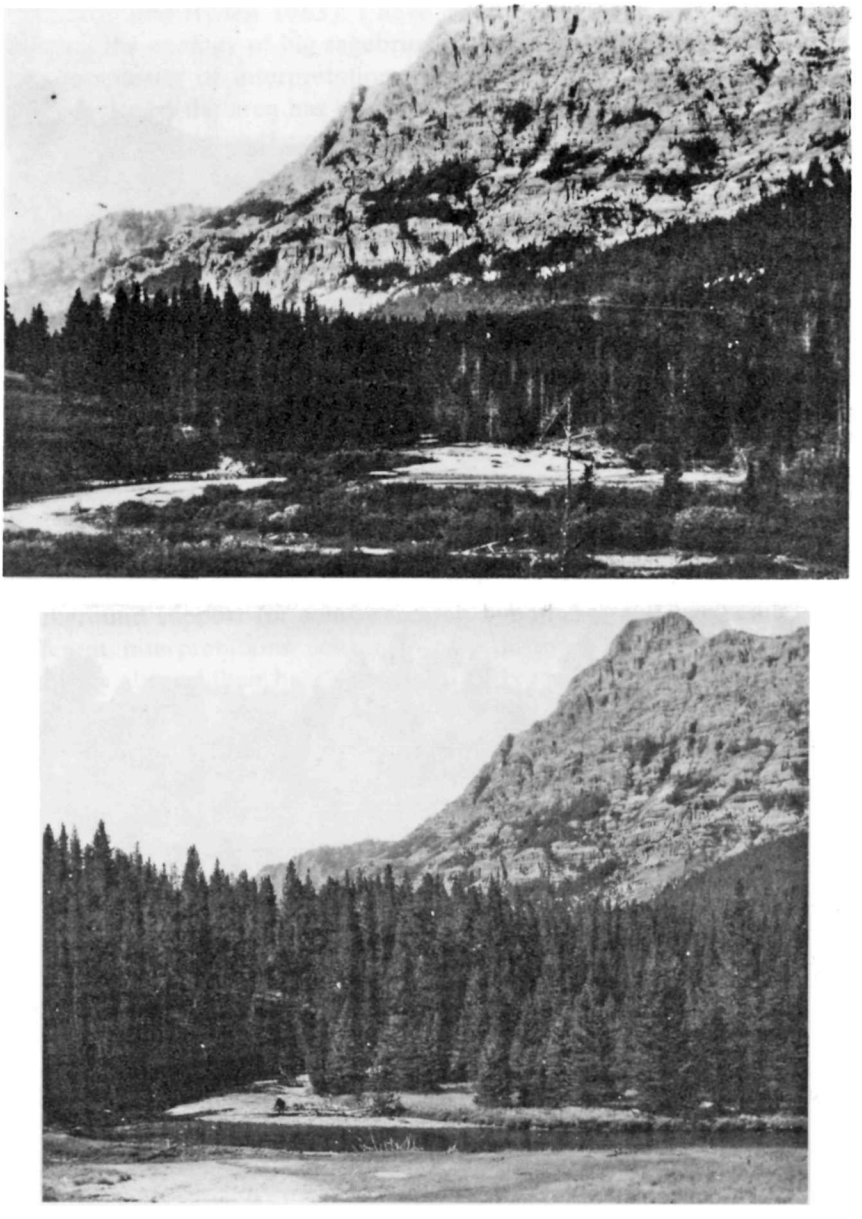

Fig. 3. Soda Butte Creek, Yellowstone National Park. Replacement of willow by conifers has occurred well outside the usual ungulate winter range in about 85 years. These changes are interpreted as representing primary succession and not retrogressive succession due to ungulate browsing. *Upper photo by* J. P. Iddings circa 1885 (USGS No. 347), *lower*, D. B. Houston 1970.

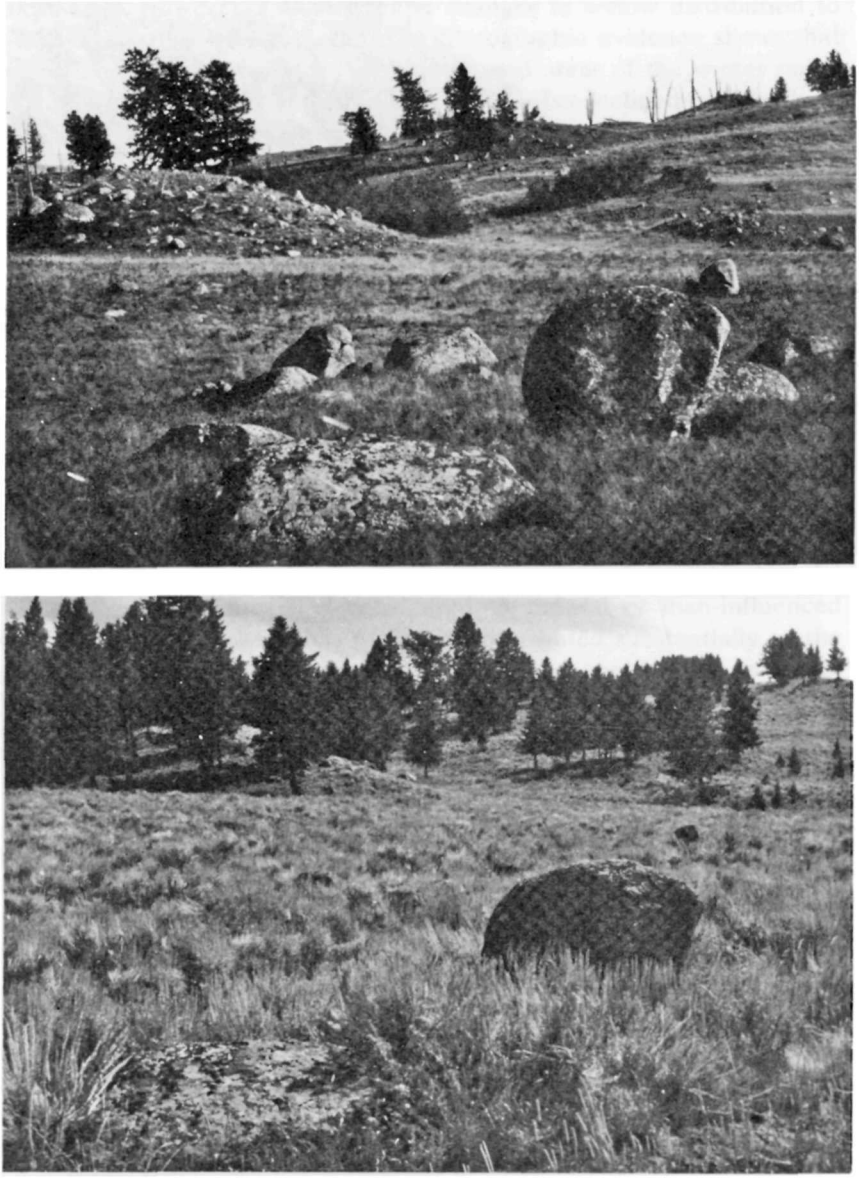

Fig. 4. Tower Junction, Yellowstone National Park. The increase in big sagebrush on *Festuca idahoensis* and *Stipa* spp. grasslands, the increase in the area and density of coniferous forest, and the decline in aspen typify the vegetative change that has occurred on the winter range. Changes are considered to support the hypothesis of a change in frequency of natural fires. *Upper photo by* J. P. Iddings circa 1885 (USGS No. 152), *lower*, D. B. Houston 1970.

(Waldrop and Hyden 1963). I have constructed three hypotheses concerning the ecology of big sagebrush (*Artemesia tridentata*) to illustrate the complexity of interpretations (Table 1). The observed decline of this species on the area has been a major concern. It is quite possible to find support for each hypothesis, but most photographic evidence favors the hypothesis that high densities of big sage at this low elevation represented a disclimax community which resulted primarily from grazing by domestic livestock and its reduction represents a return to more natural conditions (Fig. 5).

An analysis of historical records and studies of habitat use by ungulates are being used to evaluate the hypothesis that vegetation on spring, summer, and fall ranges does not depart from natural conditions. Support for this hypothesis has been provided from comparisons of historic with recent photos and from results of detailed studies of summer range conditions in southern Yellowstone National Park and on adjacent forest areas (G. F. Cole, in prep.; G. Gruell 1973).

The purpose of this paper has been to review the approach to research that is being conducted on a portion of Yellowstone's ecosystem. The review of historical information has provided background support for some research hypotheses and has resulted in different interpretations concerning the history of the northern Yellowstone elk and their habitat. It is too early to claim conclusive support for most hypotheses and there will no doubt be modifications and rejections as studies continue. There are those hypotheses that, by the very nature of the complex interactions among causes and effects in ecosystems, may not lend themselves to decisive support or rejection.

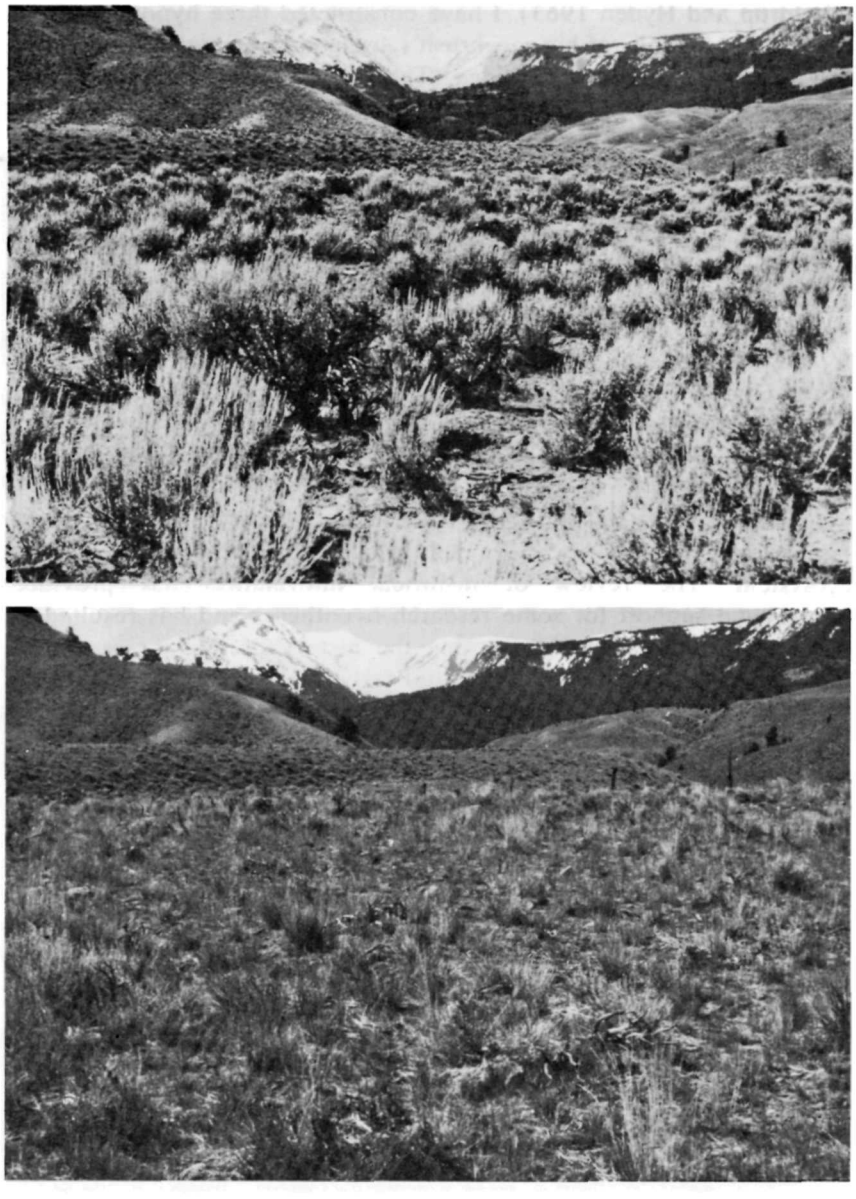

Fig. 5. The Reese Creek area was added to Yellowstone Park in 1932. Upper photo by J. E. Haynes, 1941; lower by D. B. Houston, 1971. Foreground shows a reduction in big sagebrush and its replacement by an *Agropyron spicatum-Stipa comata* grassland. Sage persists on the area beyond the fence, which is within the park, but where grazing by domestic livestock still occurs. Other photographs to 1871 suggest that the present foreground vegetation more closely approximates pristine conditions.

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Acknowledgments

I thank G. Cole, M. Meagher, L. Loope, and D. Despain for reviews of the manuscript. Dr. Meagher located many of the photos and records used in the historical review.

Winter Weather as a Population-Regulating Influence on Free-Ranging Bison in Yellowstone National Park

MARY MEAGHER, Yellowstone National Park, Wyoming

INTRODUCTION

The present bison (*Bison bison*) population in Yellowstone National Park is wild, unrestricted by boundary or internal fences; and since 1966, subject to no regulatory influence from man. The history, population characteristics, habits, and habitat relationships of the Yellowstone bison have been reported from studies that were carried out from 1963 through 1968 (Meagher 1970). These studies documented that the indigenous population of mountain bison persisted, although poached to near-extermination by about 1902. Plains bison were introduced in 1902 and ultimately mixed with native animals. From 1902 to 1966, management varied in objectives, intensity, and population units affected, but generally decreased. Management to control bison numbers (reductions) involved removing what were considered surplus animals.

The 1963-68 studies suggested how the park's original bison population was naturally regulated and indicated that all population units did not need to be controlled. Subsequent work has shown in more detail the degree to which one environmental factor, severe winter conditions, affects the bison population.

POPULATION UNITS AND WINTERING AREAS

The bison population is separated into three units according to wintering location. These are the Pelican, Mary Mountain (which includes Firehole and Hayden valleys), and the Lamar areas (Fig. 1). These population units are not geographically isolated, but interchanges of animals are limited because of their habitual use of specific wintering areas.

Pelican Valley lies at an elevation of 7800 ft. Meadows of sedge (*Carex* sp.) and grass are the main vegetation on the valley floor. Hills and trees are few within this shallow basin. Occasional stands of willow (*Salix* sp.) do not project above winter snow levels. Coniferous forest borders the valley and also covers the mountains which rise to the north and east.

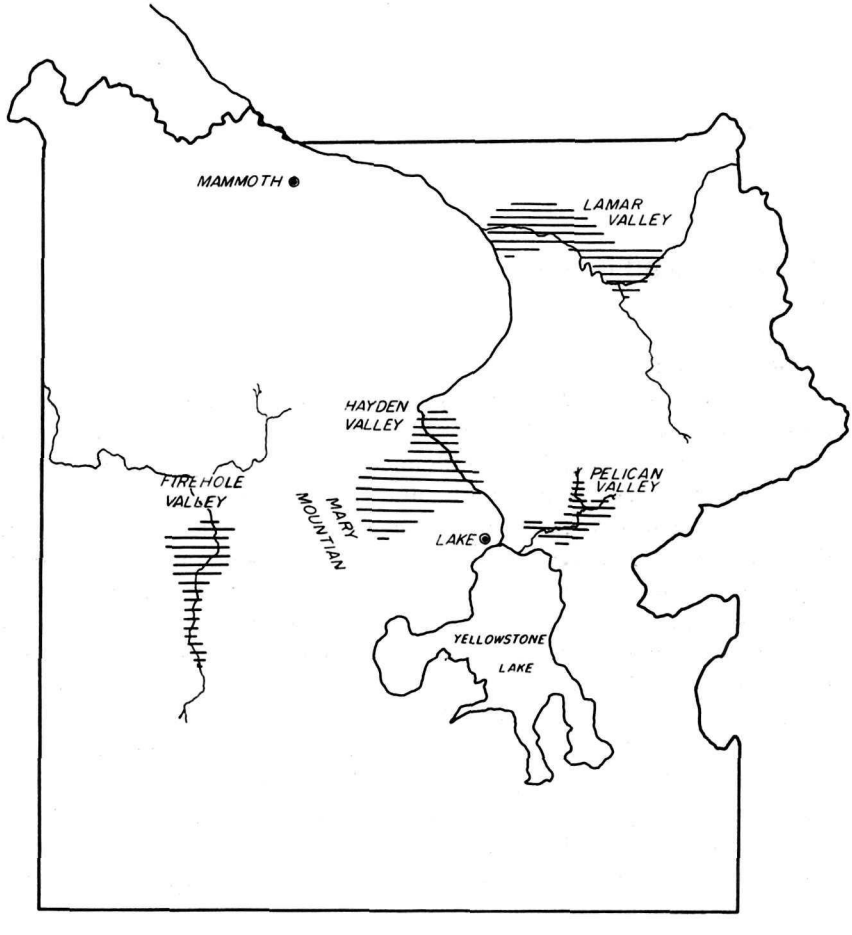

Fig. 1. Bison wintering valleys in Yellowstone Park.

The centrally located Mary Mountain area includes two well-defined valleys, bordered by extensive coniferous forest. Hayden Valley, at 7700 ft, is drained by two major streams. Its varied terrain has interspersed meadows and sagebrush-covered (*Artemisia tridentata*) hills. Scattered stands of coniferous forest also grow within this otherwise open valley. West across the low divide formed by Mary Mountain lies the Firehole area, at 7200 ft. Open meadows and coniferous forest are considerably interspersed within this long, sometimes narrow, rather flat-bottomed valley.

Lamar, at an elevation of approximately 6400 ft, is the largest valley, with quite varied terrain. Mixtures of sagebrush and grass cover extensive hills and lower mountain slopes. Coniferous forest grows on higher slopes. Willows grow along streams; aspen (*Populus tremuloides*) groves occupy limited sites within the sagebrush-grassland or at the edges of coniferous forest stands.

WEATHER CONDITIONS

Winters throughout the park are generally long and cold. A 30-year mean annual January temperature of 39.8°F is recorded for the headquarters station at Mammoth near the north boundary (Weather Bureau 1930-59). Temperatures at this station average about 5°F higher than those for most of the park. Most precipitation occurs as snow. For most of the park, between the 7000 and 8500-ft levels, the average snowfall is about 150 inches, with Lamar averaging 85-95 inches, and Lake, near Pelican, averaging 146 inches.

Weather stations and snow courses are not at locations which allow a direct comparison of weather conditions prevailing on all of the bison wintering areas. An assessment of the various available records, together with personal knowledge, indicates that winters are consistently more severe in Pelican and Hayden valleys, less so on the Firehole, and comparatively moderate in the Lamar.

Weather and snow course records from Lake, just west of Pelican Valley, permit a more detailed description of this one area. Snow covers the ground from late October to early May, sometimes later. Snow depths in the valley are usually a few inches deeper than those of the lake snow course. Average mid-winter snow depths for Pelican Valley are about 40-45 inches; snow course averages for February and March (taken about the first of each month) from 1949 through 1967 were 33 and 38 inches, respectively (Table 1). Rangers reported 75-80 inches of solid, wind-packed snow in Pelican Valley during March 1943. A maximum of 64 inches is recorded for the Lake snow course in early February 1943. Data from Lake station indicate minimum daily temperatures below zero and high winds (actual velocities not recorded) on

TABLE 1. Lake snow course measurements (inches). Depths are for the beginning of the month shown (Soil Conservation Service 1919–67; NPS 1969–71).

Winter	Snow course No.	January			February			March			April			May			Kind of winter:
		Depth	Water content	% 15-yr. avg.	Depth	Water content	% 15-yr. avg.	Depth	Water content	% 15-yr. avg.	Depth	Water content	% 15-yr. avg.	Depth	Water content	% 15-yr. avg.	
1937–38	#1							41	10.6					27	10.3		Moderately severe
1942–43	#1				64	17.7			19.7 est.		61	20.7					Extremely severe
1948–49	#1	30	7.4		35	8.1		43	12.5		47	15.2		21	7.6		Moderately severe
1951–52	#1	33	5.8		40	9.6		46	12.8		53	14.6		22	7.9		Moderately severe
1955–56	#1	40	10.2		56	15.0		59	17.5		53	18.2		41	15.2		Severe
1961–62	#1	29	5.8		36	7.8		50	12.0		53	14.4		32	9.9		Moderately severe
	#2	27	5.5		33	7.3		47	11.2		50	13.4		26	7.7		
1964–65	#1	34	7.1		52	12.1		51	14.4		51	15.8		39	14.0		Moderately severe
	#2	32	5.7		49	10.9		48	13.2		48	15.0		36	13.4		
1968–69	#2	21	3.8	108	47	10.4	179	46	12.6	154	42	14.0	141	21	8.7	112	
1969–70	#2	13	1.5	43	26	4.6	79	25	5.4	66	37	8.5	85	42	10.8	138	Moderate except late spring
1970–71	#2	29	6.2	177	38	9.8	169	44	11.8	143	52	15.0	152	43	16.5	212	Severe
Est. avg. #1, 1947–67 [a]		23	4.3		33	6.8		38	9.2		41	11.3		28	8.9		
Depths used for selection of severe winter		30			40			40			45			40			

[a] Data unavailable for specific months some years.

one-third to one-half of the days each month for January, February, and March. Pelican Valley lies exposed for its entire length to the sweep of the prevailing west and southwest winds. Ranger reports and personal experience indicate that heavy crusting may occur with warm spells from early March into April (Meagher 1971).

Data from the Lake snow course (Table 1) provide a basis for evaluating relative severity of Pelican winters. Snow depth, density of snow as indicated by water content, length of winter, and lateness of spring (May snow depth) contribute to the evaluation. The records show an extremely severe winter occurred once in the last 35 years. Winters rated as severe may occur more or less every 20 years. Winters of above average severity can be expected two or more times each decade.

INFLUENCE OF WEATHER ON BISON

Population trends based on census data from 1936 through 1971 for all three population units, together with reduction numbers, are shown on Fig. 2. Projected numbers for 1972, based on interim counts, are included. Decreases in all population units between 1956 and 1957, which are most striking in the Pelican and Mary Mountain units, coincided with the severe winter of 1955-56. The occurrence of reductions did not adequately explain the decreases. Reported winterkill as an indicator of the amount of late winter mortality suggested the effects winter conditions could exert. Emigration, disease, and predation are not factors with noticeable effect on the Yellowstone bison.

a. The Pelican Valley Herd

The Pelican unit offered the best opportunity to determine how a bison population is naturally regulated. Historical records show this area has had a wild bison population continuously since the park was established, and probably long before. Recovery from the near-extermination about 1902 occurred naturally. Reductions have been held here only twice since this time. Bison are the only ungulate which winters within this valley.

During the 15 years since the severe winter of 1955-56 Pelican bison numbers have fluctuated between approximately 100 and 200 animals (Fig. 3). A reduction of 34 animals was made in 1965; no other control has occurred. The 1965 reduction coincided with a moderately severe winter and a population decrease. After an increase between 1966 and 1970, the population has again decreased.

Mortality, largely due to winter weather conditions during two succeeding years, has been the major factor in causing the recent decrease in the Pelican population. The winter of 1969-70 was of below average severity until spring. Snow depths at the beginning of May were well

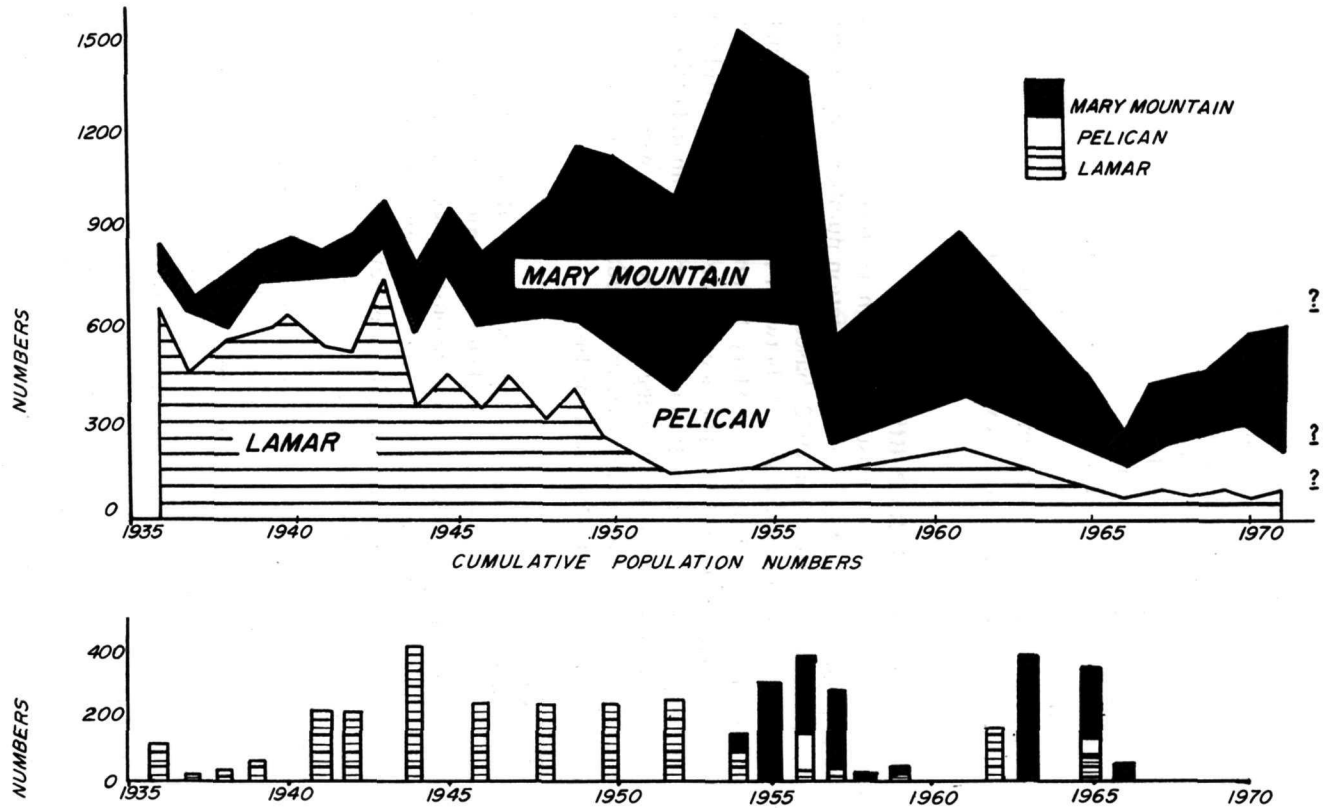

Fig. 2. Bison population trends 1936-71.

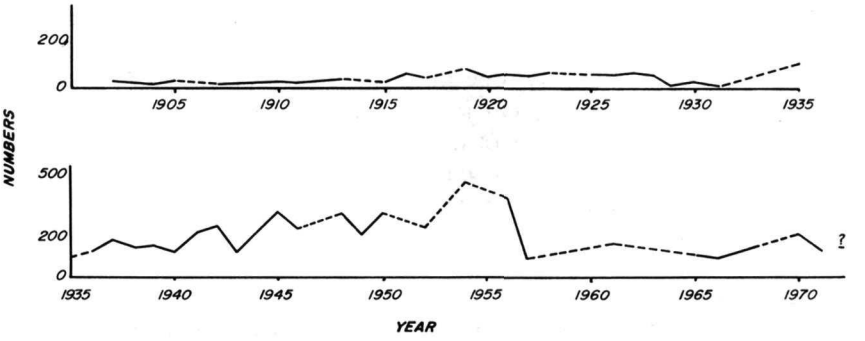

Fig. 3. Pelican area wintering bison numbers 1902-71.

above average (Table 1), and storms were continuous during the first half of May after calving had begun. Calf percentages at the beginning of June were the lowest of those recorded since 1965 (Table 2). Difficulty in obtaining percentages of calves at the end of calving season in late June precludes using exact figures but later aerial surveys confirmed that Pelican calf numbers were low by several percent. The same late winter conditions caused higher than usual mortality among other age classes, as indicated by an early summer ground survey. Aerial counts showed that the decrease in animals older than calves was 15-20%.

TABLE 2. New-calf ratios as percentages of mixed-herd numbers in Pelican Valley, 1965–71.[a]

Date	Herd total	% calves
1965, 2 June	69	14
1966	—	—
1967, 4 June	96	16
1968, 2 June	111	11
1969, 21 May	129	12[b]
1970, 3 June	131	10
1971, 2 June	118	13

[a] Mixed herds are predominately cows, subadults, and calves. Usually some mature bulls are included.

[b] Expected to be slightly higher by early June.

The following winter, 1970-71, was rated as severe in the Pelican area. Aerial and ground counts between February and early April suggested that approximately one-third of the population (about 50 animals) had died. Subsequent aerial counts confirmed the magnitude of the mortality. The number of winterkilled animals found during early summer also indicated that substantial mortality occurred. Only 14 carcasses of all ages were located, but this compares with the 1 or 2 old bull carcasses found after average winters.

b. Other Herds

In contrast to the Pelican herd, the effects of recent winter conditions on the Mary Mountain and Lamar herds were less apparent. The Mary Mountain population has increased in numbers since 1966. This was mainly in the Hayden Valley wintering segment, which is consistently much larger than the part of the Mary Mountain population which winters in the Firehole area. Essentially the same climatic factors apply to Hayden Valley as to Pelican, but the habitats differ. In spite of late storms during the spring of 1970, calf losses were not apparent in the Hayden Valley segment. More than usual numbers were winterkilled during the winter of 1970-71, but this was not sufficient to prevent the population from increasing. No unusual mortality was apparent in the Firehole segment in 1970 and 1971.

In the Lamar area, bison population numbers at present suggest stability; however, a slow increase in the proportion of the population formed by herd groups is occurring. The late storms in the spring of 1970 were less severe in this area and had no apparent effect on this population. The winter of 1970-71 was less severe than average; winterkills were no more than usual.

DISCUSSION

The ecological literature contains numerous discussions on the natural regulation of populations. Such regulation probably results from a complex of intrinsic and extrinsic factors (Slobodkin 1962). Within Yellowstone National Park, three population units of bison show three different recent population trends. This suggests that the natural factors which influence population size vary among the three.

Data from the last 2 years support the hypothesis that winter weather is a major population-regulating influence on the Pelican bison population. Although periodically severe winters have marked effects on population size, census records suggest that approximately 100 animals may survive the most severe winters that occur. Scattered, small, thermal areas, both within the valley and in the surrounding coniferous forest, may be the habitat factor which permits a bison population to persist in

the Pelican area over time (Meagher 1970, 1971). The effects of severe weather on bison mortality may be only partly density-independent, because deaths are limited to numbers in excess of the threshold carrying capacity of animals. This threshold of carrying capacity beyond which severe weather does not increase mortality may be largely determined by the amount of thermal ground within the Pelican Valley area.

Although winter weather conditions are similar in the Pelican and Hayden valley areas, the terrain and interspersion of different vegetation in Hayden Valley are more varied. The more variable winter habitat apparently provides increased opportunities for bison to secure food and survive. Additionally, some bison leave Hayden Valley in late winter, crossing to the Firehole side where weather influences are less severe. Such movements occurred between late March and early May in 1970 and 1971. However, the population decrease of 1956-57 suggests that severe winters will periodically reduce the numbers of bison in the Hayden Valley segment. Since winters that depress population numbers may occur less frequently in Hayden Valley, additional unknown factors must be influencing bison population fluctuations. The usual range of population fluctuations may be 400-600; conditions which permitted a population high of 858 bison in 1954 may not occur again (Meagher 1970).

In Lamar, where winter conditions for bison are least severe, other extrinsic and intrinsic factors may have a greater regulatory influence on bison numbers. The habitat would seem to favor a larger bison population than that which inhabits the Mary Mountain area, yet population trends since 1952 suggest that the usual winter number approximates 200 bison. Large numbers of elk (*Cervus canadensis*) also winter in the Lamar Valley, as do some bighorn sheep (*Ovis canadensis*), mule deer (*Ococoileus hemionus*), and moose (*Alces alces*). Interspecific competition for food and/or space may partly set upper limits on bison numbers.

In conclusion, the main regulatory influence on the Pelican bison herd appeared to be frequent severe winter weather. Thermal areas and probably some other habitat factors provided a threshold carrying capacity which permitted about 100 animals to survive the most severe winters. The effects of weather on other population units were less pronounced because habitat conditions were more varied, or winter conditions were not as severe compared to the Pelican area. A complex of weather, other extrinsic effects, and intrinsic behavioral responses appeared to interact to regulate the numbers in these other population units.

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Acknowledgments

Glen Cole and Douglas Houston of Yellowstone National Park provided valuable comments on this manuscript. Dave Stradley, Gallatin Flying Service, is responsible for the quality of the aerial surveys. This paper is a contribution from the National Park Service, Office of the Chief Scientist, Project Yell-N-8a.

The Status of Research on the Snake River Cutthroat Trout in Grand Teton National Park

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The Snake River and its tributaries in Wyoming contain one of the few-remaining, native cutthroat trout (*Salmo clarki*) populations in the Rocky Mountain area. The present distribution of this population is in the Snake River between Jackson Lake and Palisades Reservoir (Baxter and Simon 1970). The Snake River cutthroat trout is the only interior cutthroat trout that has maintained its integrity despite introductions of exotic trouts, including other cutthroat trout (Behnke 1971). Although the taxonomic status of this distinctive population has yet to be determined, the National Park Service has designated the Snake River cutthroat trout as a representative faunal species in Grand Teton National Park.

This trout population supports an important sport fishery which is maintained, for the most part, by natural reproduction. The Snake River in Wyoming has long had a national reputation as a top quality trout fishing stream. Narratives, photographs, and verbal reports of "old timers" indicate that fishing success was good during the 1930-60 period for trophy-sized cutthroat trout. The quality of this fishery, as reflected by rate of catch and numbers of trophy-sized trout creeled, has deteriorated since the mid-1950s.

Information on the sport fishery and the ecology of the trout population was lacking or minimal so the Wyoming Game and Fish Commission initiated a long-term study of the Snake River cutthroat in 1964. Adjunct studies on invertebrate organisms and food habits of trout and whitefish in the Snake River and on trout populations in Jackson Lake have been sponsored or conducted by the National Park Service since 1965. Harvest studies on the Snake River below Jackson Lake have been conducted cooperatively by the two agencies since 1967. The overall objectives of these studies were to determine the present status

of the Snake River cutthroat trout population and those factors influencing its welfare.

THE AREA

The Snake River originates in northwestern Wyoming's Teton Wilderness Area, flows through a portion of Yellowstone National Park, and enters Jackson Lake in Grand Teton National Park. After leaving Jackson Lake, the river flows south for about 25 miles before leaving the park boundary. Some 55 miles south of Grand Teton National Park, the Snake River leaves Wyoming and enters Palisades Reservoir in Idaho.

Within the 80-mile reach of river downstream from Jackson Lake, there are significant physical differences in habitat. A Bureau of Reclamation dam at the outlet of Jackson Lake totally regulates the flow for 4 miles downstream where two major tributaries, Pacific Creek and Buffalo Fork River, discharge into the Snake River. From this point, the Snake River flows south and west through the valley of Jackson Hole for about 47 miles. In this section, the river has cut mostly into glacial outwash of the last (Pinedale) glacial advance and the substrate consists almost entirely of quartzite cobbles (3-10 inches in diameter) firmly embedded in a sandy-silt matrix. The river is very active on its flood plain in this area and over two-thirds of the entire section consists of braided areas (multiple channels). Extensive levees have been constructed by the Army Corps of Engineers south of Grand Teton Park to prevent damage to adjacent private lands. The Snake River then swings to the south and east (following a fault structure) and enters a steep-walled canyon through which it flows south and then west into Idaho. In this canyon, the river crosses some resistant mountain structures which retard downcutting upstream.

The area has cool summers and cold winters. Precipitation amounts are variable due to topography (from less than 15 to over 60 inches annually) and most falls as snow during the November-April period. This snowpack usually begins to melt and run off in mid-May. Streams and rivers are high and turbid from this time until early July. This pattern is modified in the Snake River (particularly in Grand Teton Park) by the operation of the Jackson Lake dam which reduces the magnitude of the May-June flows and increases July-September flows from 20 to 50%.

Water quality in the upper Snake River is high, being slightly alkaline (pH 7.5-8.0) with relatively small amounts of dissolved material (total dissolved solids varies from 100 to 200 mg/liter). Both alkalinity and dissolved materials increase somewhat downstream. Cultural alteration of water quality is minimal. Primary land use in the area is recreation, and agriculture, mainly hay crops, utilizes only a small proportion of the total acreage.

THE FISH FAUNA

The fish fauna of the Snake River is typical of cold waters and is relatively species-poor. Glaciers of the Pinedale advance existed in the valley of Jackson Hole as recently as 9000 years ago (Love and Reed 1968) and the indigenous fishes inhabiting the lakes and streams of the area undoubtedly became established since then. In addition to the cutthroat trout, the native fish fauna includes the mountain whitefish (*Prosopium williamsoni*), five minnows (*Cyprinidae*), three suckers (*Catostomidae*), and two sculpins (*Cottidae*). A single specimen of the June sucker (*Chasmistes liorus*) was collected from the Snake River below Jackson Lake in 1927, but is now probably extinct (Baxter and Simon 1970). Four introduced fishes presently inhabit portions of the upper Snake River drainage in Wyoming—lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), and rainbow trout (*Salmo gairdneri*). Lake trout have become the dominant fish in Jackson, Jenny, and Leigh lakes in Grand Teton National Park, and in Shoshone, Lewis, and Heart lakes in Yellowstone National Park. Brown trout are abundant in the Lewis River drainage and are common in the Snake River north of Jackson Lake and in Jackson Lake. Brook trout are common in tributary streams, while localized populations of rainbow trout and rainbow cutthroat hybrids occur in the Snake and Gros Ventre rivers.

THE INVERTEBRATES

National Park Service-sponsored studies involving classification, life history, and downstream drift of invertebrate organisms in the Snake River were initiated in 1965. These studies indicated that the Snake River is relatively productive—quantitative collections averaged 11,399 mg of organisms per square meter. Caddisflies, mayflies, stoneflies, and dipterans composed over 98% of the total biomass of invertebrates collected. The caddisflies (particularly the genera *Hydropsyche* and *Arctopsyche*) were the most abundant and important group found. The Snake River invertebrate fauna is fairly complex—170 species were collected and identified. Major differences in species composition were observed between the two major sections of river in the park. The invertebrate fauna inhabiting the portion between the Jackson Lake dam and the mouth of Pacific Creek contained only 7 major species, while below Pacific Creek at least 23 major species were present (Kroger 1967).

Major groups of insects in the downstream drift were also important in the benthos (stream bottom community). Behavioral differences were observed in the drift among major groups—mayflies were active drifters while caddisflies were relatively inactive. Most benthic forms showed nocturnal drift patterns, but considerable daytime drift of immature

midge (Diptera) larva was observed. Emerging forms occurred in the drift at all times, but mostly at sunset and sunrise. Spent adults had peak periods corresponding with oviposition and terrestrial insects occurred sporadically (Good 1971).

Aquatic invertebrates are the most important component of the diet of cutthroat trout in the Snake River. They also compose nearly the entire diet of the abundant (and possibly increasing) population of mountain whitefish. Studies are planned or are underway to evaluate the ecological relationships between these two native fishes. A present hypothesis is that selective angling (for trout) may have altered these relationships.

Studies of the water-release patterns from the Jackson Lake dam indicated that nearly all invertebrate organisms and most sculpins in some areas of the river were left stranded when volume flows were reduced suddenly. Recommended changes in water-release practices to reduce this problem have been followed by the Bureau of Reclamation.

GROWTH AND REPRODUCTION OF CUTTHROAT TROUT

Estimates of age composition, total mortality, and age-growth relationships of the trout population were obtained from analysis of samples of cutthroat trout scales collected during harvest studies. Snake River cutthroat trout have slightly better than average rates of growth compared to other river cutthroat populations in the western United States. Average length of various age groups was: age I—211 mm (8.3 inches); age II—267 mm (10.5 inches); age III—351 mm (13.5 inches); age IV—394 mm (15.5 inches); and age V—470 mm (18.5 inches) (Hagenbuck 1970). Few Snake River cutthroat trout live longer than 5 years. Annual mortality rates of cutthroat trout for the entire study area were 66%, 71% for areas within the park and 60% for areas south of the park.

As previously stated, the cutthroat trout population in the Snake River is maintained by natural reproduction. Sporadic stocking of hatchery-reared cutthroat trout in the river proper has been done in the past, but the present policy restricts stocking to a few tributary streams. All known natural spawning of Snake River cutthroat trout occurs in tributary streams. Apparently, suitable spawning habitat does exist in some side channels of the river, but evidence of use by cutthroat trout has never been reported. In Grand Teton Park, cutthroat trout are presently known to spawn in only two tributary streams. Two other tributaries in the park which once supported large spawning runs have no known spawning today.

Snake River cutthroat trout become sexually mature at age groups III or IV, with females tending to mature later than males. There is

evidence that the river population may consist of subpopulations which spawn in different tributaries. Timing of spawning runs in three tributaries occurred from March through June with little overlap and appeared to be influenced by inherent rather than environmental factors. Mortality of post-spawning trout was about 50% in one stream, but a high proportion (17% in one year) of the survivors may return to spawn again the following year. Mortality of newly hatched trout is high, less than 5% survive the first 2 months. Young-of-the-year cutthroat trout migrate into the Snake River from September throughout the following winter although some may remain in tributary streams for over one year (Hayden 1968).

THE ANGLER HARVEST

The Snake River trout fishing season runs from 1 April through 31 October. Fishing for mountain whitefish is permitted throughout the year. Angler use is most intensive from July through September, coinciding with the peak visitation period and subsidence of high water conditions. Most people fish from the shore near one of the vehicle access areas along the river, but increasing numbers of anglers are using boats to gain access to the entire river.

The first investigation of the Snake River sport fishery was a harvest study conducted in 1955 by the Wyoming Game and Fish Commission. A portion of the area studied was in Grand Teton National Park. As a result of this study, it was concluded that the sport fishery was having no detrimental effects on the trout population. Angler success rates were considered satisfactory (0.69 trout caught per hour) since many anglers contacted were either inexperienced or were fishing during adverse water conditions (Rasmussen 1956).

Annual harvest studies have been conducted cooperatively since 1967, the National Park Service being responsible for that portion of the Snake River within Grand Teton National Park and the Wyoming Game and Fish Commission, for that portion south of the park. No trends in the cutthroat trout population (as reflected by angler harvest) were indicated during the 1967-70 harvest studies. Analysis of the 1971 data is still incomplete. There were variations in harvest estimates between years of considerable magnitude which were ascribed to variations in water conditions and sampling methods.

Catch rates for the entire study area were 0.26, 0.53, 0.31, and 0.30 trout caught per hour for the 1967 through 1970 seasons, respectively (Wiley 1969; Kiefling 1971). With an exception in 1967, in one study subsection, angler success rates within Grand Teton National Park were lower than in those areas south of the park. During the period, 59% of the total number of persons fishing the Snake River actually fished in

the park while catching 41% of the total trout harvested. There was no apparent correlation between catch and fishing effort on any section of the river. Differences in catch rates appeared to be a function of water conditions—better fishing was related to an early run-off and low water in late summer (Kiefling 1971).

Cutthroat trout are not fully vulnerable to capture by the sport fishery until age group II (Hagenbuck 1970). Average length of trout in the angler harvest has been near 11 inches although this appears to reflect angler selectivity rather than any factor in the trout population. In 1967 and 1968, when comparable data were collected, 79% of the trout harvested within the park were less than age group III, while 59% of the trout harvested from areas south of the park were less than 3 years old.

THE CUTTHROAT TROUT POPULATION

Efforts to estimate stock density of cutthroat trout in Grand Teton Park in 1968 and 1969 were not successful due to an inability to sample enough fish. Using hook and line methods to capture and mark trout and harvest information to recover the marked fish, the Wyoming Game and Fish Commission was able to make population estimates in a 10-mile river section south of the park. Because of angler selectivity, these estimates (4002 in 1969 and 9919 in 1970) were only of those trout in the population over 8 inches long (Kiefling 1971). Although strict comparison is not possible, estimated stock density of trout in the Madison River in Montana has averaged about twice as much (Vincent 1970).

Estimated fishing mortality in the river section studied south of the park was 46% in 1969 and 22% in 1970. No correlation between angler success and stock density was detected. It was concluded that the correlation between harvest rates and water conditions so distorted any relationships between catch, effort, and stock density that reliable estimates of exploitation rates were impossible (Kiefling 1971).

ALTERATION OF HABITAT BY MAN

The most obvious cultural changes in the Snake River habitat, regulated flows and levees, have undoubtedly had some influence on the trout population. Flow regulation due to the operation of the Jackson Lake dam has occurred since 1916. The dam itself is a barrier to fish migration, the biological consequences of which probably occurred long ago and are now only a matter of speculation. Prior to 1956, when Palisades Reservoir was completed, there were abrupt changes in flow (over 5000 cfs or 141.6 m^3/s a day) during the irrigation season, as dictated by the water needs of the irrigation districts in Idaho, and water was stored in Jackson Lake during the winter resulting in dewatering of the first 4 miles of river. At the present time, minimum flows are maintained throughout the winter and

summer releases are adjusted gradually to simulate natural flows. The one persistent problem concerns required periodic shut down for inspection of the dam. Both the National Park Service and the state of Wyoming are programming funds for construction of a by-pass to maintain minimum flows below the dam at these times.

The apparent effect of the levees (constructed between 1951 and 1964) is the permanent dewatering of over 8 miles of side channels, which are otherwise excellent trout habitat, and the increased hydraulic activity between levee structures (Wiley 1969). There has also been significant loss of habitat for other wildlife due to levee construction. It should be mentioned that fishing success in those river sections entrained by levees has been better than in Grand Teton National Park where no levees exist.

NATIONAL PARK SERVICE POLICIES

The basic management objective in those National Park Service areas classified as natural areas (including Grand Teton National Park) is to limit modern man to nonconsumptive uses (Houston 1971). Recreational angling violates this objective but is a traditional use established in the creation of Yellowstone National Park in 1872. Recreational fishing in some form will undoubtedly be continued in the foreseeable future.

The objectives of management of aquatic resources in national parks are to protect, perpetuate, and restore natural environments, native fishes, and the associated fauna and flora. Where fishing is encouraged, it is governed by the conservative and controlled use of native and nonnative sport fish species and by regulations and measures that are designed to encourage high-quality angling as part of the park experience without impairing the basic fish populations or other park values (Wallis 1971). High quality angling is defined as that in which a person has the opportunity to fish for and catch rare native fish or wild trout in a pristine setting under conditions where angler removals do not exceed natural replenishment rates or materially alter the population structure of the fish being harvested. A basic requirement of this definition distinguishes between catching and killing fish. Concepts such as maximum fishing opportunity and maximum sustained yield tend to upset ecological relationships and should not guide management in national parks.

CONCLUSIONS, HYPOTHESES, AND FUTURE PLANS

Condition of the cutthroat trout fishery in Grand Teton National Park is mediocre when compared to what it was in 1955 and to present con-

ditions south of the park. We interpret this to mean that condition of the trout population in the park is worse than it was previously and is presently poorer than in areas downstream. Lacking evidence of significant habitat deterioration in recent years, we conclude that recreational angling is the major cause of this decline. Cutthroat trout are quite vulnerable to capture by sport angling and removals from the population by anglers may have exceeded natural replenishment for some time. Imminent collapse of the trout population in the park is very unlikely, but survival of trout to spawning age is low. Low numbers of spawning trout coupled with periodic adverse environmental factors and/or man-caused habitat destruction may have already eliminated at least two spawning runs in the park.

Our basic hypothesis is that stock density and age structure of the cutthroat trout population in the Snake River will be improved by eliminating or greatly reducing angling mortality. In Yellowstone National Park, where angler success in the Yellowstone Lake cutthroat trout fishery was declining, two year classes (ages VI and VII) had been eliminated from the population in the more heavily fished parts of the lake and the fishery was largely supported by 4-year-old trout. In 1970, regulations were imposed placing a 14-inch minimum size on cutthroat trout kept by anglers and eliminating the use of bait. As a result of these regulations, the total harvest was reduced about two-thirds in 1970. Angler success, however, increased by 47% over 1969 (Dean and Mills 1971). Part of this increase in success rate was attributed to the presence of a strong year class of 4-year-old trout, but in 1971, when a weak age IV year class entered the fishery, success rates increased 35-40% over 1970 to nearly the highest in 21 years of record (J. L. Dean 1971, pers. comm.).

In Grand Teton National Park, we are recommending enactment of regulations to reduce angling mortality on cutthroat trout. Our specific recommendations are the complete protection of cutthroat trout in the Snake River between Jackson Lake and the south park boundary for a 5-year period and the prohibition of the use of bait. Our research efforts during this period will be to evaluate any response of the trout population. Consideration was given to the alternative of establishing a minimum size limit. Experience in Yellowstone National Park indicated that most anglers accept size limit regulations only if the fishing is good. When fishing is poor, there is a tendency to keep trout smaller than the legal size. If, as expected, angler success improves under these regulations, then a size limit on cutthroat trout may be appropriate.

To summarize, the management in Grand Teton National Park of this irreplaceable and unique resource, the Snake River cutthroat trout, has not been up to the standards outlined in National Park Service resource

policies. If we are to protect these fish and "leave them unimpaired for the enjoyment of future generations," then we must improve present conditions.

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Ecology of the Saguaro: I. The Role of Freezing Weather in a Warm-Desert Plant Population

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"The line which marks the extreme southern limit of frost is the most important climatic boundary in restricting the northward extension of perennial tropical species, and it is the line along which the influence of winter cold is the simplest in its operation."—Forrest Shreve, *The Influence of Low Temperatures on the Distribution of the Giant Cactus*, 1911:136.

INTRODUCTION

The saguaro giant cactus (*Cereus giganteus* Engelm., *Carnegiea gigantea* [Engelm.] Britt. and Rose) is the northernmost species in a large group of *tropical* columnar cacti. Herein lies its principal problem at Saguaro National Monument, a problem shared with many tropical and subtropical plant species in a locality subjected to yearly subfreezing weather (Fig. 1).

As a major plant dominant in a subtropical desert, the saguaro is a species with the majority of its geographic distribution to the south in Mexico, where it occurs throughout the mainland Sonoran Desert into the subtropical deciduous forest of southern Sonora (Fig. 2). Accordingly, its distribution occurs both north and south of the "freezing line" in central Sonora. At Tucson, the population occurs in the northeastern sector of the species distribution. At Saguaro National Monument (east), it occurs at the edge of the desert for, contrary to popular belief, Tucson does not lie in the heart of the Sonoran Desert. As we will develop throughout this paper, the saguaro population at Saguaro National Monument is periodically subjected to catastropic selection during the winter, with widespread freeze-kill throughout the population. This has become fully evident through our recent studies. Heretofore,

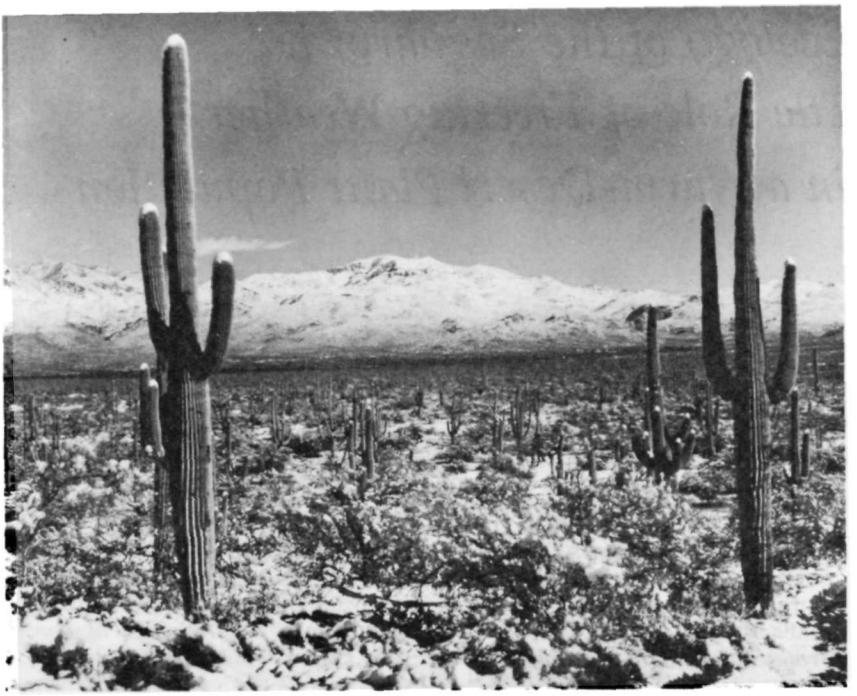

Fig. 1. Winter at Saguaro National Monument, Tucson, Arizona. National Park Service photo by George Olin, 17 November 1958.

however, and for many years, the widespread mortality of saguaros has been attributed to other causes in spite of the early observations of workers at Tucson who pointed directly to the problem (Shreve 1911; Thornber 1911, 1916 ; Turnage and Hinckley 1938; and others).

What is happening and has been happening to the saguaro at Saguaro National Monument is really no mystery and is certainly not a secret, for density-independent climatic regulators are common knowledge to all ecologists. In discussing the natural regulation of populations in general, Harper (1967) could have been speaking precisely of the monument saguaro situation: "In environments in which there is a recurrence of natural hazards, populations may spend most of their time recovering from the hazards . . . . The size of such populations may frequently be a function of the magnitude of the last catastrophe and the time available for recovery." The observations and experiments reported here confirm Harper's conclusion and apply to the saguaro population at Saguaro National Monument.

Recent reports (since 1962) on saguaro ecology include evaluation on climatic influences and historical factors (Niering et al. 1963; Hastings

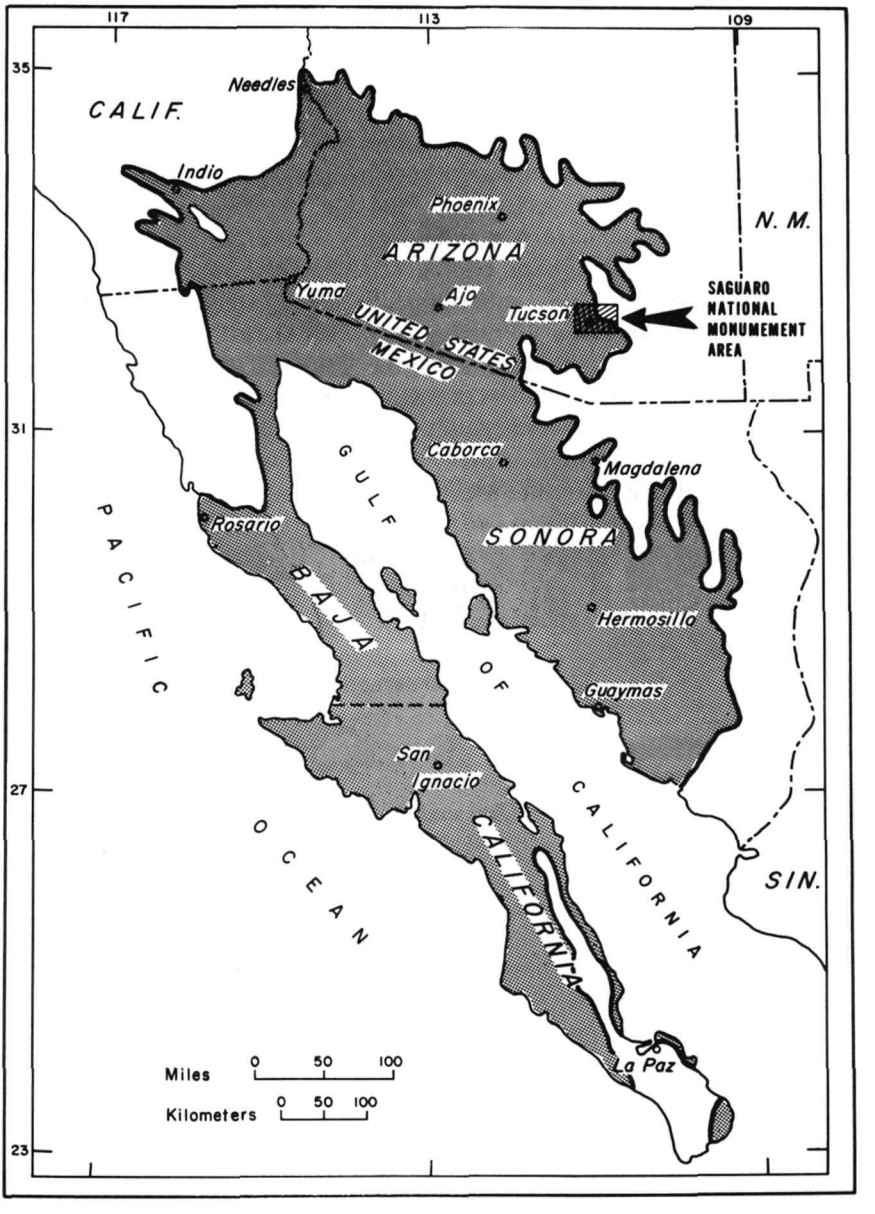

Fig. 2. The Sonoran Desert showing the Saguaro National Monument area at Tucson, Arizona (*after* Shreve 1951). The eastern portion (Rincon Mountain Section) of the Monument lies at the northeastern boundary of the Sonoran Desert. The western portion (Tucson Mountain Section) is located within, but close to the edge of, that boundary.

and Turner 1965), and mortality and survival of young saguaros (Turner et al. 1966; Steenbergh and Lowe 1969; Turner et al. 1969). Seedling respiration physiology is reported by Despain et al. (1970), germination responses by McDonough (1964), and cristation by Snyder and Weber (1966). Steelink et al. (1967) and Steelink et al. (1968) have reported on saguaro tissue chemistry, and distribution and taxonomic characteristics are included in publications by Earle (1963) and by Benson (1969).

This report on saguaro winter mortality and other investigations on the ecology of the saguaro cactus reported elsewhere (Lowe 1966; Soule and Lowe 1970; Steenbergh 1970, 1972; Steenbergh and Lowe 1969) are the result of a continuing National Park Service program of research designed to provide scientific information to facilitate the management and interpretation of Saguaro National Monument.

Field investigations were conducted in the two sections of the Saguaro National Monument near Tucson, Arizona (Fig. 2). The eastern portion (Rincon Mountain Section), situated 15 miles east of Tucson, lies along the northeastern boundary of the Sonoran Desert. The western portion (Tucson Mountain Section), located 15 miles west of Tucson, is within but close to the edge of that boundary. Elevations range from 823 m (2700 ft) to 2641 m (8666 ft) in the eastern section and from 616 m (2020 ft) to 1429 m (4687 ft) in the western section. New data reported here were obtained from December 1967 to December 1971 and include earlier observations by the authors and others on the saguaro population at Saguaro National Monument.

MATERIALS AND METHODS

Data reported here on survival and freeze-caused mortality in natural populations of saguaro cactus in both sections (east and west) of Saguaro National Monument were obtained from 3 January to 21 November 1971. Observations in 1971 were initiated concurrently with the onset of a period of subfreezing nocturnal temperatures from 3 to 10 January at Tucson Airport (U.S. Weather Bureau 1971).

Data on a sample population of 189 saguaros (height 0.09-13 m) was obtained from a 2-ha (100 × 200 m) permanent sample plot located at Saguaro Monument (west) flats (Fig. 13). All saguaros within the plot were numbered and provided with identification tags. Height of each plant, the number of arms, and the general condition of each individual were noted, together with the nature and extent of any visible freeze-caused damage. Stem-height measurements of all plants were made, using two specially designed height-guages for plants up to 6.8 m tall, and a Haga altimeter for larger plants. Heights of plants to 2 m were recorded to the nearest whole millimeter; 2-6.8 m plants, to the nearest centimeter; plants over 6.8 m, to the nearest decimeter (Table 12; Fig.

21). In addition, heights were measured, and observations on the condition of wild, previously located juvenile plants adjacent to that plot and at Saguaro Monument (east) flats (N=129) were made at irregular intervals to 21 November (Table 10, Fig. 19). Concurrent observations at Saguaro National Monument (east and west) on both wild plants and naturally growing survivors from seed-broadcasting and winter-mortality experiments of previous years were employed to obtain information concerning winter mortality of known-age (1st to 7th year) globose juvenile plants germinated 1964-70 (Tables 6, 7, 8, 9; Figs. 3, 4, 5, 15, 16, 17, 18).

As used in this paper, *seedlings* refer to plants less than 1 year old, *juveniles* are plants over 1 year old that have not reached flowering size (ca. less than 2 m height), and *adults* are flowering plants, generally over 2 m in height. *Juveniles* we further subdivide by age-related form into *globose juvenile* plants (heights to ca. 2.5 cm, age 1 to 6-7 years) with nippled (tuberculate) stems, and larger *columnar juveniles* plants with evidently fluted (ribbed) stems (Figs. 3, 4, 5, 6, 7).

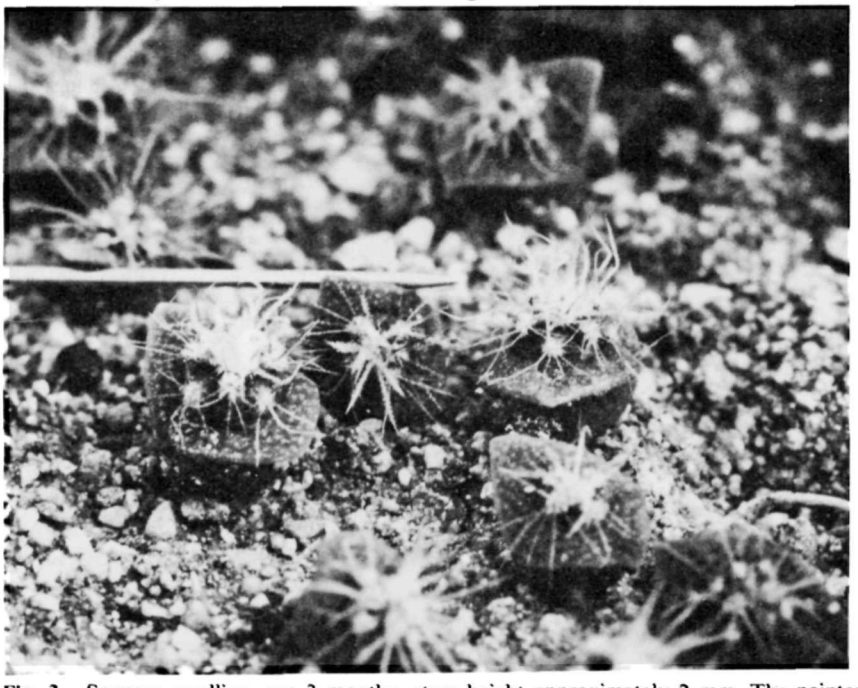

Fig. 3. Saguaro seedling, age 3 months, stem height approximately 2 mm. The pointer on the left is a common dressmaker's pin. The first year of life (first 12–14 months)—from germination to the beginning of the second summer's growth—is the critical period of saguaro establishment. Germinated 7 August 1971, photographed 4 October 1971 *by* Dana Slaymaker.

Fig. 4. Globose juvenile saguaro, age 13 months, stem height approximately 7 mm. At this age this saguaro has survived the hazards that kill nearly all of the seedlings that germinate each summer. Photographed 13 August 1970 by Harold T. Coss.

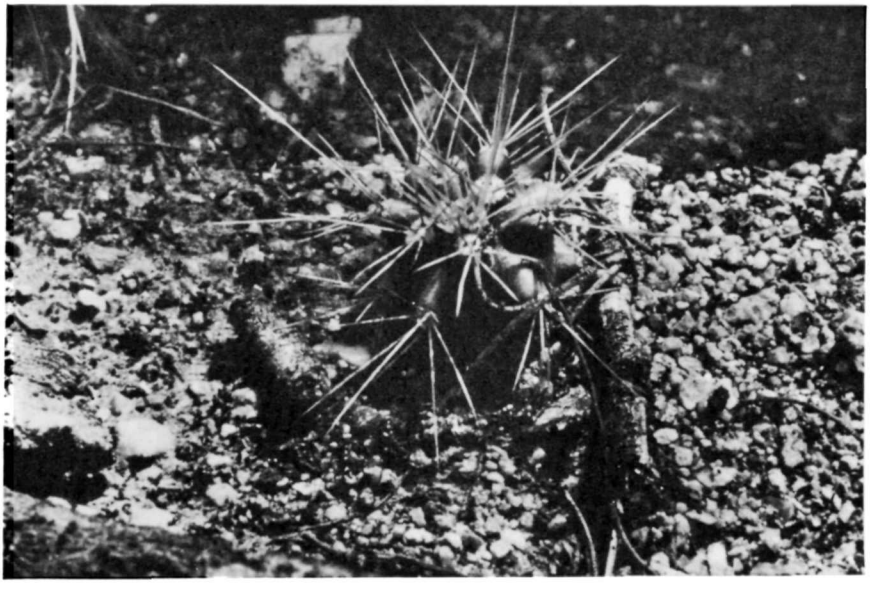

Fig. 5. Globose juvenile saguaro, age 26 months, height approximately 1 cm. Plants of this form (age 1 to ca. 7 years, heights to ca. 2.5 cm) are highly vulnerable to freeze-caused injury and death. Photographed 13 August 1971 by Harold T. Coss.

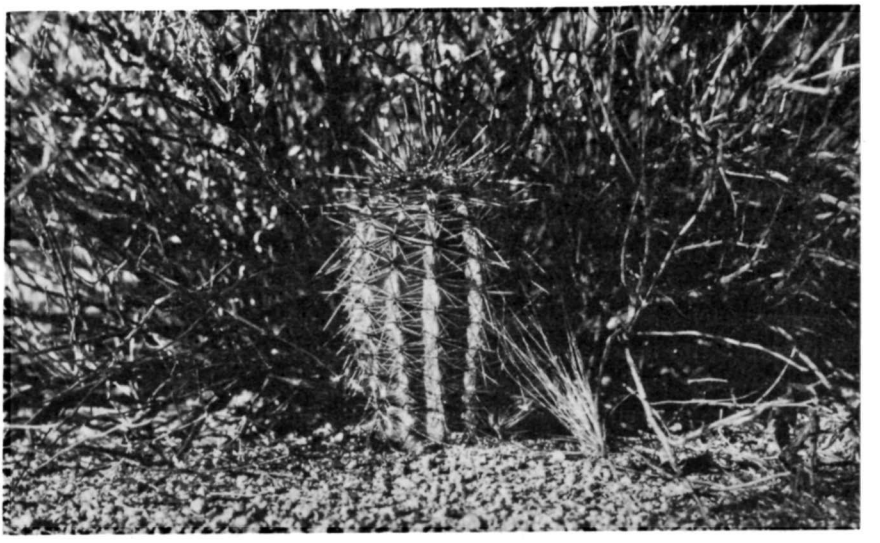

Fig. 6. Columnar juvenile saguaro, height 12.5 cm. Resistance of such plants to death from freezing increases with age-related changes in size, volume, and form. Photographed 19 January 1971.

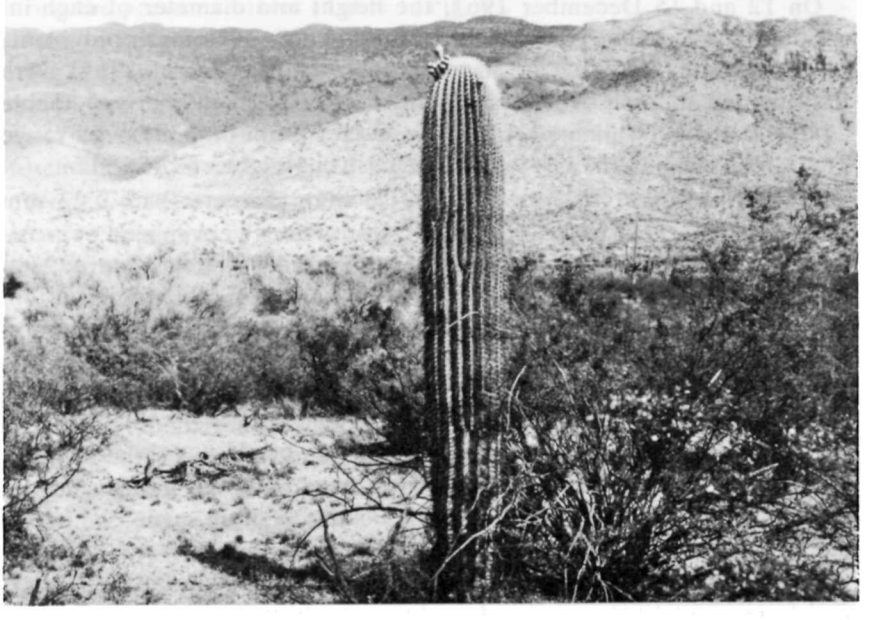

Fig. 7. Young adult saguaro, height 2.1 m (7 ft) in first or second year of flower production. Saguaros with this form (approximately 1.0–3.5 m height; 3–11.5 ft) are relatively freeze resistant. Photographed 19 June 1965. Most saguaro deaths from catastrophic freezing occur mainly in smaller juvenile and larger adult size classes of the population.

Periodic observations 3 January to 2 August 1971 on seedlings surviving from 1968 seed-broadcasting experiments in natural microenvironments were made to obtain survivorship data on 30-month-old plants at Saguaro Monument (east) flats (Table 6; Fig. 15). Observations were made to 8 April 1971 for data on comparative survival in different habitats (Table 7; Figs. 13, 14, 16), and for shielded and unshielded microenvironments (Table 8; Fig. 17). Unshielded plots were covered with round (61 cm dia. × 30 cm ht.) 0.5-inch mesh (1.3 cm) hardware-cloth exclosures; shielded plots were covered with 16 mesh (0.16 cm) window-screen exclosures of identical size.

Continuing previously reported studies on critical factors in saguaro establishment and survival (Steenbergh and Lowe 1969), the experiment utilizing transplanted juvenile saguaros to obtain additional information on minimum temperatures and winter mortality of saguaros in differing types of habitats and microenvironments was initiated in December 1967. Saguaros used in the experiment were germinated during the summers of 1964 and 1965, and grown outdoors under partial shade in wooden flats containing native soil. Seedlings were provided with supplemental water during the first growing season, and received water only from natural rainfall thereafter.

On 12 and 15 December 1967, the height and diameter of each individual were measured with calipers, and four 42-month-old plants (class of 1964) and sixteen 30-month-old plants (class of 1965) were transplanted to each of nine study sites (N = 20 plants per site, Table 2). Height of 1964 plants (N = 36) was 20.14 mm (±0.38), with range 16-24 mm; diameter was 18.44 mm (±0.40). Height of 1965 plants (N = 144) 10.61 mm (±0.16), range 7-16 mm; diameter was 9.22 mm (±0.21), range 6-14 mm. In each plot, transplants were spaced approximately 10 cm apart in five rows of four plants each, lightly watered, and the plot was covered with a 0.5-inch mesh hardware-cloth cage (30 cm ht. × 61 cm dia.) to exclude mammals and birds. Taylor maximum-minimum thermometers were installed at each site on 20 December. Each thermometer, provided with a cylindrical condensation shield (6.5 × 16-cm tin can with ends removed), was placed horizontally adjacent to the cage with a sensing bulb approximately 2 cm above the soil surface. At approximately 1-week intervals beginning 3 January, the indicated minimum temperature and the condition of all saguaros at each site were recorded (Tables 2, 3, 4; Figs. 9, 10, 11, 12).

Thermometers at the Saguaro Monument (east) flats open (SEFO) and tree-crown canopied (SEFC) sites were destroyed by vandals after the 10 January observation. Mean and 21 February temperatures for these two sites (shown in Table 2; Figs. 9, 10) were estimated using the 3 and 10 January observations and from nearby thermometer readings.

During the winter of 1968-69, further data on winter mortality was obtained using outdoor, pot-grown, first-year seedlings at three of the same Saguaro Monument (east) habitats used the previous winter (rocky north-facing slopes, rocky south-facing slopes, and flats). Seedlings which germinated about 8 September 1968, in waxed cardboard tubs (6 × 9 cm) provided with bottom drainage and filled with native soil, were grown outdoors in partial shade. Seedlings were watered weekly until mid-November when they had reached approximately the same size as first-year wild seedlings (ca. 3 mm aboveground stem height, Fig. 3). Seedlings received water only from natural rainfall after 15 November. On 13 December a tub with rooted seedlings intact was "planted" in a shallow excavation at each experimental site in the natural manner, i.e., with seedlings and the soil surface within the tub all flush with the natural ground surface. Seedlings in each tub were counted (Table 1) and covered with a single layer of Armex Polyprophylene Shading Fabric (46% shade) to prevent possible sunscald injury. Each plot was then covered with a 30 × 61-cm, 0.5-inch mesh hardware-cloth cage and a Taylor self-registering thermometer installed as in the 1967-68 winter experiment. Observations on temperature and seedling condition were also carried out in the same manner as during the previous winter (Table 1; Fig. 8).

Tucson temperature data at the University of Arizona Station graphed in Fig. 25 are from U.S. Weather Bureau Climatic Data Summaries for Tucson, Arizona (1894-1971). There and elsewhere in this paper, temperatures are reported as recorded in degrees Fahrenheit to simplify presentation of the data and facilitate comparisons here.

Winter measurements (December) referred to here for nocturnal radiative shielding by natural vegetation canopies and artificial covers were recorded with a Stoll-Hardy infrared radiometer. The saguaro supercooling limits reported were determined experimentally by continuous recording of the stem-core temperature during cooling, supercooling, and freezing. Tissue implant thermistor probes (calibrated, ±0.01°C) were imbedded in intact saguaros placed singly in pyrex respiration chambers and submerged in an ethylene-glycol water bath cooled to subfreezing temperatures. Additional samples were monitored with special fine bulb, rapid-adjusting thermometers in constant temperature cold-rooms held at subfreezing temperatures.

Age-height relationships, shown in Table 13 and Fig. 24, are based on saguaro growth curves for plants less than 1 m high from on-going investigations by the authors and studies reported by Shreve (1910) and Hastings and Alcorn (1961).

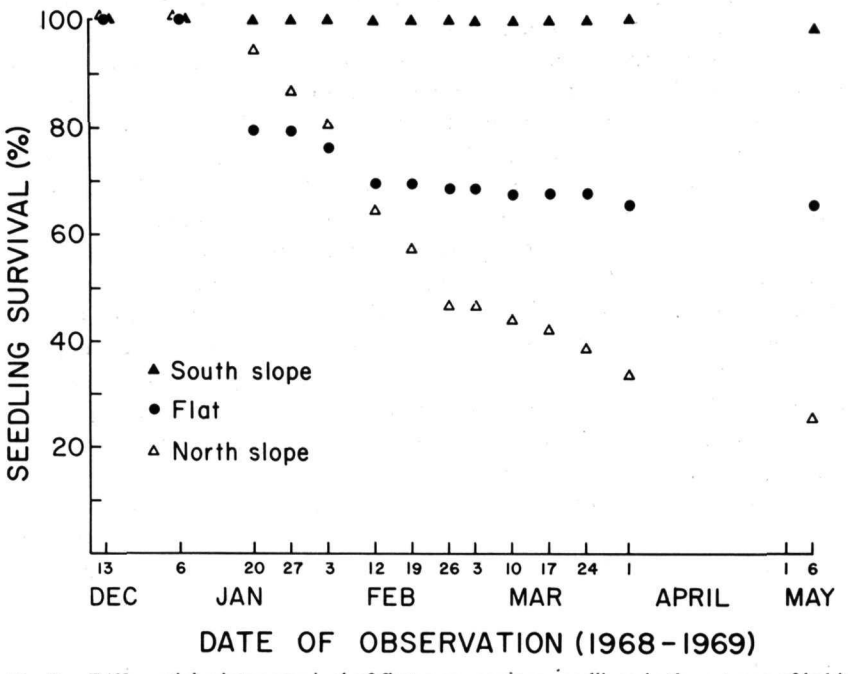

Fig. 8. Differential winter survival of first-year saguaro seedlings in three types of habitat at Saguaro National Monument, east, 13 December 1968 to 6 May 1969. Symbols indicate percent of the original population surviving on the date of observation in flat (circles, N = 92), rocky south slope (solid triangles, N = 109), and rocky north slope (open triangles, N = 107) habitats. Data in Table 1. All seedling deaths occurred as a result of freezing. Progressive die-off of seedlings occurs as a delayed response to different degrees of simultaneously occurring critical injuries from freezing.

RESULTS AND DISCUSSION

Freezing weather was the primary cause of winter deaths in all populations of known-age seedlings and juvenile saguaros observed during this investigation. Experimental data are provided. Insects were the only other observed cause of winter mortality of young saguaros.

The 1968-69 Experiment

First-year saguaro seedling survival and associated minimum temperatures in rocky north slope, in rocky south slope, and in flat habitats are shown in Table 1 and Fig. 8. Differential survival associated with differences in the winter thermal environments of each of these three types of habitats is critical to seedling establishment, i.e., survival from germination to the beginning of the second year of life.

TABLE 1. Winter minimum temperatures and survival of first-year saguaro seedlings in three types of habitat at Saguaro National Monument (east), 13 December 1968 to 6 May 1969. Temperatures are the lowest minimum temperature (°F) recorded during the interval since the last observation. Data graphed in Fig. 8.

Date (1968–69)	Rocks–S. Slope			Rocks–N. Slope			Flats		
	Survivors			Survivors			Survivors		
	No.	Percent	Min. T	No.	Percent	Min. T	No.	Percent	Min. T
13 December	109	100.0		107	100.0		92	100.0	
31 December	109	100.0	22	107	100.0	19	92	100.0	17
6 January	109	100.0	30	107	100.0	26	92	100.0	27
20 January	109	100.0	40	101	94.4	36	73	79.4	32
27 January	109	100.0	40	93	86.9	38	73	79.4	38
30 January	109	100.0	26	93	86.9	24	73	79.4	21
3 February	109	100.0	27	86	80.4	24	70	76.1	22
12 February	109	100.0	34	69	64.5	29	64	69.6	29
19 February	109	100.0	36	61	57.0	35	64	69.6	31
26 February	109	100.0	31	50	46.7	31	63	68.5	29
3 March	109	100.0	32	50	46.7	31	63	68.5	29
10 March	109	100.0	31	47	43.9	31	62	67.4	26
17 March	109	100.0	28	45	42.1	28	62	67.4	26
24 March	109	100.0	36	41	38.3	37	62	67.4	33
1 April	109	100.0	37	36	33.6	36	60	65.2	33
6 May	107	98.2		27	25.2		60	65.2	

The observable ultimate death of young plants may be delayed for a period of weeks or months after the occurrence of critical subfreezing temperatures. The length of time from critical freeze-caused injury to observable death depends upon the severity of the original injury and the directly resulting desiccation associated with warming temperatures during late winter and early spring. The severity of freeze-caused injury may be increased by subsequent occurrences of subfreezing temperatures. In summary, during this period of observation (5 months), 37% of all saguaros in the sample died from freezing.

The 1967-68 Experiment

Winter minimum temperatures and associated survival and mortality of 30- and 42-month-old juvenile saguaros (N = 180) at Saguaro National Monument during the winter of 1967-68 are shown in Tables 2 and 3 and Figs. 9 and 10. Freeze-caused damage was first observed on 3 January 1968, following the occurrence of critically low temperatures between 20 December and 3 January. Deaths resulting from these injuries were first confirmed on 17 January and continued through 27 March when the last freeze-caused death was recorded.

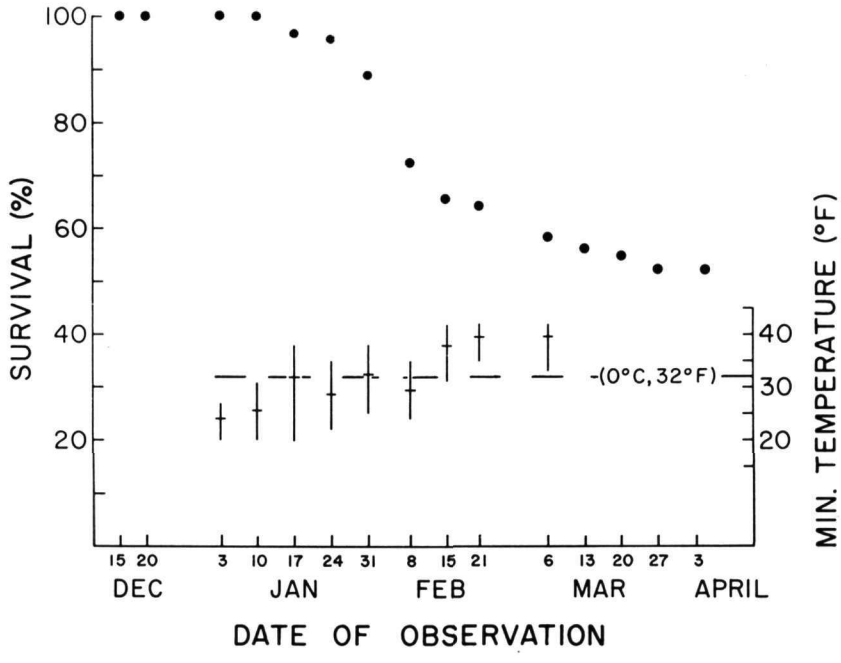

Fig. 9. Winter survival summary for known-age (30 and 42 months) juvenile saguaros (N = 180) at nine sites, Saguaro National Monument, 15 December 1967 to 3 April 1968, and associated ground-level minimum temperatures from 20 December to 6 March. Circles indicate percent of plants living on date of observation. Temperatures shown are the mean (cross-bar) and range (vertical bar) of the extreme minimum temperatures recorded at individual sites during the period between each observation. Temperatures are reported for all sites (N = 9) to 10 January and seven sites thereafter (no subsequent record available thereafter for two sites at Saguaro Monument, east, flats). Data in Tables 2 and 3. The ultimate collapse and observable death of young plants critically damaged by subfreezing January temperatures continued through February and March.

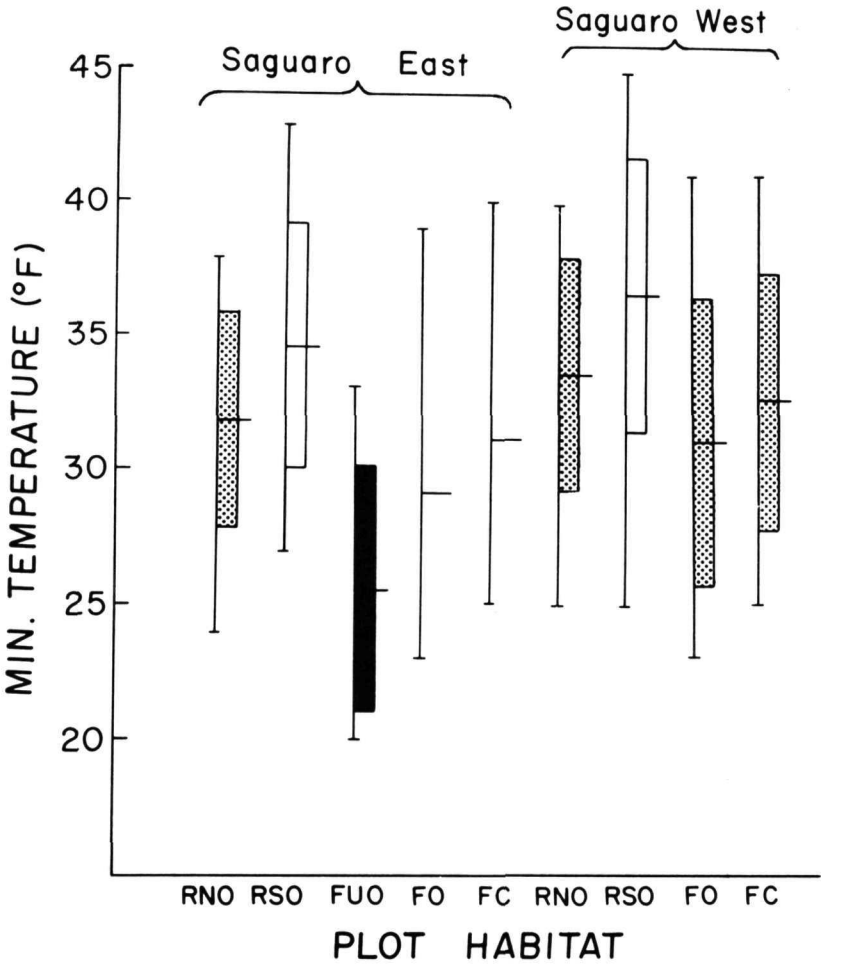

Fig. 10. Minimum temperatures (°F) at nine experimental sites, Saguaro National Monument, 20 December 1967 to 6 March 1968. Range, mean, and 95% confidence interval for the ground-level minimum temperatures at each site (N = 9 observations, see Table 2). Minimum temperatures at both rocky south-facing slope sites (white bar) are significantly different ($P < 0.05$) from the lower temperatures recorded in the cold-air drain at the wash site (black bar).

TABLE 2. Extreme minimum temperatures °F (ground-level) at 9 experimental sites, Saguaro National Monument, 20 Dec. 1967 to 6 March 1968. Values shown are the lowest minimum temperature recorded during the interval since the last observation (3 Jan. observation is for the period beginning 20 Dec.) Data graphed in Figs. 9 and 10.

Plot site symbols: SW = west monument, SE = east monument, R = rocky habitat, F = flat habitat, N = north slope exposure, S = south slope exposure, O = open site (no cover), C = under tree crown (*Cercidium microphyllum*), and U = unpaired site adjacent to wash in cold air drain.

Date (1968)	Plot									Mean
	SEFC	SEFO	SEFUO	SERNO	SERSO	SWFC	SWFO	SWRNO	SWRSO	
3 January	25	24	20	24	27	25	23	25	25	24.2
10 January	25	23	20	27	31	26	23	27	30	25.8
17 January			20	33	37	33	30	33	38	32.0
24 January			22	28	33	28	26	30	35	28.9
31 January			25	31	39	31	30	35	38	32.7
8 February			24	30	27	29	28	33	35	29.4
15 February			31	38	33	41	41	40	42	38.0
21 February	40	39	35	38	42	41	39	40	42	39.6
6 March			33	38	43	40	39	40	45	39.7
Mean	30.8	29.1	25.6	31.9	34.7	32.7	31.0	33.7	36.7	

On 3 January the stems of some injured plants exhibited white to yellow discoloration on the south side. By 10 January, severely damaged plants had a watery dark-green or black appearance, and desiccation of some individuals was evident. On 17 January, desiccation and collapse of six individuals had progressed to the extent that death could be confirmed. Similar symptoms preceded subsequently recorded deaths. Only one of the 86 recorded deaths was caused by insects.

As in the case reported above for 1968-69, survival at each of the nine 1967-68 winter study sites was associated with differences in winter minimum temperatures. Higher survival was associated with warmer sites as indicated by the recorded minimum temperatures (Tables 2, 4, 5; Figs. 10, 11, 12). The greatest survivorship, on rocky south-facing slopes, was associated with the highest mean minimum temperatures. Least survivorship was on north-facing slopes where minimum temperature means were 3.0°F (SW) and 3.8°F (SE) lower than those recorded on the opposing south-facing slopes. The survival and minimum temperature data suggest that the duration as well as the low extremes of temperature critically limit survival on north-facing slopes.

It is important to understand that saguaros do not freeze at 32°F—they supercool. Measured supercooling limits for saguaros from the Tucson region are −3.1°C to −12.4°C (mean −6.6°C, 20.1°F); this

TABLE 3. Cumulative winter mortality and percent survival of known-age (30–42 month) juvenile saguaros (N = 180) at 9 sites in Saguaro National Monument, 15 December 1967 to 3 April 1968. Data graphed in Fig. 9.

Date (1967–68)	Mortality No.	Survival	
		No.	%
15 December	0	180	100.0
3 January	0	180	100.0
10 January	0	180	100.0
17 January	6	174	96.7
24 January	8	172	95.6
31 January	20	160	88.9
8 February	50	130	72.2
15 February	62	118	65.6
21 February	64	116	64.4
6 March	75	105	58.3
13 March	79	101	56.1
20 March	82	98	54.4
27 March	86	94	52.2
3 April	86	94	52.2

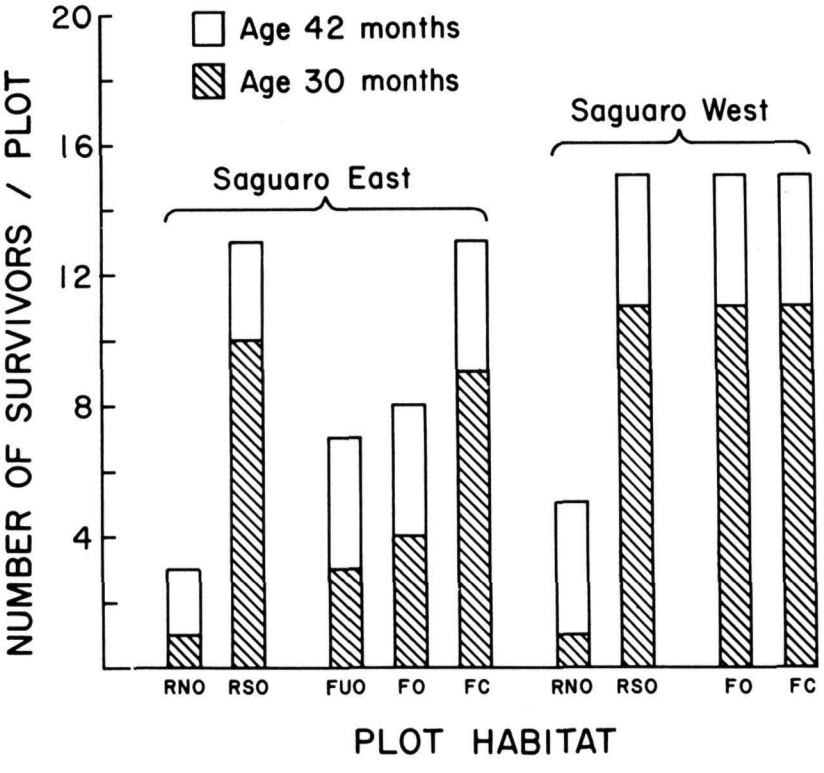

Fig. 11. Survival of known-age juvenile (30 and 42 months) saguaros (N = 180) in nine experimental plots at Saguaro National Monument, east (SE) and west (SW), 15 December 1967 to 3 April 1968. Survival is shown as number of individuals per plot (N = 20) living on 3 April 1968. Shaded portion of each bar represents the number of surviving 30-month-old plants (class of 1965, N = 16). Unshaded portion represents the number of surviving 42-month-old plants (class of 1964, N = 4). Plot symbols: R = rocky habitat, N = north-facing slope, S = south-facing slope, F = flat habitat, C = under paloverde tree crown, O = open site (no cover plant), U = unpaired plot adjacent to wash in cold-air drain. Data in Table 4. Eighty-six of the 180 plants died between 10 January and 3 April; 85 deaths were caused by freezing, one individual was eaten by an insect (class of 1965, SE-RSO site).

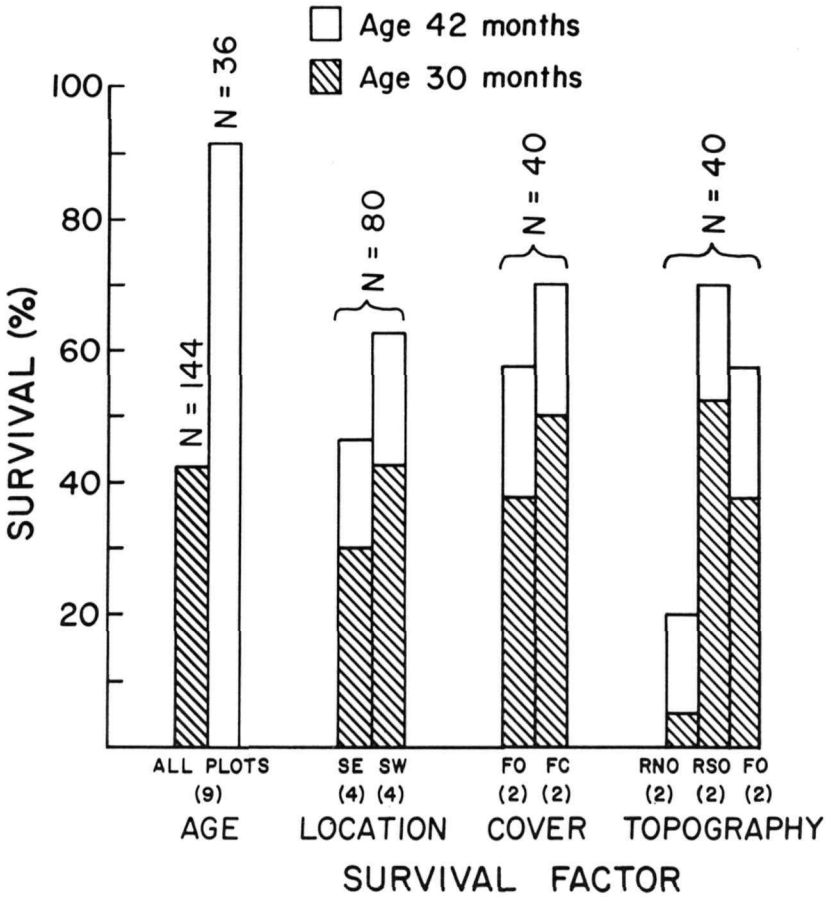

Fig. 12. Differential survival of known-age juvenile saguaros at Saguaro National Monument, 15 December 1967 to 3 April 1968. Shaded portion of each bar represents surviving 30-month-old plants (class of 1965), ht. 10.61 mm (±0.16). Unshaded portion represents surviving 42-month-old plants (class of 1964), ht. 20.14 mm (±0.38). Plot symbols as in Table 2. Data in Table 5. Differential winter mortality from freezing occurred according to (1) differences in age (plant size); (2) geographic location (Saguaro Monument, east, and Saguaro Monument, west); (3) presence or absence of associated plant cover (paloverde tree, *Cercidium microphyllum*); and (4) topography (slope and direction of slope exposure). Number of plots in each group is shown in parenthesis.

TABLE 4. Summary of winter survival of known-age (30–42 month) juvenile saguaros in nine experimental plots at Saguaro National Monument east (SE) and west (SW), 15 December 1967 to 3 April 1968. N = 20 plants per plot: four 42-month-old plants (class of 1964), and sixteen 30-month-old plants (class of 1965). Data graphed in Fig. 11.

Symbol	Plot Habitat	Cover	Survivors					
			Class of 1964		Class of 1965		Total	
			No.	%	No.	%	No.	%
SERNO	Rocks, N. Slope	Open	2	50.0	1	6.2	3	15.0
SERSO	Rocks, S. Slope	Open	3	75.0	10[a]	62.5	13	65.0
SEFUO	Flats, Wash	Open	4	100.0	3	18.8	7	35.0
SEFO	Flats, Level	Open	4	100.0	4	25.0	8	40.0
SEFC	Flats, Level	Tree	4	100.0	9	56.2	13	65.0
SWRNO	Rocks, N. Slope	Open	4	100.0	1	6.2	5	25.0
SWRSO	Rocks, S. Slope	Open	4	100.0	11	68.8	15	75.0
SWFO	Flats, Level	Open	4	100.0	11	68.8	15	75.0
SWFC	Flats, Level	Tree	4	100.0	11	68.8	15	75.0
Total			33	91.7	61	42.4	94	52.2
N =			36		144		180	

[a]Mortality includes one insect-kill.

range is from 26.4 to 9.9°F (see Lowe 1959). Assuming the same supercooling capacity for the juvenile saguaro in these experiments, a difference of 3-4°F between slope exposures on coldest nights, as recorded, demands significantly different saguaro survival rates, as determined (Tables 2, 4, 5).

Differential winter mortality from freezing of 30- and 42-month-old juvenile saguaros occurred with differences (1) in age (plant size); (2) geographic location (east and west sections of the monument); (3) presence or absence of plant cover (paloverde tree, *Cercidium microphyllum*); and (4) topography (slope and direction of slope exposure. See Tables 4, 5, and Fig. 12). The survival percentage (42.4%) for 30-month-old plants was less than half the survival percentage (91.7%) for 42-month-old plants. Survival at four east monument sites (46.2%) was lower than at four equivalent west monument sites (62.5%). Survivorship of plants in exposed plots was lower (57.5%) than survivorship in adjacent plots under paloverde tree (*C. microphyllum*) crown cover (70.0%). Highest survival (70.0%) was in south-facing slope habitats, the lowest survival, on north-facing slopes (20.0%). Survival in exposed flat habitats was intermediate (57.5%). In summary, during the period of observations (3.5 months), 48% of the saguaros in the sample died.

TABLE 5. Differential survival of known-age juvenile saguaros at nine sites, Saguaro National Monument, from 15 December 1967 to 3 April 1968. Mean height of 1964 plants (age 42 months) 20.14 mm (±0.38), height of 1965 plants (age 30 months) 10.61 mm (±0.16). Data graphed in Fig. 12. Plot site symbols as in Table 1.

Sites	No.	Class of 1964			Class of 1965			Total		
			Survival			Survival			Survival	
		N	No.	%	N	No.	%	N	No.	%
SW[a]	4	16	16	100.0	64	34	53.1	80	50	62.5
SE[a]	4	16	13	81.2	64	24	37.5	80	37	46.2
SEU	1	4	4	100.0	16	3	18.8	20	7	35.0
All plots	9	36	33	91.7	144	61	42.4	180	94	52.2
RNO	2	8	6	75.0	32	2	6.2	40	8	20.0
RSO	2	8	7	87.5	32	21[b]	65.6	40	28	70.0
FO	2	8	8	100.0	32	15	46.9	40	23	57.5
SEU	1	4	4	100.0	16	3	18.8	20	7	35.0
FO	2	8	8	100.0	32	15	46.9	40	23	57.5
FC	2	8	8	100.0	32	20	62.5	40	28	70.0

[a]Paired sites only.
[b]Mortality includes one insect-kill.

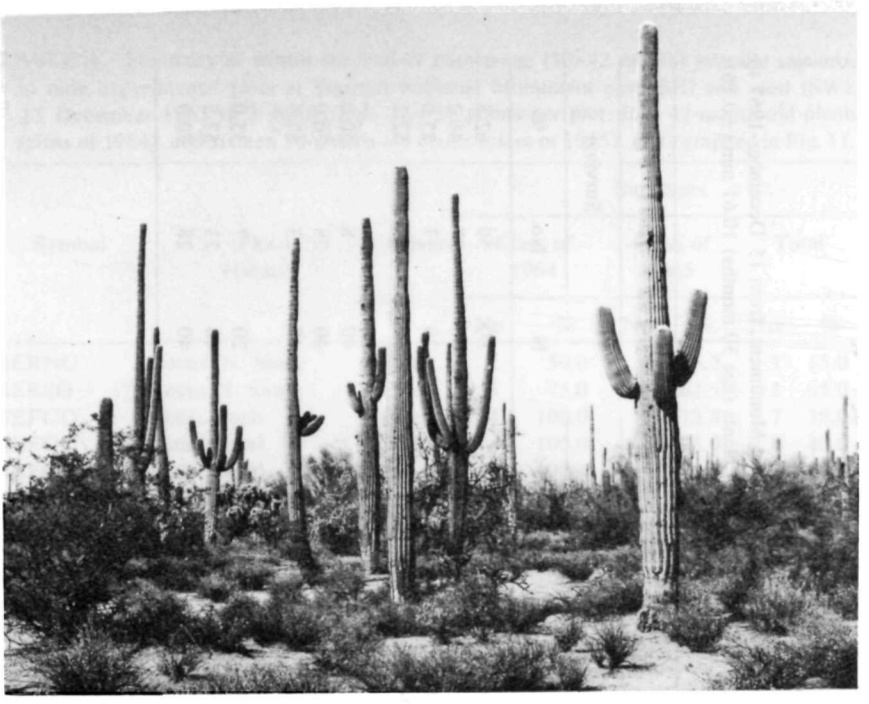

Fig. 13. Flat habitat, Saguaro National Monument, Tucson Mountain Section. In this location, the saguaro occurs with paloverde (*Cercidium microphyllum*) and desert iron wood (*Olnyea tesota*) trees. Small saguaros are usually found beneath the crown of the predominant shrub (*Ambrosia deltoidea* = *Franseria deltoidea*). Photographed 16 April 1971.

The 1971 Catastrophic Freeze

High winter mortality of seedlings and juvenile saguaros followed the period of critical subfreezing temperatures from 3 to 10 January 1971. Low minimum temperatures recorded at Tucson during the period ranged from 11°F on 7 January (Campbell Avenue Experimental Farm) to 19°F on 5 January (University of Arizona); data are from U.S. Weather Bureau (1971).

Winter survival of 30-month-old naturally growing juvenile plants in a 0.25-m^2 plot located under the crown of a large *Cercidium microphyllum* at Saguaro Monument (east) is graphed in Fig. 15 (Table 6). Fifty-three (51.5%) of the 103 plants died as a result of the January freezing injuries and 25 plants (24.3%) were consumed by insects. Thirteen of the 25 remaining plants (52.1%) suffered obvious freeze-caused injuries that deformed their stems. Three severely freeze-deformed plants died during the hot months of May, June, and July. All insect-caused deaths occurred between 11 February and 25 March. A mature cutworm found

Fig. 14. Rocky south-facing slope habitat. Saguaro National Monument. Tucson Mountain Section. This winter-warm habitat supports a vigorous stand of saguaros with abundant representation of juvenile and young adult plants. Photographed 16 April 1971.

feeding on young saguaros in an adjacent plot on 25 March was identified as *Orthodes alfkeni* Grote, a common native noctuid moth with general (nonspecific) plant-feeding habits.

Winter survival of 30-month-old naturally growing saguaros under tree canopy and situated in flat, rocky north-facing and rocky south-facing slope habitats, is shown in Table 7 and Fig. 16. On 8 April, 57.9% (239 individuals) of the plants were dead from the January freeze-caused injury. Lowest mortality was on south-facing slopes. The highest mortality occurred on north-facing slopes and in flat habitats.

Mortality of 30-month-old juvenile saguaros in screen-shielded plots was substantially lower (22.3%) than mortality in paired, unshielded (mesh-covered) plots (64.9%, see Table 8 and Fig. 17). The nocturnal thermal shading effect of the two screening materials is markedly different, as reflected in the greater winter freeze-kill mortality under 0.5-inch mesh hardware-cloth than under window-screen. The more efficient window-screen reduced the nocturnal radiative heat loss to the zenith sky by 0.486 cal/min/cm^2 compared to the hardware-cloth mesh.

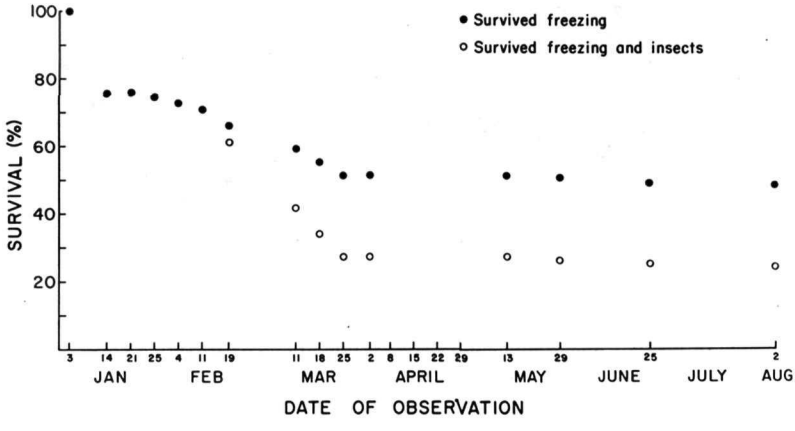

Fig. 15. Survival summary for 30-month-old saguaros (class of 1968) on flat habitat site (SEF, Fig. 7), Saguaro National Monument, east, 3 January to 2 August 1971. Open circles represent percent of original population (N = 103) surviving on the date of observation. Solid circles represent percent survival, insect-kill excluded, i.e., freeze survival. Data in Table 6. All insect-kill (25 plants consumed) occurred between 11 February and 25 March. All other deaths resulted from exposure to critical subfreezing temperatures occurring during the week beginning 3 January. Deaths recorded during May, June, and August (3 plants) were the ultimate result of January freeze damage that destroyed approximately 50% of the stem tissues of those plants.

TABLE 6. Cumulative winter mortality and percent survival of 30-month-old juvenile saguaros (class of 1968) at Saguaro National Monument (east), flats, 3 January to 2 August 1971. Data graphed in Fig. 15 (Survivorship).

Date (1971)	Cumulative Mortality				Survival	
	Insect		Freezing			
	No.	%	No.	%	No.	%
3 January	0	0.0	0	0.0	103	100.0
14 January	0	0.0	25	24.3	78	75.7
21 January	0	0.0	25	24.3	78	75.7
28 January	0	0.0	26	25.2	77	74.8
4 February	0	0.0	28	27.2	75	72.8
11 February	0	0.0	30	29.1	73	70.9
19 February	5	4.9	35	34.0	63	61.2
11 March	18	17.5	42	40.8	43	41.7
18 March	23	22.3	45	43.7	35	34.0
25 March	25	24.3	50	48.5	28	27.2
2 April	25	24.3	50	48.5	28	27.2
8 April	25	24.3	50	48.5	28	27.2
15 April	25	24.3	50	48.5	28	27.2
22 April	25	24.3	50	48.5	28	27.2
29 April	25	24.3	50	48.5	28	27.2
13 May	25	24.3	50	48.5	28	27.2
29 May	25	24.3	51	49.5	27	26.2
25 June	25	24.3	52	50.5	26	25.2
2 August	25	24.3	53	51.5	25	24.3

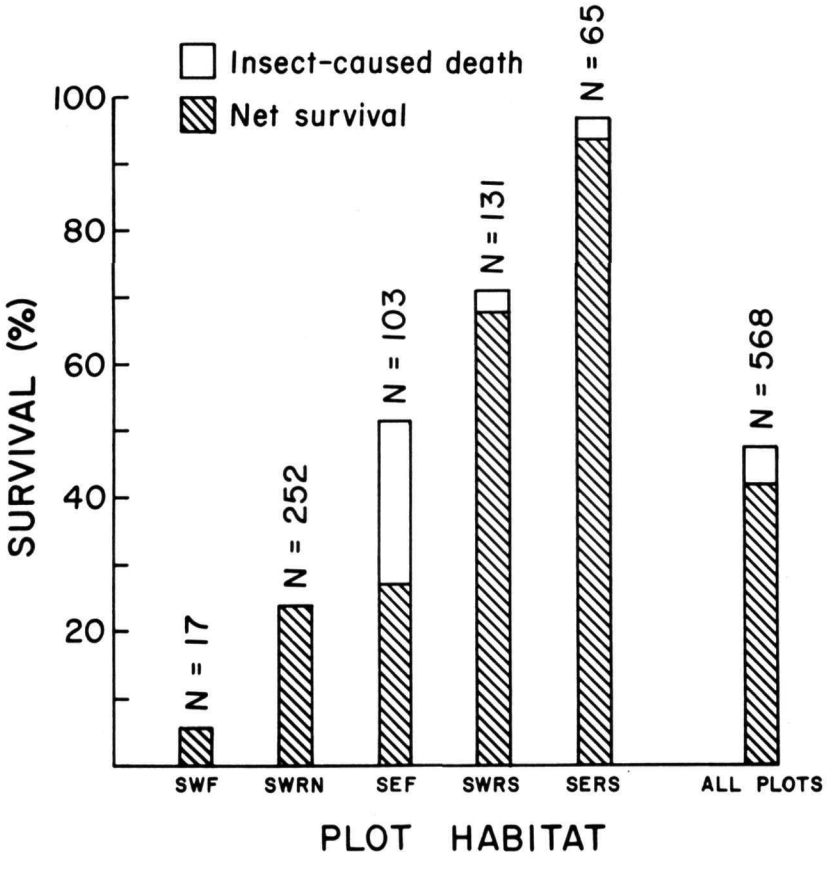

Fig. 16. Winter survival of 30-month-old (class of 1968) saguaros in five habitats at Saguaro National Monument, 3 January to 8 April 1971. Total bar height represents percentage of plants that survived freeze-caused damage. Unshaded portion represents insect-caused deaths. Shaded portion represents net survival. Habitat designations are: SE = east monument, SW = west monument, F = flats, RN = rocky north-facing slope, RS = rocky south-facing slope. Data in Table 7. During critically cold winters, south-facing slopes offer the most suitable sites for survival of young plants. Relatively high mortality in 1971 was again associated with flat and north-facing slope habitats.

TABLE 7. Winter survival and mortality of 30-month-old saguaros (class of 1968) in five habitats at Saguaro National Monument, 3 January to 8 April 1971. Habitat designations are: SE = east monument, SW = west monument, F = flats, RN = rocky north-facing slope, and RS = rocky south-facing slope. Data graphed in Fig. 16 (Survivorship).

Loc.	N	Live		Freeze Kill		Insect Kill	
		No.	%	No.	%	No.	%
SWF	17	1	5.9	16	94.1	0	0
SWRN	252	60	23.8	192	76.2	0	0
SEF	103	28	27.2	50	48.5	25	24.3
SWRS	131	89	67.9	38	29.0	4	3.1
SERS	65	61	93.8	2	3.1	2	3.1
Total	568	239	42.1	298	52.5	31	5.5

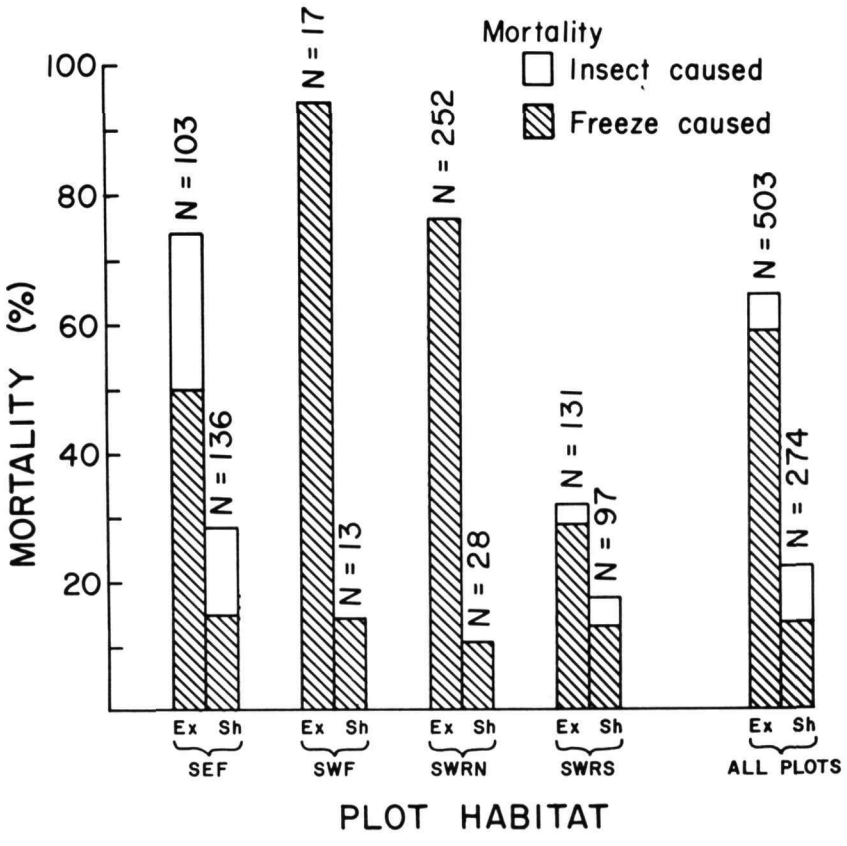

Fig. 17. Differential mortality of young saguaros (age 30 mos.) in shielded (Sh) and exposed (Ex) plots at Saguaro National Monument, 3 January to 8 April 1971. Plot locations are: SE = east monument, SW = west monument, F = flats, RN = rocky north-facing slope, and RS = rocky south-facing slope. Shaded portion of each bar represents percent of freeze-caused deaths. Unshaded portion represents percent of insect-caused deaths occurring during the period (see Table 8). The moderating effect of low canopy during critically cold periods is evident in the substantially lower mortality within shielded plots. Freeze-caused deaths within window-screen shielded plots ranged from 53.8% to 83.6% (mean 76.4%) less than in the paired exposed (mesh-covered) plots. Acting in a similar manner, low-shrub canopy moderates the severity of freezing conditions providing a warmer thermal microenvironment favorable for the survival of young saguaros during critically cold winter nights.

TABLE 8. Winter mortality of 30-month-old (class of 1968) saguaros in shielded and unshielded (= exposed) plots at Saguaro National Monument. Data recorded are freeze-caused (Fr) and insect-caused (In) deaths in eight experimental plots, 3 January to 8 April 1971. At four sites, shielded plots covered with a 16-mesh (0.16 cm) window-screen exclosure were paired with exposed plots covered with a 0.5-inch mesh (1.3 cm) hardware-cloth exclosure, each located beneath the crown of a mature *Cercidium microphyllum*. Locations are: SE = east monument, SW = west monument, F = flats, RN = rocky north-facing slope, and RS = rocky south-facing slope. Data graphed in Fig. 17.

Plot Loc.	Under *Cercidium* Nurse-Plant													
	Unshielded, Under Canopy							Screen Shielded, Under Canopy						
	N	Fr.	%	In.	%	Tot.	%	N	Fr.	%	In.	%	Tot.	%
SEF	103	51	49.5	25	24.3	76	73.8	136	20	14.7	19	14.0	39	28.7
SWF	17	16	94.1	0	0.0	16	94.1	13	2	15.4	0	0.0	2	15.4
SWRN	252	192	76.2	0	0.0	192	76.2	28	3	10.7	0	0.0	3	10.7
SWRS	131	38	29.0	4	3.0	42	32.0	97	13	13.4	4	4.1	17	17.5
Total	503	297	59.0	29	5.8	326	64.8	274	38	13.9	23	8.4	61	22.3

The difference is equivalent to 9°F (5°C), which is a significant and large nocturnal difference. Acting in a similar manner, low shrubs and tree cover provide a natural and relatively favorable thermal microenvironment for the survival of young saguaros during critically cold winter nights (see Lowe and Hinds 1972).

Age, Height, and Mortality

Age-class winter mortality of young saguaros (seedlings and globose juveniles, lst through 7th year of life) in flat habitat is shown in Table 9 and Fig. 18. The data clearly indicate greater freeze-susceptibility in this microenvironment during the first 1-4 years of life. There was zero mortality of 5th year and older plants. Vulnerability of young plants to destruction by freezing varies with age (i.e., size) of the young plant.

Height-class freeze-caused mortality and deforming injury of juvenile saguaros less than 120 cm in height in flat habitats is shown in Table 10 and Fig. 19. Observable deforming injuries to stem tissues occurred in all height-classes. Only plants less than 30 cm in height were completely destroyed by freezing (Fig. 20). Resistance of juvenile saguaros to death from freezing increases with age-related changes in the size and form of the plants (Figs. 1, 4, 5, 6).

Population Structure and the Climatic Record

Height-class distribution of freeze-caused saguaro deaths in natural populations at Saguaro National Monument, resulting from recent catastrophic freezes, in January 1962 and January 1971,are shown in Tables 11, 12, and Fig. 21. In both samples, the highest rates of mortality were in the smallest and largest plant size-classes (Figs. 20, 22, 23). The combined freeze-caused mortality data for both years show that freezing killed 15.4% of the plants less than 0.45 m in height, 2.0% of the plants 0.46- 3.80 m in height, and 12.0% of all plants over 3.80 m in height.

It is clear from these data that catastrophic freezing selectively structures saguaro populations, removing the smallest (youngest) and the largest (oldest) plants, leaving a high percentage of the large juvenile and unbranched young adult plants with heights from 0.46 to 3.80 m (1.5-12.5 ft, Fig. 7). The size-class (= age) structure of the saguaro population at Saguaro National Monument (east) flats extant in 1942 (Table 13; Fig. 24) is that of a declining population (Gill 1951; Gill and Lightle 1942, 1946; Mielke 1944). The estimated age-ranges assigned to the size-classes represented in that population permits deterioration of the approximate year of their germination. Thus the age- and height-range of the surviving plants in each class can be estimated for a previous

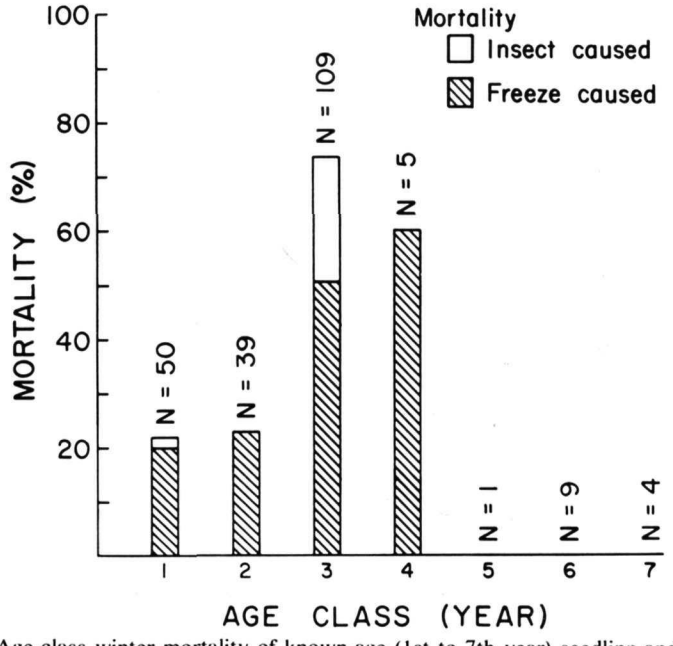

Fig. 18. Age-class winter mortality of known-age (1st to 7th year) seedling and juvenile saguaros in flat habitat at Saguaro National Monument, east. 3 January to 8 April 1971. Shaded portion of bar represents percent of freeze-caused mortality; unshaded portion represents insect-caused mortality. Vulnerability of young plants to destruction by freezing varies with the age, i.e., size of the young plant. The data clearly indicate greater freeze susceptibility in this microenvironment during the first 1–4 years of life. There was zero mortality during and after 5 years. Data in Table 9.

TABLE 9. Winter mortality of known-age seedlings and juvenile saguaros in flat habitat at Saguaro National Monument (east), 3 January to 8 April 1971. Data graphed in Fig. 18.

Age Class (Yr.)	Yr. Germ.	N	Survivors		Deaths			
					Freezing		Insects	
			No.	%	No.	%	No.	%
1	1970	50	39	78.0	10	20.0	1	2.0
2	1969	39	29	74.4	9	23.1	0	0.0
3	1968	109	29	26.6	55	50.5	25	22.9
4	1967	5	2	40.0	3	60.0	0	0.0
5	1966	1	1	100.0	0	0.0	0	0.0
6	1965	9	9	100.0	0	0.0	0	0.0
7	1964	4	4	100.0	0	0.0	0	0.0
Total		217	113	52.1	77	35.5	26	12.0

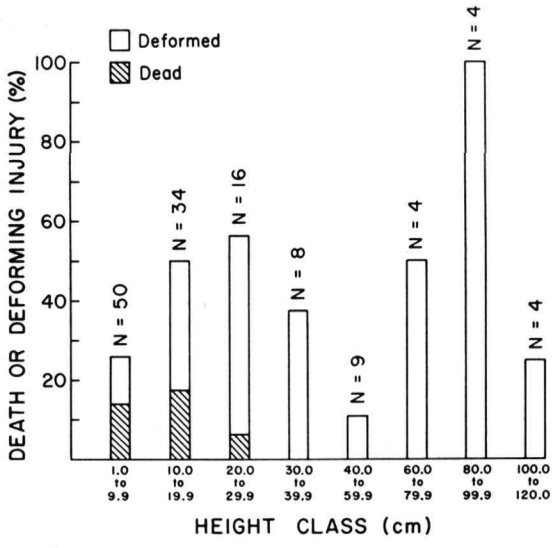

Fig. 19. January 1971 freeze-caused mortality and deforming injury of juvenile saguaros (N = 129) in flat habitats at Saguaro National Monument to 9 August 1971. Shaded portion of bars represents percentage of deaths in each class. Unshaded portion represents percent of class with observable deforming injuries. Plants in all size-classes sustained deforming injuries. Only plants less that 30 cm in height were completely destroyed by freezing. Data in Table 10.

TABLE 10. Mortality and deforming injury to 9 August 1971 of juvenile saguaros 1–120 cm height (N = 129) at Saguaro National Monument caused by freezing conditions during January 1971. Deformed plants are individuals with observable dead stem tissues. Data graphed in Fig. 19.

Height-class (cm)	N	No Deformity		Critical Injury					
				Killed		Deformed		Total	
		No.	%	No.	%	No.	%	No.	%
1.0–9.9	50	37	74.0	7	14.0	6	12.0	13	26.0
10.0–19.9	34	17	50.0	6	17.6	11	32.4	17	50.0
20.0–29.9	16	7	43.8	1	6.2	8	50.0	9	56.2
30.0–39.9	8	5	62.5	0	0.0	3	37.5	3	37.5
40.0–59.9	9	8	88.9	0	0.0	1	11.1	1	11.1
60.0–79.9	4	2	50.0	0	0.0	2	50.0	2	50.0
80.0–99.9	4	0	0.0	0	0.0	4	100.0	4	100.0
100.0–119.9	4	3	75.0	0	0.0	1	25.0	1	25.0
Total	129	79		14		36		50	
Percent	100.0	61.2		10.8		27.9		38.8	

Fig. 20. Freeze-killed juvenile saguaro (ht. 6.5 cm) at Saguaro National Monument, west section. Twelve days after the onset of the 1971 catastrophic freeze the blackish collapsed young plant has begun to desiccate. Photographed 15 January 1971.

TABLE 11. Distribution by height-class of January 1962 freeze-caused saguaro mortality in three habitats at Saguaro National Monument. Data from ten 0.1ha samples in each habitat (Niering et al. 1963). Data graphed in Fig. 21.

Height-class		East Monument						West Monument Flats[a]			All Monument		
		Slopes			Flats[a]								
Feet	Meters	N	Fr.	% Fr.	N	Fr.	% Fr.	N	Fr.	% Fr.	N	Fr.	% Fr.
To 1	To 0.3	5	0	0.0	0	0	0.0	2	1	50.0	7	1	14.3
2–6	0.6–1.8	10	0	0.0	6	0	0.0	60	0	0.0	76	0	0.0
7–12	2.1–3.6	16	2	12.5	7	0	0.0	48	0	0.0	71	2	2.8
13–18	3.9–5.5	17	4	23.5	21	3	14.3	40	0	0.0	78	7	9.0
19–24	5.7–7.3	23	8	34.8	41	8	19.5	43	1	2.3	107	17	15.9
Over 24	Over 7.5	15	3	20.0	55	12	21.8	26	2	7.7	96	17	17.7
Total		86	17	19.8	130	23	17.7	219	4	1.8	435	44	10.1

[a]Synonymous with "bajada" as used in the original publication.

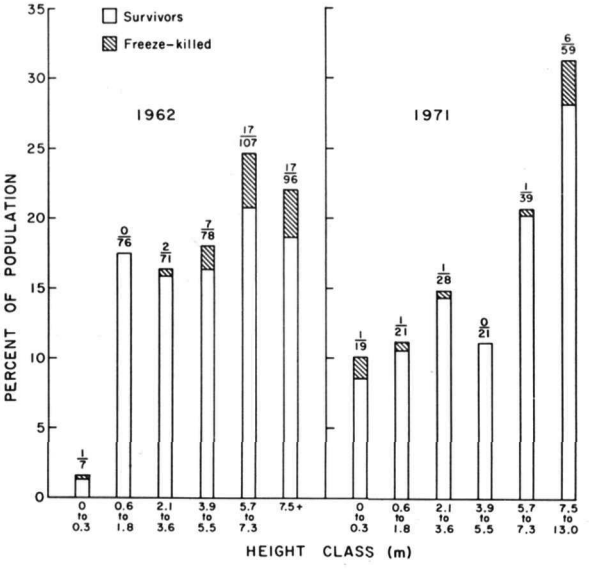

Fig. 21. Freeze-caused mortality in saguaro populations at Saguaro National Monument. Distribution by height-class of saguaro deaths from freezing during January 1962 and January 1971. The 1962 data are for both east and west monument sections from Niering et al. 1963 (Table 11). The 1971 data are from west monument section only (Table 12). Height of bar indicates percent of total population occurring in each height-class; shaded portion indicates percent of class killed by freezing. Above each bar, the number of freeze-killed plants is shown over the total number of plants in that class. The greatest mortality occurred in the smallest and the largest age-classes in both 1962 and 1971.

TABLE 12. Distribution by height-class of 1971 freeze-caused saguaro mortality in flat habitat at Saguaro National Monument (west). Height and condition of all saguaros (N = 189) in a 2-ha plot (100 × 200 m). Data obtained January to November 1971. Graphed in Fig. 21.

Height-Class		Live	Dead				Total	
			Wind		Freezing			
Feet	Meters	No.	No.	%	No.	%	No.	%
To 1	To .45	16	0	0.0	3	15.8	19	10.1
2–6	.46–1.97	20	0	0.0	1	4.8	21	11.1
7–12	1.98–3.80	27	0	0.0	1	3.6	28	14.8
13–18	3.81–5.63	21	0	0.0	0	0.0	21	11.1
19–24	5.64–7.46	38	0	0.0	1	2.6	39	20.6
25–43	7.47–13.00	52	1	1.7	6	10.2	59	31.2
Broken		2	0	0.0	0	0.0	2	1.1
Total		176	1	0.5	12	6.35	189	100.0

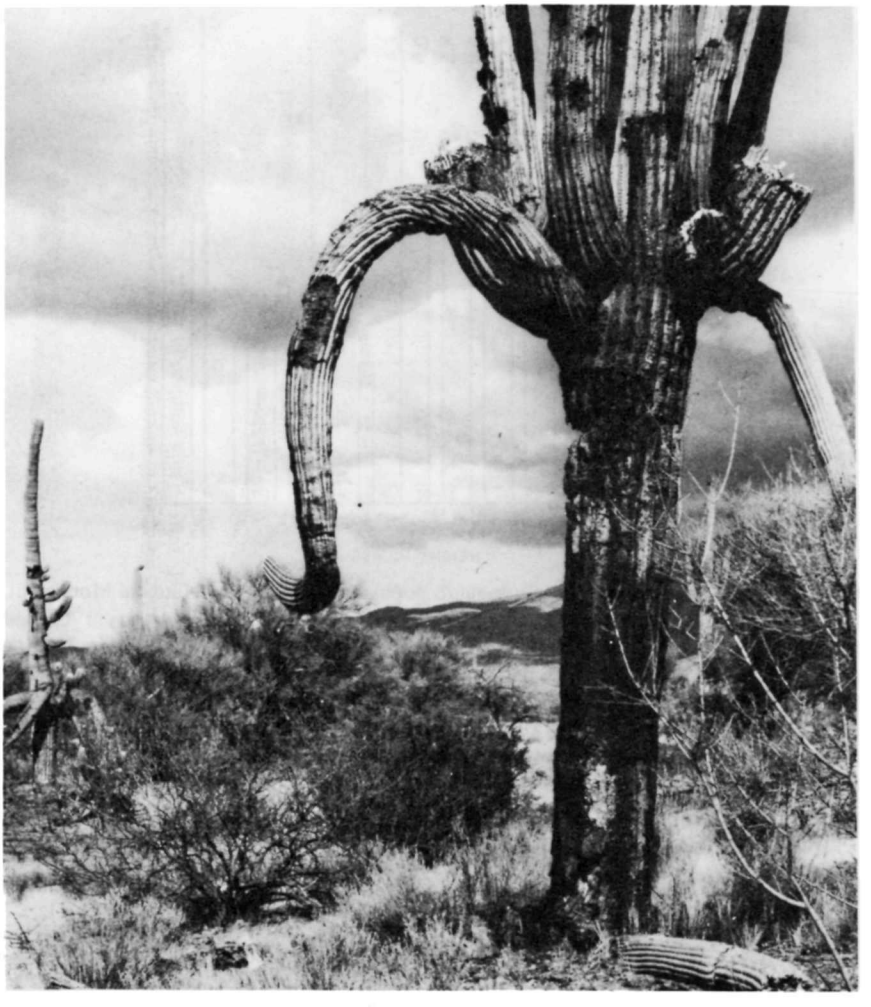

Fig. 22. Freeze-killed decomposing saguaro in "Cactus Forest" area, Saguaro National Monument (east). Drooping arms are a common indicator of damaging freeze-caused injury during earlier years. Leaning and slender top, drooping arms, and scarred stem on senescent saguaro behind, also indicate old freeze-caused damage, that is common in this population. Photographed 15 April 1971.

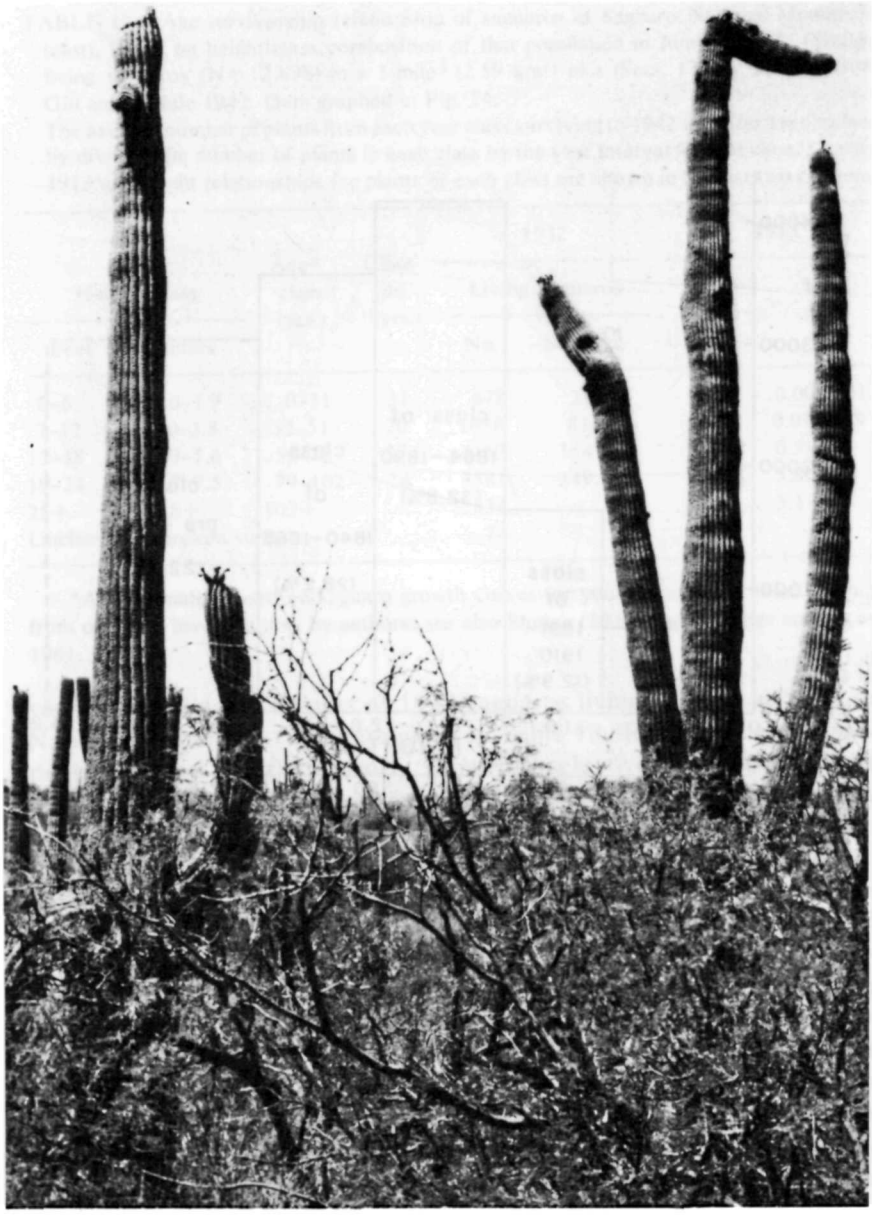

Fig. 23. Freeze-caused decapitation of saguaros at Saguaro National Monument (east). Collapsed, freeze-killed tissues at the site of woodpecker holes, as in the stem and arm of the right-hand plant, have caused decapitation of the saguaro on the left. Photographed 28 May 1971.

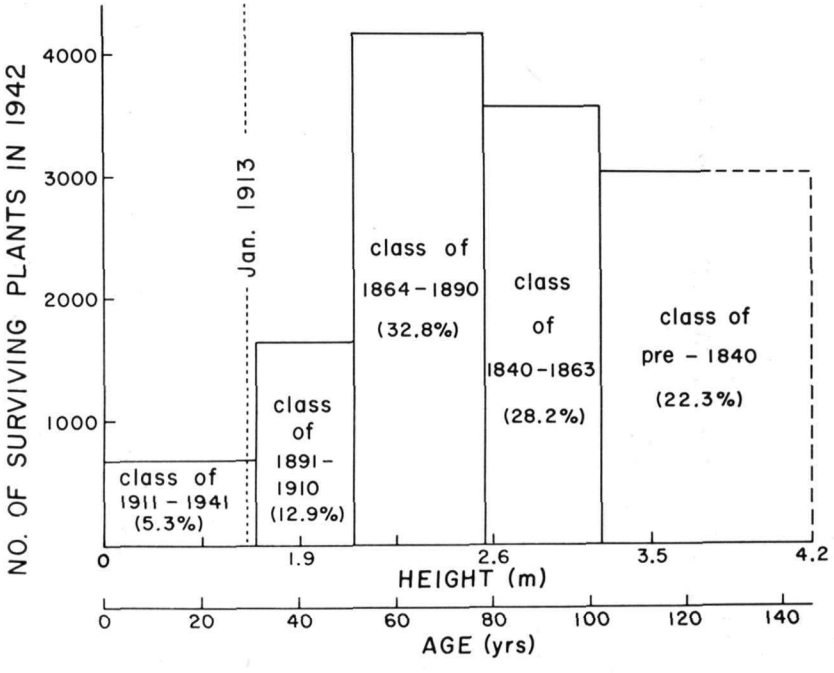

Fig. 24. Number and age of saguaros surviving to January 1942 at Saguaro National Monument, east (flats). Population data for 12,698 saguaros, from Gill and Lightle 1942, see Table 13. The disproportionately small representation (18.2%) of plants surviving from the two youngest age-classes (plants 1–51 years old) is clearly indicative of a declining local population. The obviously unbalanced age structure of the population results from recurring catastrophic freezes acting differentially (1) upon small, highly vulnerable seedlings and juvenile plants, and (2) on the relatively freeze-resistant larger juvenile and young adult plants between approximately 1.0–3.5 m in height. In January 1913, when a record low temperature of 6°F (−16.5°C) was recorded in Tucson, plants of the 1891–1910 year-classes would have attained at that time maximum heights of less than 0.5 m (age 3–22 years); plants of the 1864–90 year-classes would have grown to heights of 0.5 to 3.7 m (age 23–49 years). The large proportion (32.8%) of surviving plants from the latter class (1864–90) and from the two older classes (50.5%) strongly suggests that *catastrophic freezes* were not a characteristic of the environment in which those particular plants originated, i.e., during the period from 50 to 100 years or more prior to 1890. Since that date, however, the semi-regular occurrence of catastrophic freezes is a matter of record (see Fig. 25), and the disproportionately small representation of juvenile and young adult saguaros in this population is clearly attributable to the repeated occurrence of these devastating winter climatic events.

TABLE 13. Age-survivorship relationship of saguaros at Saguaro National Monument (east), based on height-class composition of that population in January 1942. Data on living saguaros (N = 12,698) in a 1-mile^2 (2.59 km^2) plot (Sect. 17, flat habitat) from Gill and Lightle 1942. Data graphed in Fig. 24.

The average number of plants from each year class surviving to 1942 (surv./yr.) is obtained by dividing the number of plants in each class by the year interval for that class. January 1913 age-height relationships for plants of each class are shown in the last two columns.

Height-Class		Age[a] class (yrs.)	Class int. (yrs.)	1942		1913	
				Living Saguaros		Age (yrs.)	Ht. (m)
Feet	Meters			No.	Surv./yr.		
0–6	0.0–1.9	0–31	31	678	21.87	0–2	0.00–0.01
7–12	2.0–3.8	32–51	20	1638	81.90	3–22	0.01–0.49
13–18	3.9–5.6	52–78	27	4163	154.18	23–49	0.55–3.7
19–24	5.7–7.5	79–102	24	3581	149.21	50–73	3.80–5.0
25+	7.6+	103+		2834		74+	5.1+
Unclassified (broken stems)				74			

[a]Age estimates based on saguaro growth curves for young plants less than 1 m high from on-going investigations by authors; see also Shreve (1910) and Hastings and Alcorn 1961.

year. The estimated heights of 1942 saguaros living in 1913 at Saguaro National Monument (east) are given in Table 13. These data are of particular interest for they clearly show the selective structuring of the population that results from catastrophic freeze-kill as revealed in the climatic record and in the data on freeze-caused mortality.

The climatic summary of minimum winter temperatures at Tucson, Arizona (U.S. Weather Bureau 1894-1971), graphed in Fig. 25, shows that the lowest temperature ever recorded in Tucson occurred 13 January 1913, when a minimum temperature of 6°F (−16.5°C) was observed. Minimum temperatures of 20 °F or lower were recorded during 38 of the 77 consecutive winters spanned by this record. Fully 17 of these events occurred during the 18 years from 1894 to 1913, when temperature readings of 20°F or lower were recorded one or more times during 13 winters in that period. During the 58 years since 1913, the short 8-year period between January 1937 and December 1945 was *the longest interval* between occurrences of such critical subfreezing temperatures.

The disproportionately small representation (18.2%; Table 13; Fig. 24) of plants surviving from the two youngest age-classes (plants 1-51 years old) is clearly indicative of a declining population. At Saguaro National Monument (east), the obviously unbalanced age structure of the

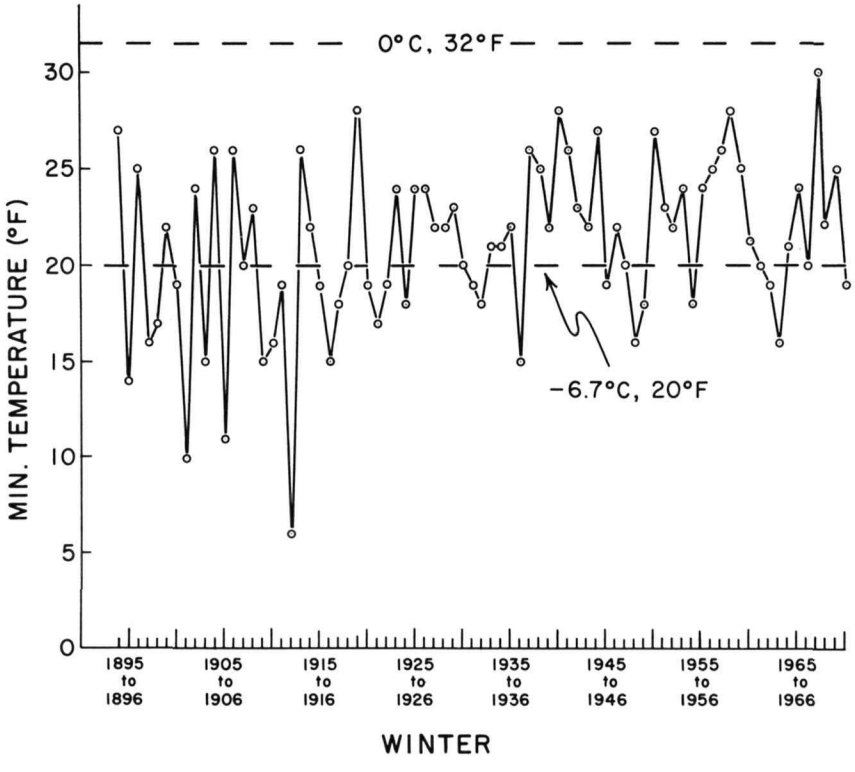

Fig. 25. Climatic summary, minimum winter temperatures, Tucson, Arizona. Temperatures (°F) are the low minimum recorded during the months of December through February of each winter, 1894–95 through 1970–71, at the University of Arizona Station. Data from Climatological Data Summaries, Arizona, Weather Bureau, U.S. Department of Agriculture and U.S. Department of Commerce, since December 1894. Minimum temperatures of 20°F or lower were recorded during 38 (approximately one-half) of the 77 consecutive winters spanned by this record. Seventeen of those events occurred during the 18 years from 1894 to 1913; temperature readings 20°F or lower were recorded one or more times during 13 winters in that period. During the 58 years since January 1913, the 8-year period between January 1937 and December 1945 was the longest interval between the occurrence of such critical subfreezing temperatures.

population results from recurring catastrophic freezes acting differentially upon (1) highly vulnerable seedlings and small juvenile plants (Figs. 3, 4, 5, 6), and (2) the relatively freeze-resistant larger juvenile and young adult plants between approximately 1.0 and 3.5 m in height (Fig. 7). We calculate that in the deep freeze of January 1913, plants of the 1891 to 1910 year-classes would have attained at that time the vulnerable maximum heights of juveniles less than 0.5 m (age 3-22 years)—plants of the 1864-90 year-classes would have grown to heights of 0.5-3.7 m (age 23-49 years).

The large proportion (32.8%) of surviving plants from the latter class (1864-90) and from the two older classes (50.5%) strongly suggests that catastrophic freezes were not a characteristic of the environment in which those particular plants originated, i.e., during the period from 50 to 100 years or more prior to 1890. Since that date, moreover, the semiregular occurrence of catastrophic freezes is a matter of record and the disproportionately small representation of juvenile and young adult saguaros in this monument population is clearly assignable to the repeated occurrence of these devastating climatic events.

SUMMARY AND CONCLUSIONS

Saguaro populations at the eastern and northern limits of the species range in northern Sonora and in Arizona are subject to recurring extremes of subfreezing winter temperatures. These events, acting in a catastrophic manner, are the primary control on the limits, local distribution, and dynamics of saguaro populations in southeastern (and northern) Arizona.

In short, in this area of their geographic range, saguaros frequently freeze to death. Accordingly, in this northern portion of the plant's range, saguaro populations at the eastern, northern, and extreme elevational limits of the species distribution are limited to specific topographic situations (microhabitats) that effectively moderate the intensity and duration of critical winter minimum temperatures, i.e., south-facing slopes, rocky footslopes, and the upper portions of adjoining valleys. These are winter-warm microenvironments. The saguaro is absent or rare on colder, north-facing slopes and areas of cold air drainage and accumulation.

Within these northern populations, differential mortality of young saguaros occurs in dissimilar microhabitats, and is attributable to differing physical characteristics of the microenvironments there. This importantly involves the protective stratification of associated plants.

Under freezing conditions, survival of the smallest saguaros is dependent upon the physical characteristics of the microhabitat—specifically, spatial relationships with other plants, rock and other objects that

mitigate the thermal environment of the plant during and immediately following the period of freezing conditions. Population density in the long run is limited by the availability of winter-favorable microhabitats that permit survival of young plants through critical extremes of subfreezing temperatures.

The percent mortality of each age-class of saguaros and the range of plant sizes affected by a particular freeze will depend upon the severity of freezing conditions, the intensity and duration of subfreezing temperatures, and other weather conditions preceding, during, and immediately following the freeze.

Vulnerability of saguaros to death from freezing is correlated with plant size and form (age). Catastrophic freezing selectively removes the youngest and the oldest members from the plant population and favors the survival of intermediate age-classes.

Accordingly, the continuing decline of saguaro populations at Saguaro National Monument and the present size-class structure of these populations is primarily the result of recurring catastrophic freezes acting differentially upon (1) seedlings and small juvenile plants; (2) larger juvenile and young adult plants; and (3) large adult plants.

Saguaro populations fluctuate in direct response to recurring catastrophic freezes in a characteristic and predictable manner, each freeze producing an abrupt reduction in the population, followed during the period of remission by gradual regrowth toward the original population level. Under such recurring stress, the ultimate *trend* of the population is determined by the *relative severity* of successive catastrophic freezes and the *relative interval* between successive freezes. If no change occurs either in the length of the interval between freezes or in the severity of successive freezes, the population could fluctuate about a more or less stable mean value and exhibit a stable age distribution. If the intervals between freezes become progressively longer or freeze severity progressively decreases, the population would increase until another factor becomes limiting. If the intervals become progressively shorter or the severity increases, the population will be unable to reach a stable age distribution and will eventually decline to extinction in the affected portion of its range.

The trend and ultimate fate of natural saguaro populations in northeastern Sonora and southeastern Arizona, including Saguaro National Monument, depend upon the future winter climate of the region—specifically, upon the frequency and intensity of catastrophic freezes. Our ability to predict the ultimate fate of some of these populations is contingent upon, and limited by, the ability to predict the occurrence of such events over a long period of time.

MANAGEMENT RECOMMENDATIONS

Under the authority of the Antiquities Act of 8 June 1906, Saguaro National Monument was set aside because of its *scientific interest*—specifically for the intrinsic interest of the natural vegetation therein.

The primary significance of Saguaro National Monument, therefore, lies in the natural associations of the vegetation found within its boundaries. The monument contains the last remaining example of an essentially undisturbed continuum of natural warm-desert to mountain-forest biotic associations in the southwestern United States. The singular rarity of this resource clearly indicates the importance of maintaining the integrity of the natural associations and relationships within Saguaro National Monument. It is upon consideration of the legislated purpose, the intrinsic natural significance of the area, and the scientific and cultural values of the resource that the following management recommendations are based:

A. Exclude developments and associated intensive use from responsive, uncommon, or rare habitats and natural communities. All use causes some deterioration of saguaro and other habitats. The question of what constitutes an acceptable level of destruction must accompany every decision to accommodate such use of the monument.
   1. Eliminate picnic areas from saguaro habitats. Soil compaction, wood-gathering, and vandalism associated with these developments contribute to the degeneration of the site and adjacent habitat, ultimately leading to the death of existing saguaros and precluding the establishment and survival of young plants.
   2. Limit further developments within saguaro habitats to those that will not attract destructive use and cannot be located elsewhere.

B. Develop management programs to provide more effective control of activities that are directly destructive to natural populations, communities, and habitats.
   1. Control uses that are destructive to saguaro habitat such as off-pavement vehicle parking and off-trail foot and horse travel. Where necessary provide and direct the use of appropriate facilities for such activities.
   2. Intensify management programs to control increasing vandalism and removal of saguaros. Old plants destroyed will not be replaced in a human lifetime. Young plants destroyed are those few that have survived the many hazards of the first critical years of life.

C. Eliminate cattle grazing. Continuing consumptive use by these exotic animals has a devastating impact upon the biotic as well as the esthetic environment. Grazing intensifies detrimental actions of natural environmental factors.

D. Continue research designed to obtain basic information on population and community dynamics and institute new programs to facilitate related studies.
   1. Continue on-going saguaro population studies and institute additional studies on related communities. The response of saguaro populations and the associated biotic communities—past, present, and future—provides a valuable measure of climatic change and the resulting effects.
   2. Institute additional studies to inventory and estimate the status and trend of saguaro populations and other key species.
   3. Establish weather stations and maintain accurate and consistent weather records using standard calibrated instruments and recognized procedures. Lack of reliable on-site climatic data has been a major handicap in efforts to relate environmental factors to saguaro population changes.
   4. Map and identify all transplanted saguaros surviving from previous research activities. The absence of such identification precludes the obtaining of accurate information on natural survival at those locations.

E. Encourage and facilitate nondestructive independent scientific research activities appropriate to the purpose and significance of the area.

F. Incorporate research findings into the interpretive program, stressing evolution and physical environment in relation to populations and communities.

G. Allow continuation of natural regenerative processes in saguaro habitats from which adverse use has been eliminated. Avoid interference with these processes by avoiding the introduction of horticultural and other programs that will unbalance on-going natural recovery of deteriorated habitats.

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Acknowledgments

Superintendent Harold R. Jones and the members of the Saguaro National Monument staff have aided the conduct of this study in many ways. We are grateful to Robert M. Linn and members of the National Park Service's Office of the Chief Scientist for their support of the saguaro ecology investigations reported here and elsewhere. We are indebted to E. Annette Halpern, David S. Hinds, Richard D. Krizman, John S. Phelps, Oscar O. Soule, and Thomas A. Wiewandt for valuable assistance in this study. We also thank Floyd G. Werner for insect identification. Lupe P. Hendrickson deserves special thanks for devoted assistance in preparation of the manuscript.

The research was supported by National Park Service Research Contract No. 14–10–0333–1303, the National Park Service's Office of the Chief Scientist, and Saguaro National Monument.

The Role of Fire in a Giant Sequoia-Mixed Conifer Forest[1]

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INTRODUCTION

Despite efforts by the best-trained firemen in the world, coniferous forests, chaparral, and similar vegetation types are periodically going to burn (Roe et al. 1971; Wilson and Dell 1971). It therefore behooves us, as scientists, laymen, and environmentally concerned citizens to learn everything we can about the natural role of fire in our wildlands and to support intelligent management based on this knowledge. This is particularly true of our national parks and wilderness areas, where natural processes are supposed to run their course, as nearly as possible.

The impact of fires on the sequoia-mixed conifer forest ecosystem and the role of fire in maintaining natural environmental conditions in this and other vegetation types in the Sierra Nevada are my primary research interests at this time. Related studies are being carried out by a number of other investigators in government agencies and universities.

Our interests are in part academic, for we hope to learn basic truths which will help us understand the complex interrelationships of this forest ecosystem. But our studies are also aimed at gathering the facts necessary to insure that this ecosystem, with all its diversity, will be managed so as to perpetuate the dynamic processes which, in an evolutionary sense, have given us the sequoia-mixed conifer forest.

In certain higher elevation forests of Sequoia and Kings Canyon National Parks, it has been National Park Service policy since 1968 to let

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[1] An expanded and more current version of this paper was presented in August, 1972, at the meetings of the Ecological Society of America and the American Institute of Biological Sciences, University of Minnesota. This expanded paper was published in 1973 in a special symposium issue of the *Journal of Quaternary Research* **3**(3):496-513.

lightning fires burn unless human life or property are endangered (Kilgore and Briggs 1972). In our lower elevation sequoia-mixed conifer forests, however, a considerable fire hazard has built up because of the exclusion of natural fire during the past half-century (Leopold et al. 1963). Hence, a program of prescribed burning has been adopted as the technique for restoring fire to this ecosystem (Kilgore 1970). In order to carry out effectively this management objective, we must know far more than we do at present about the natural role of fire in this forest.

NATURAL HISTORY OF THE SEQUOIA-MIXED CONIFER FOREST

Within a sequoia grove, the primary species are giant sequoia (*Sequoiadendron giganteum*), sugar pine (*Pinus lambertiana*), and white fir (*Abies concolor*). Incense-cedar (*Libocedrus decurrens*) joins these three in lower elevation groves. Such species as ponderosa pine (*Pinus ponderosa*) and black oak (*Quercus Kelloggii*) are not typical associates in the mesic habitat of the giant sequoia grove, but rather they represent vegetation of xeric habitats within the mosaic of mesic and xeric sites characterizing most groves (Rundel 1969). Nevertheless, from a fire ecology standpoint, we must consider the whole range of vegetation occurring within this sequoia-mixed conifer ecosystem in that each of the somewhat more mesic or more xeric subtypes make up only a portion of the complex mosaic throughout which fires function. For example, fire originating in a slightly warmer exposure site will often move quickly into a cooler or more moist exposure involving another subtype. Hence, consideration of what fire does in a strictly mesic sequoia grove would be far removed from the on-the-ground reality of how fire operates in the whole ecosystem.

What then does fire do in the giant sequoia-mixed conifer forest? I have selected seven functions of fire which seem particularly significant. Fire in this forest (1) prepares a seedbed; (2) cycles nutrients; (3) sets back succession in certain relatively small areas; (4) provides conditions which favor wildlife; (5) creates a mosaic of age classes and vegetation types; (6) reduces numbers of trees susceptible to attack by insects and disease; and (7) reduces fire hazards.

THE ROLES OF FIRE

Seedbed Preparation

Giant sequoia. Fire in the sequoia-mixed conifer forest provides soft, friable soil on which the light-weight sequoia seeds fall and in which they are buried (Hartesveldt and Harvey 1967). By consuming the accumulation of down branches, litter, and duff, fire allows the seed to reach mineral soil. And in heating the soil, fire changes the texture in a way which allows a seed to be covered by a few millimeters of soil as a result

of its fall from the tree, thus promoting germination.

Timing of the burn is important. In the Redwood Mountain Grove of sequoias in Kings Canyon National Park, one experimental burn took place in August 1969. This allowed 2 months of seed fall before winter snows came. Table 1 shows the influence of this fairly intense 1969 broadcast burn on germination of seedlings of both sequoia and a primary shrub species.

On plot 3, which burned hottest, more than 40,000 sequoia seedlings per acre were found during the first year after burning, while about 13,000 per acre germinated on more lightly burned plots 1 and 2. The three burn plots averaged nearly 22,000 sequoia seedlings per acre during the first post-burn year. By the second year, these numbers had decreased through natural mortality factors to an average of 2614 sequoia seedlings per acre. Not a single sequoia seedling was found either year on the unburned control plot. By comparison, very few seedlings germinated after another burn on adjacent plots in late November 1970. This was true, at least in part, because snow covered the ground 2 days after the fire, and there was practically no opportunity for seeds to fall and be buried in soil and ashes. For a short period of time following burning, the soil remains loose and friable. Rain and snow, however, increase the soil density again in a way that falling seeds do not penetrate the surface by impact (Hartesveldt et al. 1967).

A possible correlation between numbers of seedlings and numbers of seed-producing trees was evident in this study (Kilgore and Biswell 1971). On burn plot 3, there were more than nine sequoia greater than 6 ft diameter at breast height (dbh) per acre compared with less than five per acre on plots 1 and 2. Thus the burn plot most productive of sequoia seedlings had both the greatest numbers of large sequoias per acre and the hottest burning conditions. It appears the rising convection column of heat, which dried out and killed sequoia needles more than 100 ft up in three trees on plot 3, may have also caused the drying and opening of sequoia cones on several of these same trees and contributed to very heavy seed fall in the area of the hottest burn. The extremely large numbers of sequoia seedlings germinating in plot 3 were probably related to both ideal seedbed conditions and heavy seed fall.

Once seeds are buried and germination takes place, moisture in the rooting zone becomes a critical factor. Rundel (1972) concluded that giant sequoias are limited to habitats of relatively high soil moisture and noted this limiting factor acts through the ecological tolerances of the seedling stages. Stark (1968) found that partially burned giant sequoia litter held more available water (273% by weight) than unburned litter and that it formed a good seedbed. Furthermore, highest survival of sequoia seedlings has been found on very heavily burned soils, possibly

TABLE 1. Sequoia and deerbrush seedling response to 1969 prescribed burning at Redwood Mountain, Kings Canyon National Park, California.

Plot no.	Size	Mature sequoia[a]		Seedling sequoia				Seedling deerbrush			
				1970		1971		1970		1971	
	Acres	No. per plot	No. per acre	No. per transect	No. per acre	No. per transect	No. per acre	No. per transect	No. per acre	No. per transect	No. per acre
Burn #1	3.75	11	2.9	242	13,177	40	2,178	69	3,757	39	2,124
Burn #2	6.10	28	4.6	233	12,687	24	1,307	104	5,663	48	2,614
Burn #3	6.25	58	9.3	737	40,130	80	4,356	4	218	5	272
Burn plots											
Totals	16.10	97		1,212		144		177		92	
Means			6.0		21,998		2,614		3,213		1,670
Control	5.30	31	5.8	—	—	—	—	—	—	—	—

[a]Trees more than 6 ft diameter at height of 4.5 ft.

because of greater soil moisture availability (Hartesveldt and Harvey 1967). Other factors such as killing of fungi (Davidson 1971) and elimination of competition, however, are probably equally significant. Fire usually causes a decrease in fungal populations and an increase in soil bacteria and actinomycetes (Wright and Tarrant 1957; Roe et al. 1971).

Unpublished studies at Whitaker's Forest by Paul J. Zinke (pers. comm.) of the University of California show that 5% more moisture (% by volume) was found in the top 5 ft of soil beneath a giant sequoia after clearing of undergrowth than before such clearing. Likewise, the center of a one-half acre cleared area showed from 3 to 6 inches more moisture available in this top 5 ft of soil than was found in surrounding forested areas (Kilgore 1968).

In other vegetation types, studies confirm that additional soil moisture is available after fires, but additional surface run-off and erosion often have accomplished this moisture increase (Ahlgren and Ahlgren 1960). Such run-off and erosion are sometimes related to the phenomenon of water-repellent soils, apparently resulting from naturally occurring organic substances having hydrophobic properties. Some of these substances found in litter are driven downward in the soil by fire and condense on soil particles at lower levels, depending upon temperature gradients (DeBano 1969).

In laboratory tests of soils from giant sequoia groves. Donaghey (1969) found that temperatures high enough to destroy organic material decreased soil water-holding capacity but increased its water infiltration capacity. She found partially or wholly nonwettable soils resulted from temperatures in the 300-750°F range, but after being heated at 750°F for 4 hours or more, soils became wettable and absorbed water immediately upon contact. Temperature readings found in our prescribed burning studies currently underway at Redwood Mountain varied from no change in unburned sites and at lower soil depths to between 500 and 750°F in the first 2 inches of soil. These higher temperatures were found in a few extremely heavy fuel sites, often under sizeable logs which were completely consumed during a burning period of many hours. It would seem probable, as Donaghey suggests, that a nonwettable layer may develop in certain sites after burning under giant sequoia. However, no erosion problems have developed to date with prescribed burning on our study plots at Redwood Mountain or in our higher elevation red fir study plots (Kilgore 1971b). This may be due, in part, to the highly varied character of the burn patterns in these areas—a pattern less often found in hot brushfires studied by DeBano (1969) in Southern California chaparral, where water repellancy has led to serious soil erosion problems.

Other species. Fire also plays a role in the germination and survival of seeds of other mixed conifer species. Seedling ponderosa pine and Jeffrey pine are favored by seedbed conditions after burning (Vlamis et al. 1956; Bock and Bock 1969). Sugar pine is somewhat more shade tolerant, but its seedlings undoubtedly benefit to some extent from conditions following fire.

Various shrubs of this community are almost entirely fire-dependent, and these species have become increasingly scarce during the past 50 years, thus reducing the value of these areas for deer and other wildlife. Many such shrubs have hard seed coats which prevent germination unless cracked by fire. Others will sprout following fire, but in either case the species is stimulated to greater growth and production as a result of fire (Buchanan et al. 1966; Sweeney 1967, 1969).

Table 1 also shows the impact of the 1969 burn on germination of *Ceanothus integerrimus* (deerbrush). Contrary to the results found for sequoia seedlings, between 3700 and 5600 deerbrush seedlings per acre were recorded the first post-burn year on the more lightly burned plots 1 and 2, while only 218 per acre were found on the heavily burned plot 3. The almost complete absence of living deerbrush plants before burning makes difficult any quantitative estimate of seeds available in the soil. Hence, the greater number of shrub seedlings on the less heavily burned plots must be explained by the fact that heavy burning conditions destroy seeds, while lesser temperatures crack seed coats and allow germination. Smaller numbers of other brush species, *Ceanothus parvifolius*, *Arctostaphylos patula*, and *Ribes roezlii*, were also found on the burn plots, while no shrub seedlings of any kind were found on the unburned control areas. There are apparently no fire-type herbaceous species associated with a conifer forest (Sweeney 1969), but several species increased in coverage or frequency following burning in the giant sequoia-mixed conifer forest, perhaps in part because of the increase in sunlight reaching the forest floor (Kilgore 1971a; Hartesveldt et al. 1967; Rundel 1971).

Nutrient Recycling

The giant sequoia-mixed conifer forest may be a prime example of an ecosystem which will not function unless it is periodically burned (Lyon and Pengelly 1970). Here, as in other coniferous forests, fire plays an important role in returning various mineral nutrients to the soil. Mineral absorption by plants is a constant drain upon the soil (Behan 1970). A sizeable quantity of minerals is incorporated in living and dead tree trunks and retained for many years, while needles and small twigs are dropped annually as litter. Minerals are gradually returned to the soil from this litter by leaching and by the relatively slow action of decom-

poser organisms. The nitrogen and potassium tied up in litter represent a fair drain on the soil's reservoir of these nutrients (Cole et al. 1967).

Nutrient capital may be depleted when hot fires volatilize nitrogen and potassium or when soil and dissolved minerals are lost in run-off from rains following fires (Behan 1970). Light burns, however, often increase soil pH, stimulate nitrification, and improve soils chemically. The ash deposit increases available phosphorus, potassium, calcium, and magnesium (Hare 1961).

The effects of light burning on soil nitrogen are more complex. Ponderosa pine seedlings planted in soil samples taken from the top 10 inches of burned and unburned plots showed greatest growth in more hotly burned areas, suggesting greater availability of nutrients (Vlamis et al. 1956), sterilization of the soil, or both. Seedlings on burned soils showed nearly a 50% increase in weight over seedlings on unburned soils. An increase in both nitrogen and phosphorus in burned soils was found in another study (Vlamis et al. 1955). Less immediate but important chemical changes in soil can occur when fire stimulates growth of such nitrogen-fixing shrubs as *Ceanothus* spp.

The growth release pattern of surviving trees following fire is another indication of the quick conversion of nutrients tied up in dead plant materials to new living tissue. Weaver (1947) found the average diameter of 40-year-old ponderosa pine on a burned area was 7.4 inches compared to 1.7 inches on an adjacent unburned site. Giant sequoia have shown marked growth increases after fires (Hartesveldt 1964), indicating that nutrients and moisture formerly tied up in various kinds of litter and in certain standing dead and living trees were made available to the remaining sequoias through burning.

Impact on Succession

Before the early 1900s, frequent and widespread surface fires kept the sequoia-mixed conifer forest open and park-like (Biswell 1961). Pioneer or secondary successional stages were favored over climax forms; sun-loving species were favored over shade-tolerant forms; and fire-resistant and fire-dependent species and associations were favored over nonfire-dependent forms.

European man has caused two types of changes in fire ignition patterns which, in turn, have affected the successional stages now seen in the mixed conifer forest of the Sierra Nevada: (1)With the arrival of western man in the 1850s, burning carried out as part of Indian culture declined and was virtually eliminated by 1865 (Vankat 1970); and (2) during the last decade of the 19th century and the first decade of the 1900s, fire suppression activities were undertaken by Federal Government agencies in the Sequoia and Kings Canyon National Parks areas.

Vankat (1970) reported two increases in numbers of white fir (a notoriously shade-tolerant species) in Sequoia National Park—one in the 1860s which coincides well with the elimination of Indian burning and another in the 1900-1910 period which coincides with the beginning of Federal fire suppression activities. He also found a corresponding decrease in cover and density of shrubs such as manzanita and *Ceanothus* because of increased competition with tree species.

Rundel (1971) notes that sequoia groves represent a fire-climax community whose stability is maintained by frequent burning of the understory. Without regular surface fires, litter accumulation limits sequoia seed germination, and the grove community becomes a "long-standing seral stage in succession toward a climax overwhelmingly dominated by *Abies concolor*, with giant sequoia absent."

Our recent prescribed burning work at Redwood Mountain in Kings Canyon National Park has begun setting back succession in a modest way by killing many young white fir seedlings and saplings which have become numerous beneath the giant sequoia and sugar pine. To date, however, the changes are not as great as would have been accomplished by periodic natural fires during the past 50-70 years.

One of the results of the *natural* process which may be most difficult to duplicate at the present stage of plant succession is fire's role in making openings in the crown canopy. When periodic light fires burned through the forest, young white fir were killed when they were still part of the understory level of vegetation and fuels. Fairly mild burning conditions could still accomplish this and leave a mosaic of openings in the crown. These openings in turn allowed sunlight to reach the forest floor and permitted growth of sequoia seedlings, shrubs, and herbaceous plants which require substantial sunlight. Since fires have been suppressed, however, certain fir trees—perhaps not large in numbers yet—have continued to grow in height and size in a way that (1) they have become part of the crown canopy, or at least the lower levels of this canopy, and hence fire moving into this canopy can more readily threaten crowns of other trees, including giant sequoia; and (2) they are much less likely to be killed by moderate fires because the trees are much larger and have much thicker bark.

Such small but important openings in the crown canopy did not generally result from the type of minimum treatment employed by Biswell at Whitaker's Forest in which white fir and incense-cedar less than 11 ft tall were cut, piled, and burned (Kilgore 1971a). We recorded an increase from an average of slightly less than 9% to about 12% of full sunlight on the forest floor in this work; in certain small thickets of saplings having less overstory vegetation, however, an average of 36% of sunlight was found after burning (Kilgore 1968).

A few white fir and sugar pine between 12 and 24 inches dbh were killed in the hotter prescribed burn areas at Redwood Mountain in 1969, while few trees as large as 12 inches dbh were killed in the milder 1970 burn. Hartesveldt's work with small plots did bring about openings in the crown canopy by felling snags, cutting out white fir thickets, bucking up all logs, piling all material with a bulldozer, and burning. This was, of course, a major departure from natural burning conditions and cost from $300 to $500 per acre (Hartesveldt et al. 1967).

Such intensive work would be impossible over large acreages from an economic standpoint and perhaps would be undesirable ecologically as well. However, some sizeable white fir may need to be cut and burned in certain high value sequoia groves, or we may have to accept some fairly hot burning conditions to restore the system to what we believe were more natural environmental conditions. Once this is achieved, we would hope to perpetuate equilibrium conditions by allowing natural forces, including lightning fires, to play their original role as nearly as possible, even in these purportedly high fire hazard giant sequoia-mixed conifer forests.

Faunal Relationships

The good deer ranges which have nutritious and palatable browse are usually found in subclimax stages of plant succession. As Leopold (1966) points out, "Burned or cutover forest lands support most of the deer in the continent." In a cut, pile, and burn program in a giant sequoia-mixed conifer forest, Lawrence and Biswell (1972) found that browse and forage were more abundant, more heavily hedged by deer, and more nutritious on the burned areas than on untreated controls. Such results are found in many forest types (Ahlgren and Ahlgren 1960) and relate to the processes of shrub regeneration referred to earlier.

Bird populations have also increased in numbers or biomass following fire in various vegetation types (Marshall 1963; Lawrence 1966; Bock and Lynch 1970). In a second-growth giant sequoia forest, however, elimination of saplings less than 11 ft tall did not make major changes in species composition of a breeding bird population (Kilgore 1971a). Compared with results from areas where wildfires or logging operations have made substantial changes in cover type or set succession back severely, this degree of habitat modification resulted in relatively small changes in avifauna.

The importance and the complexity of ecosystem relationships involving fire and wildlife are highlighted by the role which a small mammal and an insect seem to play in sequoia seedling regeneration in the sequoia-mixed conifer forest. Researchers from San Jose State College,

under contract to the National Park Service, have recently found that the chickaree or Douglas squirrel (*Tamiasciurus douglasii*) and a small cerambycid beetle play a significant role in sequoia reproduction. Outside sequoia groves, Shellhammer notes that this tree squirrel commonly feeds on seeds of sugar pine, white fir, and ponderosa pine. Within the groves, the chickaree also cuts sequoia cones, not for their tiny seeds, but instead to chew on their green, fleshy cone scales. Some 80% or more of the seeds are unharmed by the squirrel's feeding process (Hartesveldt et al. 1970).

Certain squirrels cut large numbers of cones from individual sequoias, and perhaps seeds from a few of these cones may be useful in production of seedlings. But apparently the squirrel's most important role is its feeding upon cones within the tree itself, allowing seeds to fall from considerable heights (Hartesveldt et al. 1970), thus maximizing seed impact on the soil and seed dispersal.

Age of the cones is also involved. Greatest seed viability was found in 5-year-old cones (Hartesveldt and Harvey 1967) with a gradual decrease thereafter. Chickarees seem to prefer young green cones 2-5 years of age, while older cones are subject to the workings of the larvae of the beetle *Phymatodes nitidus*. Stecker found that the larva of this small, long-horned beetle chews its way inside the cone and gets nourishment from the tissues (Hartesveldt et al. 1970). In so doing, it cuts vascular channelways, causing the gradual death and drying of the cone. As the cone dries, it opens, and the seeds fall from high in the trees.

The relationship between fire and the squirrel and beetle would seem to be this: Following fire, when a squirrel cuts cones and particularly when it feeds on them in the tree, the seeds or cones fall into the soft, friable seedbed of mineral soil and ash which is ideal for sequoia germination and survival. The work of the beetle causes the older cones to dry on the tree; as they dry, cones open, allowing seeds to fall, sometimes in great numbers, at a time when germination and survival possibilities are highest. Partly as a result of these two animals, heavy burning conditions under giant sequoia seem to favor sequoia regeneration over any other species (Kilgore and Biswell 1971) unless a crown fire should develop which would completely consume the seed source high on the mature trees—a highly unlikely prospect under natural conditions where periodic fires kept ground fuels and understory vegetation at low accumulations.

Formation of a Vegetative Mosaic

Fire often burns in a highly variable pattern. It may burn hot in one site, lightly nearby, and not at all in another site. Surface temperatures

can vary from 400°F to 1200°F or more with no uniformity of distribution in a given burn (Lindenmuth 1960; Sweeney and Biswell 1961). The result is that over the years fire—in combination with other factors such as exposure, slope, soil type, insects, and disease—brings about the development of a mosaic of age classes and vegetation types.

In describing this phenomenon in a ponderosa pine forest, Weaver (1967) says: "Periodic burning causes development of uneven-aged stands, comprised of even-aged groups of trees of various age classes." This system operates because fire kills small pines under the canopies of larger trees but not in openings. It does so because heavy accumulations of flammable needles, cones, and bark scales build up under these larger trees and carry a surface fire. But here and there, throughout the forest, single, mature trees or groups of trees have been killed by insects, disease, lightning, or windthrow. These dead trees are gradually reduced to ashes in subsequent burns. An opening develops within which young pine can both germinate and survive, because the small accumulation of needle fall from large trees will not support a surface fire. Hence, until the pines are large enough to build up fuels under themselves, fires would not be intense enough to kill them; and by the time they do create such heavy fuels, many of them are also large enough to withstand the surface fires.

Reduction in Insect Susceptible Trees

Fire also has a sanitizing effect by thinning stands or eliminating old stands or old trees before insects and disease have overtaken them (Heinselman 1970; Loope 1971). As an example, under natural fire cycles, outbreaks of spruce budworm may have been less prevalent, bark beetle epidemics may have been less common and less severe, and dwarf-mistletoe may have been held more in check.

Without fire, older trees become more susceptible to insect attack or disease (Hare 1961). Weaver (1964) believes recent heavy western pine beetle attacks resulted from excessive competition in dense stands of ponderosa pine which developed in the absence of fire. Under these circumstances, trees killed by insects leave a forest more susceptible to fire (Wellner 1970). Lyon and Pengelley (1970) point out that insects and disease are also vital components of the dynamic forest ecosystem. Their role may be related to increasing forest fuel accumulations and, hence, the probability of fire following their own activities. Some trees wounded by fire are in turn attacked by insects and disease and may die, again building up more fuel.

In the giant sequoia-mixed conifer forest, there has been concern expressed about the role of the giant carpenter ant (*Campanotus levigatus*) in building nests in the heartwood of the tree (Jack Hickey pers.

comm.). Large numbers of these ants were found at the points of breakage of two sequoias in the Hazelwood section of Giant Forest in 1969. There is certainly a possibility that natural fires kept numbers of this insect at a lower level from that we find today by burning out ant nests found in the bark and heartwood of the sequoia and in other living and dead woody materials in the forest. The National Park Service has contracted with the Department of Entomology and Parasitology at the University of California, Berkeley, to investigate the role of this ant in the forest. We hope to be in a better position soon to judge what role natural fire and human visitation to these groves may have in altering numbers of this insect and its nest-building activities in the giant sequoia.

Fuel Reduction

In one year an acre of forest converts solar energy into vegetative matter equivalent to 300 gallons of gasoline (Roe et al. 1971). By putting out lightning fires in the mixed conifer forest, we have been merely postponing the inevitable release of this energy stored through photosynthesis. Unless we take action soon, future wildfires will be far more destructive than those we have previously faced (Biswell and Weaver 1968).

For this reason the major current problem in management of the giant sequoia-mixed conifer forest is the high fire hazard that has built up since the turn of the century. In the absence of lightning fires and aboriginal burning, formerly open forests now have a dense understory of young trees. The bulk of these are white fir, which germinates readily in shade and survives in dense thickets in the absence of light surface fires. While virgin forests in California were once said to be uneven-aged, patchy, and broken—so much so that "a continuous crown fire is practically impossible" (Show and Kotok 1924)—such crown fire im-

TABLE 2. Flash fuel and duff weights[a] before and after burning at Redwood Mountain, Kings Canyon National Park, California.

	Control plots		Burn plots	
	Before	After	Before	After
Flash fuel	9.1	9.7	12.4	3.1
Duff	45.6	42.5	37.7	4.7
Total	54.7	52.2	50.1	7.8

[a] Oven dry weights in tons per acre.

munity has now been lost in many of our mixed conifer forests. A wildfire in 1955 swept up from the chaparral country below the Grant Grove of giant sequoias in Kings Canyon National Park. In a short time, it had devastated more than 13,000 acres of brush and mixed conifer forest and had threatened a grove of giant sequoias.

In our first major effort at reducing such fuel hazards in the sequoia-mixed conifer forest, some 100 acres of forest were burned under prescribed conditions in late summer and early fall of 1969 on the ridge of Redwood Mountain in Kings Canyon National Park. A second burn involving research plots took place in late fall of 1970. Preburn data were collected on a variety of vegetation and weather parameters and included weight measurements of flash fuels and duff. Before burning, more than 50 tons of fuels per acre were stored in the litter and duff layers alone, without taking into account the logs and standing dead and living trees (Table 2). Following the November 1970 burn, this total had been reduced some 85% to 7.7 tons per acre. Numbers of young trees in the understory had also been greatly reduced, and while data is now being analyzed for publication, it appears that crown fire potential has been decreased substantially.

Immediately downslope from this largest grove of giant sequoias, fuel weights on the west slope of Redwood Mountain have been calculated at 20-40 tons per acre (Agee 1968). In a cut, pile, and burn program at Whitaker's Forest, mid-way on that slope, some 22 tons of fuels per acre were burned, including nearly 1000 living saplings and more than 500 dead trees per acre (Biswell et al. 1968). Costs of this manipulation ranged from $114 to $146 per acre.

The importance of fire to the fuel reduction process of the fire-dependent forest ecosystem was set forth clearly by Mount (1969):

> . . . one aspect of fire that requires most study is its role in destruction, removal and recycling of forest products, especially the dead components of the vegetation. . . . Fuel reduction burning fits in as part of the natural role of fire. Nutrient recycling, patently not fully achieved by biological agencies in forests where fuels accumulate, is more efficiently carried out by the combination of storage in durable debris and periodic processing by fire. Biological agencies are just not capable of breaking down some of the complex polyphenols and terpenes.

Whether we call this process "dry ashing" or "ecological recycling by environmental pyrolysis" or, simply, "prescribed burning," the need is there in our sequoia-mixed conifer forests, and fire seems to be about the only way to get the job done efficiently and completely.

FIRE FREQUENCY

Mutch (1970) hypothesizes that, "Plant communities may be ignited accidentally or randomly, but the character of burning is not random.

. . . Fire-dependent plant communities burn more readily [and more frequently] than non-fire-dependent communities because natural selection has favored development of characteristics that make them more flammable."

The giant sequoia-mixed conifer forest is such a fire-dependent community. And the National Park Service program of fire research and management in this forest type is based on the assumption that fire plays an important role in seedbed preparation, in nutrient recycling, in modifying successional patterns, in providing a mosaic of age classes and vegetation types important to wildlife, and in reducing fuel hazard in the forest. But how often did it play this role in the past? What was the natural frequency or periodicity of fire in a sequoia-mixed conifer forest, particularly in the forests at Sequoia and Kings Canyon?

To answer this question, we are currently analyzing fire dates on stumps of trees cut on adjacent national forest lands (Weaver 1951; Heinselman 1969). In detailed studies of small 7-10 acre plots, involving sugar pine, incense-cedar, white fir, and ponderosa pine, frequencies in the range of 7-9 years seem to be developing. In preliminary work on the relatively few stumps of sugar pine and ponderosa pine cut within sequoia groves during past insect control programs, we found a most interesting frequency record on three sugar pine stumps located within 100 years of each other in the Redwood Mountain Grove (Table 3). The period between fires, recorded on one or more of these stumps varied from 3 to 15 years, and averaged about 9 years. This is fairly comparable to the overall frequency of fire in Sierra Nevada forests determined by Wagener (1961) and the fire frequency for Southwestern ponderosa pine forests found by Weaver (1951). It is considerably more frequent than the 20-25 year fire periodicity which Hartesveldt and Harvey (1967) estimated for a given locality in the Mariposa Grove of sequoias in Yosemite. Our findings, however, are similar to the more frequent fire pattern noted by Presnall (1933) and Hartesveldt (1964) for fires somewhere in the 250-acre Mariposa Grove.

Fire frequency and intensity must have varied somewhat from habitat to habitat within the mixed conifer forest. The more mesic east and north slopes do not burn as readily as the more xeric west and south slopes. Because of this, when they do burn, they may burn more intensely than those that burn more frequently. A similar relationship was found in Soeriaatmadja's (1966) study of past fire frequency in ponderosa pine in the Central Cascades of Oregon. There, however, elevation was the variable which led to somewhat more mesic or more xeric conditions with consequent fire-frequency differences.

The records of fire frequency that we are gathering for Redwood Mountain and from nearby mixed conifer forests will offer concrete

TABLE 3. Dates of fires and intervals between them on three neighboring sugar pines, Redwood Mountain, Kings Canyon National Park, California.

Date	No. of stumps with date	Interval [a]	Date	No. of stumps with date	Interval [a]
1705	1		1792	3	
		14			5
1719	1		1797	3	
		7			12
1726	1		1809	2	
		12			4
1738	1		1813	1	
		14			6
1752	2		1819	1	
		7			12
1759	1		1831	3	
		6			12
1765	2		1843	2	
		7			4
1772	1		1847	1	
		9			11
1781	2		1858	3	
		4			15
1785	1		1873	2	
		7			

[a] Mean interval = 8.84 years.

evidence of the periodicity which fire assumed naturally in these forests. For stump records gathered to date extend far beyond the time when European man played any role as ignition source for fire. The role of Indian burning (Stewart 1956; Reynolds 1959) as compared with lightning ignition (Taylor 1971) must still be worked out. But for purposes of restoring natural environmental conditions to the parks of the Sierra Nevada, this distinction may not be essential.

We expect to complete the first segment of these studies in 1972 and hope to publish our results soon thereafter. These frequency records can then become the basis for determining how frequently we should use prescribed burning within our sequoia-mixed conifer forests.

WOOD SMOKE AND PUBLIC REACTION

Concern is often expressed about the public's willingness to accept a new fire management direction (Pechanec 1970) and about their willingness to accept a reasonable explanation of the difference between the air pollution contribution of wood smoke compared with automobile exhaust (Zivnuska 1967).

The National Park Service is greatly interested in studies of wood smoke which are now underway at the University of California's experimental forest adjacent to Redwood Mountain as well as air pollution studies being carried out by the U.S. Forest Service (Barrows 1971). We will want to take advantage of the best weather conditions for burning to minimize any possible adverse influence (Roe et al. 1971). No one should forget, however, that the quality and quantity of materials released in wood smoke are not the same as those found in industrial pollutants or automotive exhaust systems. And the desire to eliminate smoke from prescribed burns must be tempered by the desire to control air pollution from the inevitable present and future wildfires (Roe et al. 1971).

Based on our experience at Sequoia and Kings Canyon, the public seems quite ready to accept the natural role of fire in the forest and our plans to restore fire to that role as nearly as possible. We take every opportunity—through the press, in community talks, and in park interpretive programs—to explain the reasons for both our natural fire program in higher elevation forest types and for the use of prescribed fire in our lower elevation forests and chaparral country. We feel confident that candor on our part will continue to enhance public acceptance of this new, exciting, and ecologically viable management of park lands.

CONCLUSION

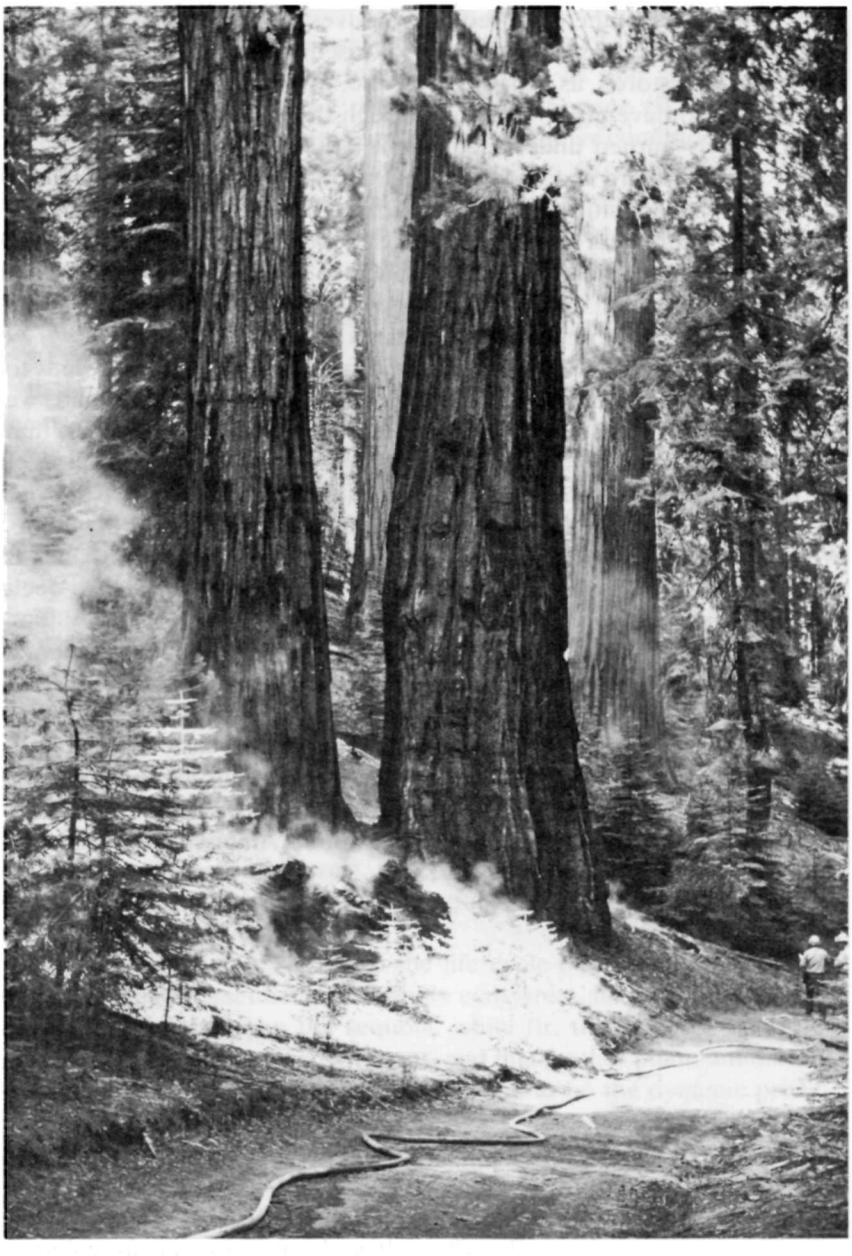
The original conifer forests of much of North America—including the giant sequoia-mixed conifer forest—were fire-dependent ecosystems. Whether ignited by lightning or Indians, fire was the key environmental factor that initiated new successions, controlled species composition and age structure of the forest, and produced the mosaic of vegetation which supported the animal components of these communities (Heinselman 1970).

Fire appears to be essential to the life cycle of the giant sequoia. As such, it becomes essential to the whole ecosystem, involving complex interrelationships between the sequoia, white fir, the Douglas squirrel, a cerambycid beetle, the carpenter ant, and many other plant, animal, and soil components of this system. Fire appears to be the dynamic process that allows minerals and energy to cycle faster within the ecosystem's operation. In theory, similar decomposer functions are performed by fungal and bacterial action. But these processes are far slower than fire, and it is doubtful whether these organisms have ever played the complete decomposition role without fire. Through our fire suppression programs, we have slowed this cycle and allowed the buildup of perhaps the highest degree of fire hazard ever observed in sequoia communities (Hartesveldt 1964).

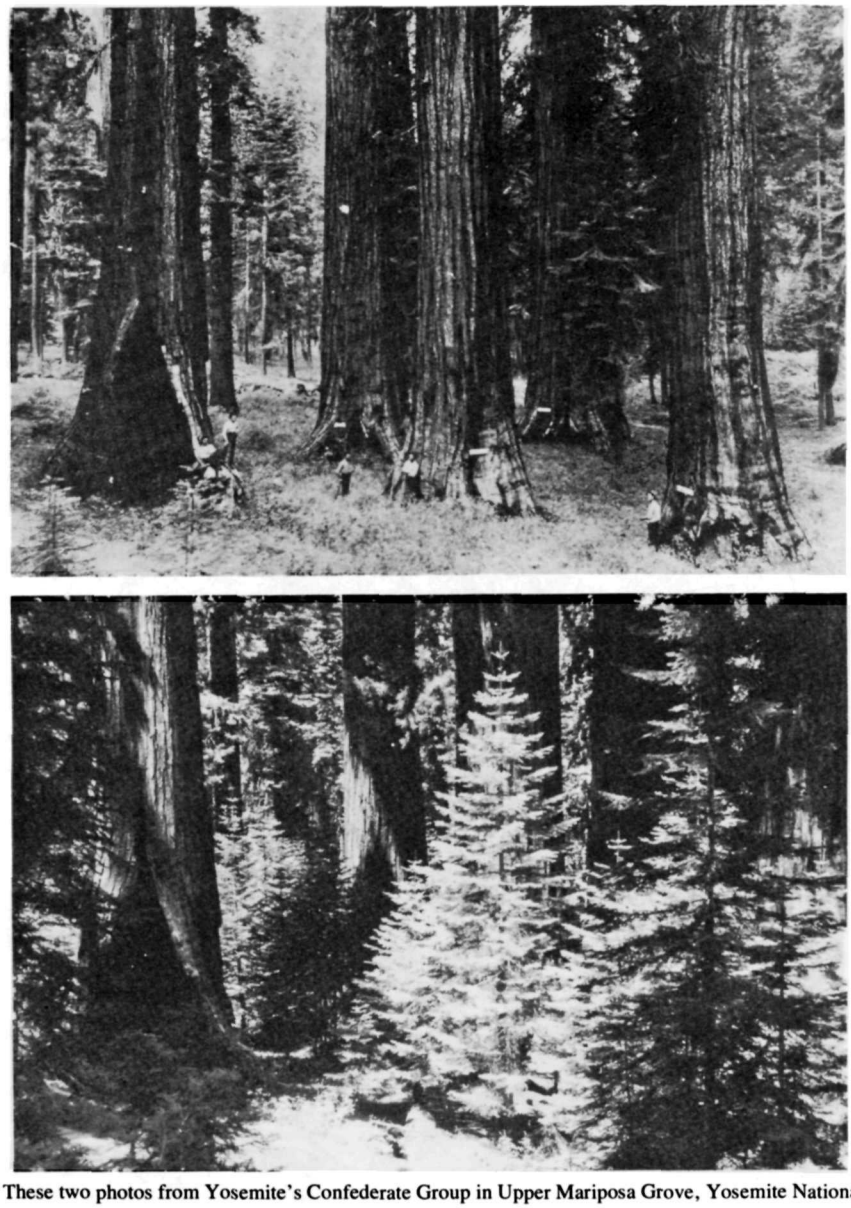
In all probability, the giant sequoia survives today because of the role fire plays in the ecosystem operation of a sequoia-mixed conifer forest. Fire must be restored, as nearly as possible, to that natural role if we are to continue to have giant sequoias through the next many millenniums. Fire probably burned under sequoias at least every 10-20 years. After longer periods, there is danger that fuel buildup will allow many mature trees to be killed. Until we are sure that fires which start by natural ignition will not threaten whole groves of sequoias or human life, the National Park Service will continue a policy of prescribed burning of the understory vegetation and accumulation of down logs and litter to bring the groves back to more natural conditions.

In managing this ecosystem, we are trying to restore natural forces to the forest; when natural frequencies of fire have been determined, we will incorporate these into our burning programs. We expect that enough mineral soil will be exposed by burning to allow germination of seedling sequoias. Burning will also aid establishment of native shrubs, an important segment of the natural community required by wildlife. When a better system of judging fuel buildup and climatic variables is developed, we will utilize this system in making the best possible decisions about managing with fire.

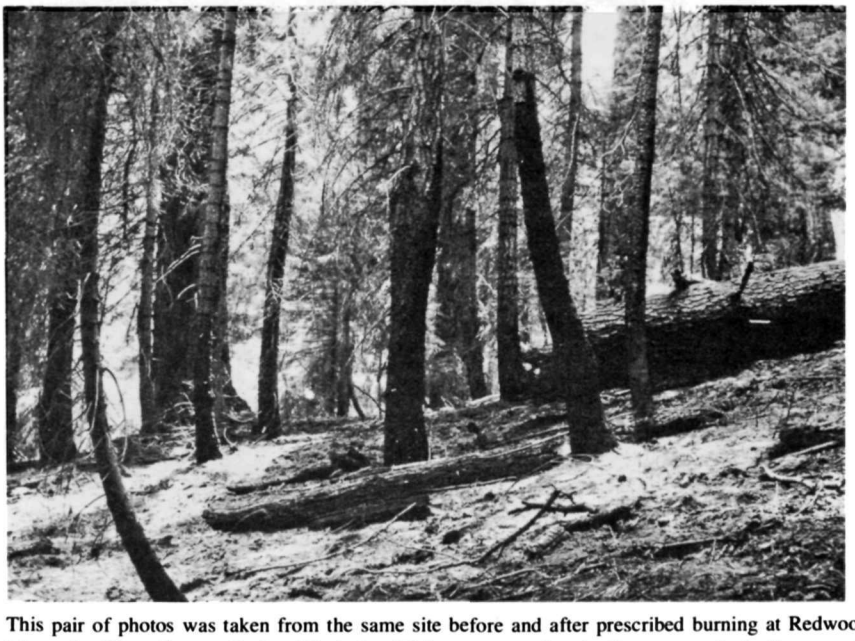
We must approach the assignment of restoring natural environmental conditions with humility and great ecologic sensitivity. Some will feel we are arrogant when we try to second-guess the current stage of plant succession. Others may feel we are becoming gardeners instead of guardians. Our guiding principle should be that, "Above all, the maintenance of naturalness should prevail." And whenever and wherever possible, the best way to restore a vignette of primitive America may be to let natural forces run their own course.



Prescribed burning in the Redwood Mountain Grove of giant sequoias, Kings Canyon National Park. Fire consumes the accumulation of forest fuels, leads to a recycling of nutrients and reduction in wildfire hazard, and prepares a seedbed for sequoias. During these early efforts, National Park Service crews used fire hoses as an added safety precaution. National Park Service photo by Bruce M. Kilgore.



These two photos from Yosemite's Confederate Group in Upper Mariposa Grove, Yosemite National Park, taken in 1890 and 1959, illustrate the successional process which occurs in the absence of fires. Thickets of white fir have grown up which could fuel a crown fire fatal to giant sequoias. Note the large fire scar on the sequoia (left) caused by a series of lighter ground fires. The early photo is by George G. Reichel, courtesy Mrs. Dorothy Whitener; the later photograph is by A. W. Hood. Such historical documentation by National Park Service collaborators Mary and Bill Hood lends strength to both research and management efforts.



This pair of photos was taken from the same site before and after prescribed burning at Redwood Mountain, Kings Canyon National Park. In addition to consuming the fir carcasses in the foreground, the fire burned considerable fine litter and duff, reducing litter weights from about 50 tons to less than 8 tons per acre. National Park Service photos by Bruce M. Kilgore and Dan Taylor.

National Park Service forestry foreman uses a drip torch in igniting forest litter under the canopy of giant sequoia. Fire will consume most of the litter and will kill some of the understory fir trees which have grown here in the absence of fire during the past 50 or more years. National Park Service photo by Bruce M. Kilgore.

The frequency of natural fires before the coming of European man in the late 1800's, is clearly documented in the growth ring pattern seen on this section cut from a sugar pine stump in the Redwood Mountain Grove, Kings Canyon National Park. On this particular tree, fires were recorded on an average of every 18 years between 1778 and 1867. Fire scar records in other localities in the grove indicate more frequent fires. National Park Service photo by Dan Taylor.

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Crocodilian Ecology in Southern Florida

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At a meeting of the crocodilian specialist group of the International Union for the Conservation of Nature (IUCN) conducted in New York City in March 1971, it was concluded that of the 27 living species and subspecies of crocodilian in the world, all are declining in numbers except for the American Alligator (*Alligator mississipiensis*). It was recognized that the alligator's favorable status is only a recent development, and is due to several pieces of legislation passed during the last 2 years which served to limit severely the North American market for alligator skins. Of the remaining 26 crocodilian forms, the IUCN group considered 22 to be severely endangered (Anonymous 1971).

Two crodocilian species are native in the United States, the previously mentioned American Alligator, a fresh-water and estuarine inhabitant endemic to portions of the southeastern coastal plain, and the American Crocodile (*Crocodylus acutus*), which occurs primarily in coastal zones from Ecuador and Venezuela northward to Mexico and southeastern Florida. The range of these two species barely overlaps in mangrove-lined creek and pond estuaries of southeastern Florida, primarily within Everglades National Park. In addition to containing this zone of overlapping ranges where both species are relatively uncommon, Everglades National Park also contains larger areas used exclusively by one species or the other: the broad, interior, fresh-water marshes and swamps, and shallow, saline, Florida Bay. The former habitats apparently support the largest concentration of alligators remaining in Florida, while eastern Florida Bay supports a majority of the remaining Florida population of crocodiles. Studies are now underway in Everglades National Park for purposes of quantifying natural and human-related factors which regulate distribution, nesting success, and population size of the two species, and to establish alligators and

crocodiles as indicators of park water requirements, general health of ecosystems, and as a measure for visitor impact on wildlife. More ideally, the studies also explore the desirability and reality of managing portions of alligator and crocodile habitats to reestablish numbers of these two species to population levels that more nearly approximate the historical numbers in the respective habitats. Greatly increased numbers of alligators would be especially desirable for their contribution toward reestablishment of a properly functioning everglades ecosystem, a relationship to be discussed in more detail later in this paper. The present studies in Everglades National Park are primarily ecological in design, and are intended to build upon a base of previous observations and studies, primarily by Craighead (1968), Hines et al. (1968), and Kushlan (in prep.) in Florida, and Chabreck (1971) and Joanen (1969) in Louisiana.

I will discuss first the American Alligator, restricting this report to habits and ecological relationships of alligators in the everglades region of extreme southern Florida, south of the Tamiami Trail. Names and descriptions of plant communities used here closely follow terminology and descriptions recently suggested by Craighead (1971).

The subjective quality of most 18th and 19th century first-hand accounts of alligators in southern Florida mean that these reports are of little use for calculating the total numbers that once occurred. However, these early reports leave no doubt that, at least in certain areas and seasons, alligators massed into concentrations much greater than have been seen in recent decades. One recent effort at estimating the former alligator population for the area of Florida south of the Tamiami Trail was made by Craighead (1968). He calculated approximately 1 million alligators, based on the approximate number of limestone solution holes and creeks that exist in extreme southern Florida which appear capable of supporting alligators. Human disturbance to this alligator population, largely through killing for commercially valuable skins, and more recently through habitat disturbance caused by water management efforts, eliminated concentrations of alligators from all areas not vigorously protected or far removed from drainage or water impoundment sites. By the 1960s, the overall reduction of alligator numbers south of the Tamiami Trail probably exceeded 90% of the pre-white man alligator population.

The present distribution of alligators south of the Tamiami Trail reflects to a great degree the past human effects on this alligator population. Alligators are most numerous down the center of the principal everglades drainage, an area known as the Shark River Slough, and along mangrove-lined headwater creeks at the lower end of the Shark Slough. Historically, the Shark Slough may have been a comparatively

less suitable habitat for alligators than adjacent cypress swamps, fresh-water mangrove swamps, or higher rockland everglades. However, these adjacent habitats were either more accessible to hunting or, being on higher ground, have suffered greater loss of alligator habitat as south Florida ground water levels have lowered. Therefore, these habitats have experienced the higher percentage of alligator losses. Accentuating the contrast between historical and present alligator distribution is the probability that the Shark Slough is more suitable to alligators at present than prior to white man's influence in south Florida. Some 19th-century journalists and soldiers who traveled in the central everglades produced reports (e.g., Dimock 1915) which indicate that in some years the Shark Slough was too deeply flooded to allow for alligator nesting, and that because of deep water, large veterbrates were scarce in the central everglades.

The Shark River Slough, where present alligator studies are centered, is a broad, fresh-water marsh, seasonally reflooded during and following an annual rainy season, June through October. Vegetatively, the slough is dominated by expansive marsh communities of sawgrass and spike rush; these marshes are interrupted by numerous islands of woody vegetation on slightly elevated sites. Where limestone bedrock mesas extend 1-3 ft above general ground level, the woody vegetation is predominately hardwoods species of West Indian origin; elsewhere on elevated peat deposits, woody vegetation is primarily swamp hardwoods including abundant willow. Also generally distributed through the slough are solution hole depressions in the porous limestone bedrock, usually bordered by willow or other swamp hardwoods. Narrow, head-water creeks which penetrate the sawgrass marshes in the lower slough are bordered by thickets of swamp hardwoods and red mangrove.

Basic life history of alligators within this environment is as follows. Sexually mature alligators, 5-6 ft in length or longer, occur throughout the Shark Slough and center their activities around water-filled limestone depressions (known as solution holes, survival holes, or alligator holes). Each hole usually supports either one mature male or one mature female, and may also have several juvenile alligators 1-2 years old. Presumably, the juveniles found with big females are her offspring. Also present with either adult male or female alligator may be several 3- to 5-year-old nonbreeding subadults. The solution hole provides a place of refuge from predators for the juvenile alligators, a den for adults, and a source of food. This latter function is of particular importance during dry seasons if surface water disappears from the surrounding marsh. Mating most often occurs in mid- or late spring, during a period of weeks when adult males wander fairly great distances from their holes to locate females. Nests are constructed and eggs are laid primarily in

June. Nests are most often located within a few hundred feet of solution holes and are situated either in dense strands of 6 to 10-ft-high sawgrass or in thickets of tall sawgrass mixed with scattered swamp hardwoods at the edge of tree islands. Nest sites and solution holes are connected by multiple trail systems through the marsh. Nest mounds are composed of local vegetation, most often sawgrass leaves and stems, and measure 1.5-2.5 ft high in the center, and 5-7 ft across at the base. Most nests are built in water less than 10 inches deep. Between 20 and 55 eggs are laid in a depression in the nest center, then covered over by vegetation. Female alligators usually remain near nests during the 60 to 65-day incubation period, often digging temporary holes or dens in soil or under willow root systems located near the nests. The nests serve to maintain eggs at rather constant temperatures, approximately 80-85°F, and some 10-20°F below maximum outside air temperatures. Female alligators are most attentive at nests early and late in incubation periods, and may defend nests from intruders, including humans. There is good evidence, but not certain proof, that females assist newly hatched juveniles to escape from nests by tearing away a portion of nest material shortly after hatching occurs. The stimulus for the nest-opening behavior of females presumably is the vocalizations by newly hatched juveniles in the nest. Juveniles often remain in or near the female alligator's solution hole for 1-2 years after hatching, but the exact relationship between adult and juveniles is uncertain. Alligators 3-5 years old are inclined to wander, and often make up the majority of alligators seen in perimeter canals or headwater creeks adjacent to the Shark Slough. Often hundreds of 3-5 ft subadults may be seen in a single creek, suggesting that these age classes may travel several miles to suitable sites. Alligators are opportunistic feeders, with adults feeding primarily on fish, and smaller alligators feeding on a wide variety of aquatic invertebrates and small vertebrates.

In sufficient numbers, alligators have considerable effect on distribution of plant communities and abundance of certain animal species in the interior swamps and marshes of southern Florida. To understand the effect of alligator activities on plant distribution, one must remember that the Shark River Slough and adjacent habitats are extremely flat regions where only minor changes in land elevation determine the length of time a site is flooded, a factor of considerable importance in determining distribution of plant communities. The interface between woody and marsh communities is often sharp, directly related to the abruptness of land elevation change. The effect alligators have on land elevation and plant distribution is demonstrated in the Shark Slough in the following ways.

NEST LOCATION

All nests I have examined that were located at natural sites in the Shark Slough have been situated in shallow water, with the center of the nest mound elevated 1.5-2 ft above water. Although some nests are reportedly used more than 1 year, most are abandoned after the initial use. These abandoned nests, composed of compact, rotting vegetation, remain as low platforms in the sawgrass marsh and provide a substrate capable of supporting plant species which have less flood tolerance than is inherent in surrounding marsh species. Plant species that establish on old alligator nests are a mixture of woody, swamp hardwoods and understory forbs native to nearby tree islands and other forb species characteristic of early successional stages on disturbed lands outside of the everglades marshes. Survival of these species on the nest sites is dependent on at least two interrelated factors. Vegetative composition and size of nests affect the rate of decay and length of time each nest survives successive seasonal floodings, and thereby the length of time an elevated site exists for the establishment and support of invading plants. Closely related, the amount of rainfall, depth of flooding, and duration of flooding in successive rainy seasons following establishment of seedling plants on nests will affect their survival; the chance of survival obviously is highest if successive rainy seasons produce lower than average rainfall. I have found that most water-located nest mounds in the Shark Slough decompose at such rates during 1-2 years of normal or above normal flooding that little of these nests remain above water after the 2nd year. Although few quantified data are yet available to show the actual survival rate of plants on the nest mounds, it is true that relatively short periods of 1-2 years of mound survival during series of wetter than normal years is too brief for most species, and that most plant survival to adequate size in order to withstand occasional flooding must occur during back-to-back or longer series of below-average rainfall years.

ALLIGATOR EXCAVATIONS

In the Shark Slough it is characteristic for the numerous solution holes to be rimmed by a dense thicket of willow and other swamp hardwoods. The elevated soil banks which border each solution hole and which support woody growth are in part created and maintained by activities of alligators which live in the holes. In certain seasons, particularly as water levels are dropping, alligators actively push and clear sediment and vegetation to the edges of holes, an activity which serves to maintain a relatively deep pool of open water in the center of the hole. Alligators also dig so-called caves or dens in the sides of alligator holes, causing portions of the solution hole edge to be pushed upward and thereby further contributing to development of earthen banks. Because

of the greater soil content characteristic of solution hole banks than of nest mounds, and because of regular re-charge of organic material to the banks, solution hole banks are more nearly permanent than are nest mounds. They provide more stable sites for establishment of woody vegetation in the Shark Slough marsh. The woody vegetation that surrounds solution holes provides an important part of nesting sites utilized by two marsh birds, the Anhinga and Great Blue Heron.

ALLIGATOR TRAILS

Several mangrove-lined rivers, which flow into the Gulf of Mexico in southwestern Florida, have their extreme headwaters in the fresh-water marshes at the lower end of the Shark River Slough. At these headwaters, located along the approximate inner edge of a broad mangrove forest, numerous, mangrove-lined creeks penetrate sawgrass marshes. Alligators are common in these creeks, where a good food supply exists and ideal nesting sites are available in thick sawgrass strands immediately behind the woody creek edges. Along this mangrove-marsh interface, activities of alligators serve in at least two ways to affect the density and distribution of woody plants. (1) Frequent use of the creeks by large alligators both for feeding and routes of travel serves to control encroachment of red mangroves from the banks into the center of creeks as the animals constantly tear away invading mangrove prop roots. In areas where alligator numbers have been reduced and where water tables have lowered, a combination of events of rather common occurrence in south Florida in recent decades, smaller creeks, particularly less than 10 yards in width, have become completely closed by vegetation. In turn, closure of most small creeks in a local area presumably alters surface water drainage patterns, reduces the capability of creeks to serve as survival sites for aquatic animals, and may reduce species diversity and density of small fish populations. (2) Alligators establish and maintain trails through marsh vegetation which interconnect adjacent mangrove-lined creeks. The trails are repeatedly used, and deepen into narrow channels that are clear of emergent vegetation. Trails which connect parallel creeks usually run perpendicular to the direction of local surface water drainage. During seasons when surface water is deepest in the marshes, floating mangrove seeds disperse from the creeks along the marsh trails, and may become lodged in edge growth and germinate. The resulting narrow strands of mangroves are capable of collecting floating debris, and eventually may form narrow dikes through the marshes. The biological consequences of these dikes has not been studied, and in fact their occurrence in the lower Shark Slough is uncommon. However, it does appear that these narrow, mangrove dikes do form shallow impoundments of surface water in local areas.

SURVIVAL HOLES

There is one important relationship between alligators and other aquatic animals in the everglades region that has long been recognized, but only recently has been quantified at one site through the studies of Kushlan (in prep.). Solution holes that are occupied by alligators are kept open and deep through the activities of the alligators and serve as dry season survival holes for other aquatic animals. As surface water dries from the surrounding marshes, alligators restrict their activities to the deeper holes and maintain these holes as open pools of water throughout dry seasons in most years. The concentrations of frogs, fish, fresh-water crustacea, and other invertebrates that occur in these solution holes provide breeding stock to repopulate the flooded marshes during the following rainy season, and a most important food supply for upper trophic species during dry months. The failure of Wood Storks, White Ibis, and egrets to nest successfully in Everglades National Park in most recent winters is almost certainly due to an inadequate food supply during the critical bird-nesting season. The recent decline in food species is due to more than one single factor, but an important part of the problem could be the loss of hundreds of solution holes which have become filled with sediment and vegetation as alligator numbers and the everglades water table both have dropped.

The work of Kushlan clearly shows the survival value of open solution holes in the everglades region. Table 1 shows the density of 17 species of fresh-water fish and 1 fresh-water shrimp during low-water and high-water sampling dates in a large alligator hole near the Everglades National Park boundary. The important comparison to note is the approximately 953 fish and shrimp per square meter of water in May, compared to 11.9 fish per square meter in August. The dry season concentration is due primarily to animals that moved into the hole from the surrounding marsh, and less to reproduction in the solution hole. Concentrations of birds that feed at these holes during dry seasons are often spectacular.

Thus far I have been summarizing the effects that alligators in sufficient numbers have on certain plant and animal species or communities in the Shark River Slough. The reverse considerations are the effects that various environmental elements have on alligators. We are especially interested in determining how such environmental elements as fire, flood, and drought, which have been altered either in frequency or intensity by human activities, affect the size, density, and nesting success of the Shark Slough alligator population.

Very briefly stated, water management activities in south Florida have created a complex network of drainage canals which have altered fresh-water environments by increasing the frequency and duration of drought conditions as ground water levels have generally lowered

TABLE 1. Comparison of the density of aquatic organisms in the alligator pond during low and high water periods from the studies of Kushlan

Species	Low water 9 May 1969 number/m²	High water 20 Aug. 1969 number/m²
Lepisosteus platyrhincus	4.8	0
Notemigonus crysoleucas	+[a]	0
Notropis maculatus	+	0
Ictalurus natalis	0.3	0
Fundulus chrysotus	19.0	1.1
Jordanella floridae	+	+
Lucania goodei	52.2	0.4
Gambusia affinis	468.5	5.3
Heterandria formosa	303.8	5.1
Poecilia latipinna	5.0	+
Elassoma evergladei	0.4	0
Enneacanthus gloriosus	1.7	0
Lepomis gulosus	1.3	0
Lepomis macrochirus	0.2	0
Lepomis microlophus	0.5	0
Lepomis punctatus	0.8	0
Micropterus salmoides	0.02	0
Palaemonetes palusosus	94.2	+
Total species	18	7
Total number/m²	952.7	11.9

[a] + Indicates present but not part of quantitative sample.

throughout the southern peninsula. A by-product of overdrainage has been more intensive and frequent wildfires. Conversely, the frequency and duration of flooding or general high-water conditions in the everglades region have declined. Yet, paradoxically, the water management system through manipulation of storage water is able to produce unnatural and sometimes sudden rises in surface water at almost any season of the year. I will discuss the effects of these changes as they relate to alligator nesting success.

Alligators do have the ability to adjust nest height, at least within certain limits, to water levels in the marshes at the time of nest construction. This is shown in Table 2, where the heights of measured nests shortly after construction, and the depth of eggs in these nests, are compared with local water depths, for 3 different years. This comparison shows that the highest nests were built in the year (1970) of deepest water, while the depth of eggs in the nest remained relatively constant. Also shown in Table 2 are measurements from two nests constructed out of water on higher ground. These two nests were the smallest mea-

TABLE 2. Relationship between nest measurements and water depth at alligator nests in the Shark Slough, Everglades National Park, 1970–72.

	1970				1971				1972				High ground			
Nest #	Nest height	Depth top eggs	Depth bottom eggs	Early season water level	Height	Top eggs	Bottom eggs	Water depth	Height	Top eggs	Bottom eggs	Water depth	Height	Top eggs	Bottom eggs	Water depth
1					24	–	–	5.5	38	10	17	5.5	19	11	18	–
2	30	7.5	–	12 inches	30	10	18	4.5	31	10	14	4				
3	32	7	–	11.5	26	10	16	5.5	29	10.5	14	8				
4	31	3	11	8.5	21	6	12	6	29	12	20	6				
5	35	15	–	9	22	7	13	4.5								
5A									30	6	11	8				
6	31	12	–	13	22	8	13	–	24	5	9	7.5				
7									28	7.5	12	11.5				
8									27	4	10	6.5				
10									25	5	10	5.5				
11									27	10	17	5.5				
12									28	12	18	8				
13									24	6	11	7				
14													18	9.5	16	–
Average	31.8	8.9	–	10.8	24.1	8.2	14.4	5.2	28.3	8.2	13.5	6.4	18.5	10.2	17	–

sured, a fact which further suggests that alligators have the ability to adjust nest height to local water depths.

These data in Table 2 show that a rise in water any time during the 60-65 incubation period which is much greater than 6 inches above June levels, probably will destroy the eggs in many nests in the Shark Slough. The average June-August rise in the Slough (P-33) for years 1953 through 1970 was 7 inches, indicating that it is not unusual for lower eggs in nests to be flooded late during incubation, and perhaps most nests contain a few eggs that do not hatch due to flooding. An important water management consideration, therefore, is that excessively heavy deliveries of surface water into the Shark Slough be avoided during the 2 summer months when most alligator nests contain eggs, to avoid loss of most nests through flooding. For this reason, a 6 to 7 inch rise in water probably should be considered the maximum desirable water rise for the period between mid-June and mid-August. In years similar to 1971 when there was an excessively dry spring and late starting rainy season, alligators will not start nesting until late June or early July, and hatching will occur by early September. In these years, an excessive rise in water should be avoided if possible until after the early-September hatching of most nests.

The effects of drought on nesting success are less well known. Drought conditions which existed in the southern everglades during the spring of 1971 provided our first opportunity to study nesting under such conditions. Summer rains began in early June and were sufficient to reflood the Shark Slough between mid- and late June. Alligators built nests about 3 weeks later than average, mostly during early July, and produced a large hatch of juveniles in early September. The density of nests in the Shark Slough was less than in the previous 2 years, although the number of eggs per nest was the same as the average for earlier years. The large hatch in September may be misleading as a measure of real production, as our observations indicate that juvenille alligators are less well prepared to survive the stress of food shortage such as occurred in the everglades region after the almost total loss of surface water early in 1971. The total rainfall over the Shark Slough for 1971 through mid-December has been 17 inches below normal, and almost certainly the Slough will become dry again in the spring of 1972, adding further stress to the 1971 hatch of alligators. Such back-to-back droughts may result in higher than usual mortality to juvenile alligators (less than 2 years old), but most subadults and almost all of the adult breeding stock survive.

Aside from the obvious direct effect of fire on alligators, fire in the everglades marshes also has an important negative effect on acceptability of sites for nests. As I previously mentioned, the usual nest locations in the Shark Slough are the interiors of dense sawgrass, either in pure strands or along the borders of tree islands. The height and density of

sawgrass at these nesting locations is a function of soil depth and time since the previous local fire. Following an everglades fire, recovery of sawgrass heights to the height at acceptable nest sites is rapid, often taking no longer than 6-8 months. However, density of plant leaves and stems and accumulation of dead vegetation per square meter, to a condition similar to sawgrass densities at active nest sites probably require 2-3 years following a fire. Therefore, large everglades wildfires may eliminate expansive sections of marshland for 1-3 years, forcing a considerable reduction in alligator nesting or relocation of nests (tree islands) where nesting success may be lower. We are presently attempting to better quantify these effects of fire.

The American Crocodile population in Florida has not been accurately surveyed, but probably is between 100 and 300 individuals. The area where a viable population of crocodiles certainly continues to exist is a rather small strip of estuary in extreme southern Florida, from the portion of Biscayne Bay that is south of Miami, south and west into central Florida Bay and along the main Florida Keys, at Key Largo and probably Plantation Key. There is also an isolated, small number of crocodiles in the lower Florida Keys in the area of Big Pine Key. Crocodile distribution within this range is about as one might expect, that is, numbers are very low and distribution is spotty except for a few areas where human development has been limited. Apparently the greatest density of crocodiles remaining in south Florida is along a 15-mile section of shoreline in northeastern Florida Bay, and eastward around the shores of Barnes Sound-Lake Surprise. Most of this shoreline is low and swampy and not readily suited to human use; additionally, Florida Bay is within the boundaries of Everglades National Park. Interestingly, this same northeastern Florida Bay shoreline was described by Dimock (1915) as the center of crocodile abundance, at a time prior to much human influence to the overall Florida Bay-upper Keys area. Therefore, habitats in northeastern Florida Bay may represent some of the most suitable available to crocodiles in Florida.

Our primary interest in crocodiles is to preserve a viable population in Everglades National Park, in the face of a slow decline in the numbers remaining in Florida. Field studies presently underway are restricted primarily to northeastern Florida Bay and are designed to determine factors affecting crocodile nesting success, and to better understand habitat requirements and the present pattern of distribution. Northeastern Florida Bay is the upper end of a broad, shallow bay approximately 35 miles long and 7-20 miles wide. The eastern end is largely cut off from tidal influence by the main chain of Florida Keys. This portion of the bay exhibits some marked seasonal fluctuations in salinities and composition of aquatic animal and plant species. Highest salinities, up

to 55/1000, are recorded in drying ponds on Florida Bay keys during dry season months, while at the low extreme, salinities near 5/1000 have been detected close to the mouths of creeks which drain the mainland during the summer-fall rainy season. The mainland shoreline of eastern Florida Bay is an irregular series of coves or bights, intersected by several narrow creeks which drain small, inland bays and inland freshwater wetlands. Eastern Florida Bay is composed of several large, deeper pools, called "lakes," 2-4 miles across and 6-8 ft deep, separated by groups or chains of low keys covered mainly by mangroves.

The keys are often interconnected by submerged marl banks which support *Thallasia* and other marine plants. Vegetation on the mainland shoreline is largely mixed thickets or fringes of red and black mangroves growing on low marl banks. Where there are slightly elevated shorelines, small dense hammocks of West Indian hardwoods occur, and where these hammocks are immediately on the shoreline, small sandy beaches have developed.

Life history and ecological data for crocodiles in southern Florida is less well known than for alligators, but basically the story in Florida Bay is as follows. Adult crocodiles are distributed throughout the eastern bay, but are most numerous near the edges, either along the mainland shoreline or close to Key Largo. Nests are located on relatively high ground within 5-35 ft of water. The two most frequently used types of nest sites are banks of narrow creeks which cut through the marl, mainland shoreline, or inside the edge of shoreline hammocks at the heads of narrow sandy beaches. Nest mounds are most often composed of sand or marl, with little or no vegetation, and are quite variable in size. Largest mounds are 15-20 ft in diameter at ground level, and 2.5 ft high at center, while at the other extreme are those nesting sites where eggs are deposited in an excavation below ground level, and covered over so that the site is flat with the surrounding terrain. There apparently is no correlation between nest composition, size of mound, or susceptibility of a nesting site to occasional flooding. Nest mounds are built during late March or April, and eggs are usually laid by the end of April. The incubation period is approximately 90 days, with hatching occurring between late July and mid-August. The average clutch size in eight nests in 1970 and 1971 was 39 (range: 28-52), and the average number of young hatched from five of these nests was 29 (range: 11-39). There is not a great deal known of the relationship, if it does exist, between newly hatched young and adult females, but hatched young do disperse rather quickly from immediate areas of nests, particularly nests located in areas of relatively high salinities. Most sightings of juvenile crocodiles (those less than 1 year old) have occurred in low salinity ponds and creeks at mainland sites adjacent to Florida Bay. Our hypothesis is that

the movement of newly hatched crocodiles to areas of low salinity is food-oriented. Reports of stomach contents in *Crocodylus acutus* from Central America, by Schmidt (1924), support the hypothesis by showing that juvenile crocodiles there feed opportunistically on juvenile fishes and a wide variety of aquatic invertebrates, primarily insects, crustacea, and mollusks. In Florida Bay these types of prey species are most abundant in low salinity areas, presumably due to low salinity tolerances characteristic of many estuarine invertebrates. We do not yet know the time required for juvenile crocodiles to move from nest sites to nearest creeks or inland ponds, but the distance from some nests to nearest likely feeding areas is as much as 3-4 miles.

Nesting success by crocodiles at 16 nests during 1970 and 1971 was as follows: nine successfully produced young; four nests destroyed by predators; one nest opened by unknown human; one nest constructed but never received eggs; and one nest contained eggs, apparently undisturbed, which failed to develop. Based on this sample, the most important regulators of nesting success are natural predators. At the four nests destroyed by predators, our identification of the culprits were raccoons, notorious egg-eaters in Everglades National Park. Previous studies in the Everglades, including the work of Holden (1965) with Loggerhead Turtles and Allen (1942) with Roseate Spoonbills, have also reported on the adverse effect raccoons may have on reproductive success in egg-laying species.

One other consideration concerns the effect of exotic Australian pine (*Casuarina*) infestations on crocodile nesting sites. *Casuarina* is an aggressive invader of disturbed beaches in south Florida, and its seeds are rapidly dispersed in salt water, particularly during tropical storms. Klukas (1967), in recent studies of Loggerhead Turtle nesting in Everglades National Park, reported on the way dense stands of fast-growing *Casuarina* eliminate turtle nesting sites at the heads of sandy beaches. The same adverse relationship exists between *Casuarina* and crocodiles, although infestation of eastern Florida Bay is less advanced than on the Cape Sable beach where Klukas worked. Nine of 11 crocodile nesting sites in Florida Bay that have been closely surveyed for vegetation were found to support *Casuarina*, and therefore are considered to be in danger of being lost as acceptable nesting sites. A *Casuarina* control program is called for, to insure that stands do not develop on crocodile nesting beaches.

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Marine Research and Resource Management in Virgin Islands National Park

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In the years following 1934, when submerged marine lands were included within Everglades National Park, the marine resources responsibility of the National Park Service (NPS) has expanded rapidly, now including hundreds of thousands of acres of submerged and coastal lands in eight national seashores and seven national parks and monuments. An additional 30 units of the Service, including large areas in Alaska and Hawaii, Washington State, California, and Maine, are located along, and intimately related to, submerged marine lands. With the inclusion of these areas in the park system, there has evolved an interest in research and management of the full range of marine ecosystems—invertebrate benthic and planktonic communities and intertidal associations—as well as the fisheries. With SCUBA, snorkeling gear, and other viewing devices, it is now common practice to confront underwater systems visually and directly. Such confrontation has brought increasing awareness by visitor and park manager alike that these habitats, like those on land, deserve preservation and enjoyment intact, not merely as what remains following policies of fisheries exploitation.

The following paper briefly traces the evolution of marine research and management activities in one of these marine areas—Virgin Islands National Park, on the island of St. John, in the U.S. Virgin Islands. I believe that the research which the National Park Service has supported there reflects a general Service-wide interest in a comprehensive understanding of the marine habitats within its jurisdiction, and an increased awareness that marine environments are often intolerant of excessive change.

The northern Virgin Islands, including St. John, are centered at about 18°30′N, 64°30′W. Geologically a part of the Greater Antilles, like Puerto Rico just 100 km to the west, the principal islands of the group

are typically low and mountainous with altitudes of less than 500 m, of mixed sedimentary and volcanic origins. Receiving 100-150 cm of rain each year, they are clothed with mixtures of moist deciduous forest and dry, wind-adapted scrub and cactus. Sea surface temperatures are consistently above 20°C, and the shallow coastal waters support a moderately diverse assemblage of reef-building corals (30+ species) and alcyonarians (45+ species) as well as extensive areas of coarse, clean sand and productive turtle grass beds.

Although the terrestrial boundaries of Virgin Islands National Park were authorized in 1956, submerged lands adjacent to the park were not incorporated until 1962. During that interval, the Service, recognizing the importance of an inventory of the submerged resources, participated in a 2.5-year marine biological and fisheries survey of the waters of St. John. The project's principal investigator was John Randall, now of the Bishop Museum in Hawaii. Others involved included staff from the Virgin Islands Government, Bureau of Sport Fisheries and Wildlife, National Science Foundation, and the Marine Laboratory of the University of Miami. These workers produced a remarkable series of maps and scientific publications on the distribution of shallow habitat types (Kumpf and Randall 1961), the sport fishery, fish food habits, shellfish ecology (Randall 1964), and the systematics of Caribbean reef fishes (Randall 1968). It was primarily from observations on St. John that Randall derived his hypothesis that the bare sand band commonly separating reefs from adjacent grass beds is due in certain areas to the grazing of herbivorous reef fishes who venture only a short distance from the protection of the reef (Randall 1965).

With a biological inventory at hand, the potential park value of the waters of St. John and of Buck Island off St. Croix were readily recognized by the Territorial and Federal governments, resulting in formal designation of these areas as underwater reserves within the National Park System.

In 1966, in response to a request by local college and government research interests, Virgin Islands National Park entered into a cooperative agreement for the establishment of an ecological field station within the park. Lameshur Bay, on the southern shore of St. John, was selected as the site of the Virgin Islands Ecological Research Station. During the station's 8-year history, staff and visiting workers have undertaken a diversity of projects with park approval and support, including a number of research problems of special interest to park resource management. These range from an analysis of local fishing practices and intensity and the repopulation dynamics of overfished reefs (Dammann 1969) to a better understanding of the ciguatera fish-poisoning problem (Dammann 1970). The Service is continuing to work closely with the

research station in order to stimulate further basic and management-oriented research in both terrestrial and marine subjects.

In 1969 the Virgin Islands (specifically Lameshur Bay on the southern shore of the park on St. John) were selected as the site for an ambitious man-in-the-sea project called "Tektite I." Although directed by the Office of Naval Research, other agencies including the Department of the Interior, National Aeronautics and Space Administration, and the General Electric Corporation participated. In Tektite I, four Department of the Interior aquanaut-scientists spent 60 consecutive days on a 16 m-deep reef in Lameshur Bay in an underwater habitat (Pauli and Cole 1970). In a subsequent return in 1970, 11 teams totaling 55 highly qualified geologists, oceanographers, marine biologists, animal behaviorists, and habitat engineers spent a combined total of 6 months living and working out of the same structure. Projects undertaken from the habitat were selected for their potential contribution to a better understanding of local marine natural history, fish behavior, reef structure, and geologic history (Clifton et al. 1970; Miller et al. 1971; Collette and Earle 1972). The National Park Service, especially in the 1970 Tektite II operation, was an active contributor to the program, providing personnel support, services, and direct contributions in excess of $100,000. Of particular interest was the spiny lobster (*Panulirus argus*) investigation, begun in Tektite and continued from the research station facilities for an additional 6 months. Through tagging and sonic tracking, considerable information of management value to the park is now available on population-limiting factors, growth, mortality, and movements of local spiny lobsters, plus a reasonable estimate of island-wide abundance (Olsen et al., 1971).

In 1970 the Service was able to assign a full-time research biologist to the Virgin Islands, whose responsibilities include marine and terrestrial research in Virgin Islands National Park and Buck Island Reef National Monument. In that position it has been my function to serve as liaison with the research station, with the Tektite project, and to develop a reasonable, long-term set of research goals and resource management plans.

In conjunction with local park staff and personnel in the Office of the Chief Scientist, a resources management plan (Robinson 1971) has been prepared which sets priorities on various projects and aids in efficient programming of needed funds. Since a number of natural resource problems encountered in Virgin Islands National Park are peculiar to marine parks, these are briefly described in the remainder of this report.

CONSUMPTIVE USES

Special regulations allow limited sport and domestic fishing within park waters. Seining and spearfishing are prohibited, but a substantial

amount of fishing continues by trapping, using single-entry, fine wire-mesh traps of a traditional Caribbean design. Since these traps are usually placed adjacent to reef structures, they tend to trap selectively the common and frequently territorial reef species. The effect of this trapping on the composition, density, and territorial dynamics of the general reef fish population is still poorly understood. Observations made during one of the Tektite II missions (High and Beardsley 1971) and a long-term investigation by workers at the University of the West Indies, Jamaica (Munro et al. 1970), have provided some data necessary for a reevaluation of fishing practices in the park. Particular attention has been focused on the fineness of the mesh used and the effects of lost traps which continue to fish for extended periods.

VISITOR IMPACT ON CORAL REEFS

With greater numbers of park visitors actually entering the marine environment with SCUBA and snorkeling gear, there is increasing opportunity for physical damage to reef structures. There is also a potential for alteration in reef fish behavior and dynamics which is very difficult to assess. These problems are particularly acute in areas which may have been set aside and appropriately marked as underwater nature trails, and which consequently receive a heavy concentration of visitors.

Two such underwater trails were set up in park waters in the Virgin Islands in the early 1960s. At the time the trails were first established, visitation was low, and unfortunately little attempt was made to document the initial condition of the area. It quickly became apparent that indiscriminate anchoring by visiting boats was a serious cause of breakage, and mooring buoys were installed to control boat access. A program has now been implemented to accurately map and survey each trail area periodically to monitor visitor impact. It has become obvious that we need to know considerably more about natural reef changes in order to distinguish the effects of visitor impact from natural factors—for instance, periodic influxes of bottom sand may destroy large areas, and reexpose old basement reefs; heavy siltation associated with landslides or land-derived erosion may cause die-off on horizontal surfaces. Violent wave action can devastate whole sections of reef, the extreme situation being a hurricane, where whole reefs and other benthic systems may be extensively modified (Glynn et al. 1964).

As one means of determining recovery rates of disturbed areas, NPS is continuing to monitor the hard and soft coral growth on an 11-year-old artificial reef on a sandy bottom in Little Lameshur Bay. Growing conditions there are not ideal, since the reef is subjected to some abrasion by shifting sand, and observed rates are probably minimal. Eventually, results of such studies on visitor impact and on recovery rates

will allow reasonable management decisions on the carrying capacity of a given underwater area and the feasibility of establishing a rotation schedule for heavily used areas (Robinson 1973).

WATER QUALITY AND ENVIRONMENTAL MONITORING

Within National Park Service areas, it is axiomatic that natural water quality should be maintained; but the ease with which this can be done is in direct proportion to the amount of control over the watershed which the Service can exert. Virgin Islands National Park, like some other relatively new parks, still contains large inholdings of private land. Developments on these lands frequently result in increased erosion and fresh-water runoff into park waters. There are also increasing numbers of overnight boat visits and municipal developments on park boundaries, with consequent sewage pollution and solid waste disposal problems.

The island of St. John is fortunate in being situated in an area of strong surface currents; at present the islands immediately up-current (the British Virgin Islands) are relatively undeveloped and are not significantly affecting the quality of marine waters down-current. Should there be considerable industrial development on adjacent islands without safeguards, there is a real danger that incoming water quality will be degraded both chemically and biologically. There exists a serious potential threat, at least esthetically, from local up-current islands and from general surface pollution of the Caribbean, as evidenced by the quantity of nondegrading solid waste and oil residues already accumulating on the east-facing beaches of St. John.

The park personnel have outlined a series of studies which should result in a comprehensive understanding of water movements and water quality around St. John. In cooperation with local government programs the first stages have concentrated on establishing baselines of water quality on which to judge subsequent changes (unpubl. EPA-NPS data). Permanent sampling stations still must be established in critical areas of heavy use and in waters which retain essentially wilderness character. Concurrently, projects are proposed to study the nearshore fixed and tidal currents in order to determine circulation and flushing in certain bays and provide an objective basis for determining the density of boat use allowable in heavy use areas.

BEACHES AND SAND TRANSPORT DYNAMICS

The succession of coral sand beaches along the northern coast is a major esthetic and recreational asset of Virgin Islands National Park. The highly sculptured nature of the coast, with successive bays separated by rocky headlands and varying degrees of wave exposure,

creates a complex and largely unstudied pattern of circulation and sand movement. Annual changes in beach character are sometimes great, with cut-back associated with heavy swells arriving from far-distant winter Atlantic storms, and deposition occurring generally during calmer summer conditions. A number of beaches appear to be undergoing net regression, in certain cases altering or eliminating recreational swimming areas and destroying the protective line of sea grape trees. Although some short-term protective measures have been taken, local park managers have resisted major beach management schemes until a full-scale analysis of sand transport, sand sources, wave energies, beach profiles, and historical changes has been effected.

The first phases of such an investigation have been completed through intensive monitoring of a full annual cycle of several north shore beaches by a joint NPS-University of Virginia team. Incoming wave energy parameters including height, approach angle, period, and the duration of storm-produced swell were recorded in conjunction with daily responses of the beaches. Transects with SCUBA and fathometers extended the data collection into the critical sand zones directly offshore. Preliminary analysis shows that 95% of the material making up these beaches is directly derived from nearshore coral reefs (Hoffman et al. 1973). In addition, this material is typically very fine (75% <200 microns), suggesting that even small alterations (natural or artificial) in the incoming wave-energy pattern could have considerable effect on redistributing the beach material, possibly causing it to be deposited on the critical supply reefs offshore.

Decisions regarding the feasibility or appropriateness of any beach management scheme must await final analysis of the current investigations. Presumably additional factors relating to recreational value and the protection of outstanding natural features or established developments will enter into the final determination. Current local policy seems to be tending toward the realization that beaches are dynamic structures whose presence is transient. Dependence upon a given extent or form of a beach is unrealistic, and natural features, facilities, or other developments on such a transient base should be considered expendable. Interruption of the dynamic process, regardless of the sophistication of the scheme, usually requires an energy input of great cost and low efficiency, producing ecological consequences too often unpredicted and unwanted.

SUMMARY

The highest priorities, then, lie in these four areas—visitor impact, consumptive uses, water quality, and beach dynamics. In addition, we have identified a number of further research needs within the park. Some relate to the ecology of coastal wetlands, including salt ponds and mangrove swamps, since these areas

play important roles in providing breeding sites for sea birds or act as nursery grounds for juvenile reef fishes. Saltponds are also important buffers between land and sea since the ponds tend to trap silt-laden runoff and prevent turbid waters from flowing directly onto nearshore reefs.

In addition to its support of research aimed specifically at park management problems, Virgin Islands National Park has elected to cooperate with research agencies and conservation groups in the Virgin Islands and in the Caribbean as a whole. This effort generally takes the form of participation in advisory councils and regional conferences, and jointly reviewing proposals for applied and basic research by outside workers. The park is increasingly called upon to provide advice and guidelines for the development of other marine and island parks. An encouraging number of such requests have already been met, from Barbados, Costa Rica, Curaçao, Dominica, Guadeloupe, Hawaii, and Vieques.

It is hoped that the National Park Service can continue to provide such advice and services, in the conviction that the role of the Virgin Islands National Park includes not only the preservation and interpretation of the island of St. John, but also an obligation to resource conservation and a rational development of the Caribbean as a whole.

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Intragroup Social Structure and Social Solidarity in Park Settings

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The study of the formation of social bonds is central to the understanding of the behavior of many social species. This is particularly true among primates, where it is well established that knowledge of genetic mechanisms is an insufficient basis for the prediction of social behavior. Studies of animal rearing in social isolation, which are part of a larger class of sensory deprivation studies, have established that animals reared in essentially sensorially depleted environments tend to show unusual and bizarre adaptations to many common social situations later in life.[1] Such adaptations are unusual and bizarre from the perspective of the previously identified patterns of adaptation common to the species under consideration. The range of adaptation is well documented in the literature and occurs in almost all aspects of the animal's life including reproductive, parental, agonistic, feeding, and other forms of behavior. Of course, individual adaptations may be functional while not contributing to species perpetuation.

Social bonds are, quite simply, attachments among individuals of the same species so that they react differently toward those conspecifics with which they are bonded than they do in similar situations with others.[2] Among primates, it appears that culture, which is a primary mode of species adaptation, is substantially implicated in almost all aspects of a species social behavior. Whether it provides alternatives for adaptive problems which are more efficacious than other modes remains to be ascertained. Although we are only beginning to study the comparative efficacy of various types of adaptation for clearly delineated functional problems characteristic of a species or several similar species, some interesting results are emerging. For example, Baldwin reports that he was unable to detect any evidence of stress among free-ranging primates under conditions of increasing density comparable to those at times reported among other vertebrates.[3] To

what extent differential efficacies of modes of species adaptation may be implicated remains to be examined. What is suggested is that mechanisms of adaptation based upon learning and a culture may provide dimensions not otherwise available to a species. What is also suggested is that mechanisms for adaptation which are apparently similar may not function similarly among several species.

SOCIAL BOND RESILIENCIES

The strength of social bonds among individuals is a matter of some interest. How much stress and of what kind can different types of social bonds withstand? Among rabbits, Kenneth Myers found that the social bonds uniting a breeding group were capable of withstanding considerable pressures from increasing densities.[4] Apparently, although he documented over a considerable period of time significant changes within individuals in terms of various physiological states, including reproductive capacities, the social bonds were the last to undergo observable variations. Certainly, any student of adaptation must distinguish between changes occurring within an individual animal, whether they be physiological or psychological, from those occurring between individuals.

Given the resiliency of social bonds observable in several species, what are the facilitating conditions which account for these strengths? One answer is conditioning or habituation. But that is the mechanism by which a *particular* bond is strengthened among particular individuals. How is it that some social bonds seem to share a common level of strength among many recognizable members of a species who are themselves never in interpersonal contact? The answer, in part, moves into an examination of social solidarity whenever the species under consideration is *Homo sapiens*.

Sociologists, along with other social scientists, have been intrigued with the nature of social bonding among *Homo sapiens* for some time. Indeed, one might say that it is *the* intellectual problem which binds the field together and unifies it as a body of scientific inquiry. The challenge has been to understand the constituent elements in the solution to the problem of Hobbesian order. Briefly, social solidarity is the consensus existing among individuals in the definition of a social situation.[5] It usually presumes cooperation among the individuals (in several forms) and the existence of a shared set of symbols. As Emile Durkheim suggested, social solidarity may have varied sources and it may arise in differing ways.[6] Clearly, the persistence of a particular state of solidarity among a collectivity of individuals presupposes the satisfactory operation of processes of socialization to insure the continued presence of knowledge among participants about symbols, attached meanings, etc.

An important aspect of such processes is the setting in which the processes of "identification with" and "identification of" occur.[7] All social orders, irrespective of species, appear to have settings which are strategically important for particular aspects of the process of socialization. It is apparently not sufficient to have the right kinds of individuals, i.e., in terms of age, sex, etc., to efficiently maintain or create a given state of solidarity. A particular kind of setting is often a seemingly necessary condition,[8] which brings me to the subject of parks and park-like places in human social orders.

LEISURE LOCALES IN HUMAN SOCIAL ORDERS

All social orders exhibit an economy. The nature and extent of them are many and varied. Among *Homo sapien* social orders, economies are often characterized in terms of the mode of production characteristic of an historical era. Thus we speak of pre- as well as post-industrial societies. An apparent characteristic of human economies is the extent to which diverse forms of divisions of labor arise. Industrial economies permit, perhaps require, a more expanded division of labor than is usually found among nonindustrial economies. Basically, it is a matter of specialization and specification, that is, behavior which is recognized as specific to task accomplishment tends to become "bundled together" into particular occupational social roles. The demarcation between behavior deemed relevant to the economy and behavior deemed not relevant tends to become quite distinct, as contrasted with some nonindustrial economies.[9]

Associated with such matters are the observed distinctions within a species of individuals of differing age grades and how they are articulated with the economy. Adults tend to perform those social roles essential to the economy, while nonadults tend to perform nonessential roles, if any. Economies where the rationalization of production processes has taken place tend to separate production locales from nonproduction locales. This separation is not so much in terms of place, as a distinguishing feature of human social orders, as it is a matter of the separation of role behavior and hence social age categories. But human social life is a continuous process. Though *Homo sapiens* may separate age grades in an industrial economy in a manner different from that in other economies, such separations are momentary in the lives of the individuals who continue to persist in living in social groups throughout most of their lives.[10] Participation in the economy of a social order does not constitute the totality of existence. Not surprisingly, human social orders tend to be characterized by other specialized settings where various age grades participate *together* in ritualized behavior that transcends the particularities of specific institutionalized aspects of cultural systems.

The study of human leisure is merely beginning in a systematic sense. Some students have demonstrated the importance of play for the development of the individual into a functioning adult member of a social order. This has been demonstrated in a rather substantial manner in species other than *Homo sapiens*.[11] As a part of this increasing interest in the study of human leisure, an investigation of leisure locales may enable an increased understanding of the manner in which social solidarity is facilitated in human social orders, while also increasing our understanding of the conditions under which social bonds are strengthened among *Homo sapiens*. In a study conducted several years ago, we began to examine these phenomena and in the balance of this report we will discuss some of our findings.[12]

CHARACTERISTICS OF HUMAN LEISURE LOCALES

Leisure locales are places where members of a human social order ordinarily engage in noninstrumental behavior, i.e., behavior not ordinarily associated with an economy. This definition is an attempt to recognize that most human behavior is "place specific;" that is, space is divided into "territories" in which certain behavior is expected to occur and symbols appropriate to the behavior are shared among members of a social order.[13] For example, beach wear is ordinarily taboo at a formal dinner while, conversely, formal attire is unusual at the beach. But costume is only one among many symbols which are essential for the recognition of "locale." Not only are there expectations about the behavior of individuals or appropriate costuming, but there are expectations about the nature of the social relationships which will hold among the participants in that particular setting. For example, for many adults in this society it is considered unusual to go to a park with their boss. One of the reasons is that the "setting" is incorrect for the kinds of interaction which ordinarily occur within an "employee-employer" social relationship. In short, one of the characteristics of a leisure locale is the nature of the social bond which holds among particular individuals within the setting. For example, we found that approximately 87% of the respondents in the study had gone to a park with others. This was in contrast to the approximately 82% who reported that they went to work alone. Thus, one characteristic of a park, as a leisure locale, is the expectation that individuals encountered therein will be present as members of a two or more person social group. Thus, an individual will enter the setting as a participant in a previously existing social group whereas entry into a setting associated with the economy is likely to be as an individual, preparatory to entering an occupational social role.[14] In a leisure locale, among adult members of the society, many of the symbols and social norms characteristic of social solidarity may be present

within the social groups of which they are a member.

In order to ascertain if such experiences are common, we asked if the respondents normally went to a park with these same others. Approximately 79% reported affirmatively. Another indication of the nature of the social bonds shared by persons in a park is suggested by the finding that 90% of the respondents who reported going there with others also reported that the group had remained physically together throughout the period of time present therein. In an effort to gain some further insight into the nature of the social bonds which existed among the social persons in these groups, we inquired whether they, as individuals, had accompanied the group willingly or not. Seventy-nine percent reported that they had gone to the park because they had wanted to. Apparently, a park as a leisure locale is characteristically a setting where individuals are members of relatively stable social groups which have previous experiences in such settings. The social bonds among the members of the groups appear to be comparatively strong (meaning repetition tends to strengthen relationships via the mechanisms of habit strength formation) and cognitively defined as affectively positive. In short, the social bonds holding among the members of the groups appear to be highly particularistic, as contrasted with more universalistic criteria.

Additional support for this observation was obtained when we examined data concerning the characteristics of the social groups in the parks. Approximately 57% of the groups were kinship groups, that is, all members were related to each other by blood or marriage. About 29% of the groups were friendship groups; that is, members were friends although some members might also be related through kin ties. The balance of those individuals who had gone with others did so as members of organized groups such as clubs, tour groups, etc., but were not characterized by kin ties among the members though some members might have previously been in a friendship relationship. Most people in such groups were previously not known to each other. Thus the observation that the nature of the social bonds existing among members of the social groups present in the leisure locale of a park are predominantly particularistic tends to be confirmed.

An additional characteristic of the park as a leisure locale is that it is a setting where social groups, characterized by particularistic bonds among individual members within them, come into social and physical proximity. Few such situations exist elsewhere in the society. What are the consequences of this juxtaposition of such groups for the emergence, perpetuation, or diminution of social solidarity within a society?[15]

INTERGROUP CONTACT AND SOCIAL SOLIDARITY

Social groups of the kind which characterize parks, as a special case of leisure locales, tend to be closed groups; that is, individuals not sharing social bonds based upon kinship or friendship ties are unable normally to gain access to the social transactions occurring within them. This appears characteristic of social groups wherever they are observed within the animal kingdom. They are exclusive and tend to maintain their social boundaries. Attempts to penetrate such systems of particularism by either individuals or other groups are normally repulsed in varying ways, either culturally or biologically. The observations of Georg Simmel have enabled an understanding of how conflict tends to increase intragroup solidarity.[16] In short, conflict seems to tend to strengthen the social bonds existing among individuals in a social group at least for a finite period of time. But what about the strength of social bonds within the group once a conflict situation no longer exists? Do they attenuate and if so, at what rate? If not, what other complementary social process operates to maintain a state of social solidarity such that we may speak of the presence of a human social order?

At quite another level of analysis is the question of how social groups, as entities per se, are related to each other in the face of conflict and, more importantly for our concerns, in the face of an apparent lack of manifest conflict? Within a functionalist orientation, perhaps it is the function of leisure locales to assist the maintenance of social bond strength in a manner not otherwise widely available in a society. If this is so, how might it be accomplished?

First, parks themselves are symbolic of certain shared values common among members of a society. Particular empirical classes of parklands are legitimated in terms of metaphors within the common symbol system of a society. National parks, for example, commemorate selected aspects of a society's history, both natural and military. State parks commemorate more localized historical happenings and so on.

Second, most parklands in this society are supported by public monies or gifts for the public weal. Thus social groups gather in space without the concerns of boundary maintenance so characteristic of much of the space they occupy throughout most of their daily lives, with the exception of those social groups who attempt to impose their own special definition upon a particular subarea of a park through its repeated use. In short, parks are settings where many of the otherwise expected reservations attenuating intergroup noncompetitive or conflictful exigencies may not operate.[17] Perhaps it is the opportunity to view the behavior of others in social groups much like one's own (analytically speaking) which assists the formation of the consensual basis so essential for social solidarity among social groups. Our data suggest that the observation of

the behavior of others while in parks is a major concern of respondents. Seventy-nine percent reported engaging in it.

However important this may be, it is probably necessary for some exchanges of verbal communications between social groups to occur in order to maintain the social definition of the parkland as a space where essentially benign interactions are expected to occur. Theoretically, in societies where "gesellschaft relationships" are thought to predominate, it is to be expected that anonymity and personal reserve characterize ordinary, daily life. The exchange of greetings among strangers is a comparatively rare occurrence in such societies. Our data indicate that respondents report less likelihood of talking to people previously unknown while walking down a street than when they were present in a park *as a member of a social group*. This suggests that perhaps the presence of significant others is a necessary condition for such interchanges to occur. Of equal importance is the existence of places such as parks in which such interchanges may transpire. Although a history of parklands, as cultural phenomena per se, has yet to be written, impressionistically it appears that most literate societies have places similar to these. Why this should be so may, in part, be explained by some of the characteristics discussed above. In short, parks may be particularly important for the maintenance of social solidarity among social groups in societies having industrial economies. Far more than the recreational ideology of individual renewal presumed to transpire in such locales may be the perpetuation of symbols and myths necessary to the social order under observation.

SUMMARY

No social order, particularly of *Homo sapiens*, can exist which is comprised solely of instrumental relationships among individuals. Professor Walter Wallace cogently pointed out that even within sociology there is no unitary theoretical position regarding the extent to which subjective states of individuals were necessary datum for the science.[18] The same dilemma characterizes other sciences which share with sociology an interest in the nature of social bonding within the social orders of the social species. What our work during the last few years in the study of parks and human behavior therein suggests is that such areas may be immensely important not only for the understanding of the behavior of species other than *Homo sapiens* but also for it as well. Perhaps at the bicentennial symposium in 2072 some of our colleagues will address themselves more knowledgeably to that proposition.

REFERENCES AND NOTES

[1] Although there is a considerable literature on this topic, its scope is perhaps well exemplified by the work of H. F. Harlow and his associates of the University of Wisconsin. A technical bibliography is beyond this paper but a recent popular summary may be found in "Monkeys at Play" (with Stephen J. Suomi) in *Natural History*, Vol. LXXX, No. 10, Dec. 1971, pp. 72–75.

[2] This definition follows somewhat the one employed by Lionel Tiger in *Men in Groups* (New York: Random House, 1969) p. 19.

[3] Baldwin, John reported in a symposium session during the annual meeting of the Rural Sociological Society, August 1971. Professor Baldwin is at the University of California.

[4] Myers, Kenneth, *Effects of Density and Space on Sociality and Health in Mammals*, presented during annual meeting of American Association for Advancement of Science, Dallas, Texas, 1968. Mr. Myers is with the Commonwealth Scientific and Industrial Research Organization located in Australia.

[5] One of the better studies of social solidarity is Frank W. Young *Initiation Ceremonies: A Cross-Cultural Study of Status Dramatization* (Indianapolis: Bobbs-Merrill Co., Inc. 1965).

[6] Durkheim, Emile *The Elementary Forms of the Religious Life.* (Glencoe, Ill.: Free Press 1954).

[7] Gregory P. Stone has done much to differentiate these two complementary aspects of the larger process.

[8] An interesting treatment is found in Brian Sutton-Smith "Play, Games and Controls" in *Social Control and Social Change* edited by John Paul Scott and Sarah F. Scott (Chicago: University of Chicago Press 1971).

[9] Note this is a comparative statement. The situation being described is but a variation with the larger phenomenon of culture per se. It is, in short, always a matter of degree.

[10] cf. Burch, William R., Jr. "The Social Circles of Leisure" in *Journal of Leisure Research*, Vol. 1, No. 2, 1969.

[11] Harlow, H. F. and Stephen F. Suomi, *op cit.*

[12] The data reported are from a study in which 1251 adult respondents were interviewed about going to parks. The sample was an area probability sample.

[13] A detailed study of this phenomenon can be seen in Gerald D. Suttles *The Social Order of the Slum* (Chicago: The University of Chicago Press 1968)

[14] I have discussed some additional aspects of this in my "Towards a Theory of Not-Work" in *Pacific Sociological Review* Vol. 14, No. 3, July 1971, p. 245 ff.

[15] The importance of this is suggested by S. L. Washburn when he states "Our ancestors lived in very small groups and we have evolved to *feel strongly about only a very small number of people*" (emphasis added, NHC). cf. Washburn, S. L. ed. *The Social Life of Early Man* (Chicago: Aldine Books 1961) in particular his "Conflict in Primate Society" p. 11 ff.

[16] See Coser, Lewis *The Functions of Social Conflict* (Glencoe, Ill.: Free Press 1965) for a cogent reformulation of Simmel's insights in the processes operating.

[17] Erving Goffman has written suggestively about the mechanisms through which collective definitions of social situations he terms "public" are maintained. See his *Relations in Public: Microstudies of the Public Order* (New York: Basic Books, Inc. 1971).

[18] Wallace, Walter, ed. *Sociological Theory* (Chicago: Aldine Books 1970).

Parks as Aspects of Leisure in the Inner City: An Exploratory Investigation[1]

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This paper is a summary of the general findings of a recent exploratory investigation into the leisure activities among lower, working, and middle-class blacks and whites living in a middle-sized city—Nashville, Tennessee.[2]

We attempted to study leisure in its social context; that is, in addition to identifying which particular social and economic groups participate in various leisure activities, we attempted to examine the nature of the social relationships, if they existed at all, which characterize a particular form of leisure.

The data were generated by means of a questionnaire survey taken in the spring of 1971. The sample consisted of 301 adults, half of whom were white (149) and half were black (152). Respondents were the heads of households systematically selected so as to have an approximately equal number of blacks and whites in three roughly defined status groups—lower, working, and middle class.[3] With this sample we have been able to investigate racial difference in leisure activities, while controlling, through sampling and statistically, the effects of social and economic status. Similarly, we have been able to examine social class difference in leisure within and between racial groups.

Using a relatively large number of open-ended questions, we obtained information on an extensive range of informal and formal activities which our respondents were engaged in during their nonwork time. Included were questions about evening activities, sports participation, voluntary associations, hobbies, visiting with neighbors and friends, vacation travel, musical preference styles, and the use of local, state, and national parks and recreation areas.

There are several general findings which we feel are significant. These are:

(1) Leisure activities are social activities. Among all urbanites, and particularly among blacks, they occur in relatively small social groups characterized by relatively high continuity of membership.
(2) There is a relatively strong relationship between social and economic status and patterns of leisure activities. In addition to the general relationship which suggests differences in kinds of leisure activities associated with different social classes, our data also indicate that the urban poor—both black and white—are principally concerned with basic problems of housing, food, clothing, and only secondarily concerned with recreation and leisure.
(3) Differences in the use patterns of local neighborhood parks as compared to state and national parks reflect differences in the life styles and social and economic constraints which are placed upon inner-city residents.

A brief review of the results of our investigation which have led us to these generalizations follows.

THE SOCIAL NATURE OF LEISURE

One major conclusion is that leisure activities are group phenomena. In almost every activity that we investigated, the major exception being hobbies, informal groups of family and friends are involved.

Evenings are frequently spent in the home, either watching television with family or visiting with relatives and friends. The home is the favorite location for meeting close friends and associates.

Most sports, by their nature, are group activities. Yet in addition to this, our data indicate that most sports participation takes place with the same people—either family or friends—who are members of a small and relatively cohesive group. Seventy-five percent of our respondents who participated in a sport indicated that it was usually played with the same group. While two-thirds of the respondents who participated in a sport indicated that they enjoyed the activity for the physical exercise, a third of them indicated that they were primarily motivated by the social, rather than physical, nature of the sport.

Formal voluntary associations, such as unions, P.T.A., service clubs and fraternal organizations, are generally thought of as means for political and economic representation, community service, etc.[4] While this may be the case, our results indicate that a relatively large number of our respondents have particular friends whom they meet at such formal meetings. Our data also indicate that the presence of friends is strongly related to the frequency of attendance. These results suggest that these organizations provide a setting in which small, relatively cohesive groups of friends are established and maintained.

In the case of vacations, as might be expected, we found that vacation travel frequently involves family and friends. Previous researchers have suggested that families travel to "see the sights." This is also true of our respondents, but an additional finding is that sights seen are in locales of extended family and friends.

People rarely go to parks and recreation areas alone. Over 95% of those going to parks go with family or friends. Significantly, the most popular activities in local, state, and national parks— picnicking, walking and hiking, swimming, using playground equipment, "laying around," "doing nothing"—are activities that are characterized by a relatively low level of organization. As such, they provide the highest potential for spontaneous social interaction among the participants.

THE EFFECTS OF RACIAL AND SOCIAL STATUS

Of the two major independent variables we have focused upon—race and socioeconomic status—our findings indicate that social class is far more important in determining patterns of leisure than is racial status. There are some differences in the leisure activities of blacks and whites after controls have been made for social and economic status.

Our data indicate that the rank order (by frequency of participation) of evening activities found among whites is similar to that found among blacks. Of the several activities which were mentioned by our respondents, sports participation, going out of the home for entertainment, reading, and attending a cultural event were positively related to social status.

Concerning sports participation, our data suggest that whites, in general, do not participate in sports as frequently as do blacks. Those whites who do participate in sports are more likely to be of higher status. Among blacks, sports participation is more frequent and more widely distributed across social status groups.

Participating in voluntary associations is related to both social class and race. Respondents who are of higher status belong to more organizations than those of lower status. In contrast to membership, we have found some indications that the intensity of involvement in voluntary organizations varies inversely with status, i.e., respondents of lower status apparently belong to few organizations, but their membership is more involved, they attend more frequently, and are more likely to have friends who are also members. Blacks in every status group, particularly the lowest, report higher rates of membership and higher levels of involvement in voluntary associations than do whites.[5]

Vacation travel is strongly related to social class and race. Respondents in groups of higher status and whites travel more. Traveling alone is infrequent in all groups, yet it occurs most often among whites of

higher status. Blacks are more likely to travel further, in a northerly direction, and are more likely to visit relatives and friends during vacation travel than are whites.

The results of an attempt to obtain some indication of the presence of class and ethnic subculture in the urban community by asking questions about musical preference styles indicate that among whites there may be two such subcultures. One, highlighted by a preference for country and western music, is found among the lower and working class; the second, clearly more ambiguous in content although dominated by "pop" music, is found among middle-class whites. Our data indicate that there are musical preference styles that are distinctively black, i.e., soul, gospel, jazz. These are preferred throughout black communities and are not strongly associated with any status level.

Finances seem to play a major role in determining the leisure activities of our respondents. In order to obtain some indication of leisure preferences, without regard to finances, we asked, "Now we would like you to imagine that you were suddenly given a large sum of money, let's say $1,000, to spend on yourself and your family. What things would you buy?" The answers were coded in one of 15 categories developed after the interviewing was completed.

When we began looking at the answers given to this question, we saw that we were not obtaining the kinds of data that we had unthinkingly expected. Even though the question was asked toward the end of a questionnaire in which leisure activities were frequently mentioned, only 9% of our respondents mentioned a purchase related to recreation or leisure—most of these were whites of higher status. Only 1% of the black respondents and 2% of the lower and working class respondents mentioned recreation and leisure.

There emerged a relatively clear pattern between the answers to this question and socioeconomic status. All those items which were related to everyday needs of family and household, i.e., paying bills, housing, home mortgage, remodeling, clothing, transportation, medical care, were most often mentioned by the respondents of lower status—both black and white.

Those items which were not related to immediate consumption and survival, i.e., life insurance, investments, savings, education, gifts or contributions, or those which were for vacation expense or recreation transportation were more frequently chosen by respondents of higher status.

We feel the implication of this data is quite clear. Even in the middle of a questionnaire where recreation and leisure have been identified and talked about, most of the respondents, particularly those who are of lower status, have major concerns with basic day-to-day survival. Purchases

that do not satisfy these requirements—either those which are "for the future" or those which have little connection with daily survival—and recreation and leisure expenses for vacation and travel are not frequently mentioned. In short, these data strongly suggest that before people concern themselves with elaborate forms of recreation and leisure, the basic requirements of housing, food, clothing, and transportation must be satisfied.

In addition to the expected finding regarding the general effect of socioeconomic status on leisure activities and the understandable finding concerning economic constraints on recreational leisure, two general patterns emerge from our data regarding leisure activities of blacks and whites. First, it appears that blacks, particularly those who are in lower social and economic groups, are members of more closed or cohesive groups. This is seen in a variety of leisure activities and is suggested in a variety of ways. For example, blacks are more likely to entertain their friends in the more closed and familiar settings of home and neighborhood than are whites. Among lower class blacks, not only is the level of participation in sports relatively high but also we have found that there is a particularly strong tendency for lower-class blacks to participate in a sport with the same people each time they play. Vacation travel for blacks, although less frequent than whites, is more likely to be with family members and blacks are more likely to visit family members than are whites. Similarly, with voluntary associations, blacks are more likely to be members and and more likely to have particular friends whom they meet when they attend the meetings of the organization.

The second general tendency which emerges from our data is found in the relationship between social and economic status and leisure activities within racial groups. We have consistently found, with evening activities, sports participation, activities with friends, voluntary associations, vacation travel, and musical preference styles, that the relationship between social and economic status and variety in leisure activities is more pronounced among whites than among blacks. In other words, we found that the patterns of leisure characterizing middle-class blacks are not greatly different from those of lower status. Among whites, in contrast, there are relatively large differences in the leisure activities of different status levels.

We anticipated neither of these findings. We do believe, upon reflection, that they are related to one another, and that they reflect some of the consequences of racial prejudice and discrimination for the life styles of blacks. Racial discrimination, indeed racial conflict, has had the consequence of increasing the level of cohesion within the black community.[6] This is reflected in the higher level of social closure which

seems to characterize the leisure activities of the blacks we have investigated. Second, racial discrimination has had the effect of limiting the life-space of blacks relative to whites; that is, blacks have a much smaller or more restricted field of leisure opportunities. As a consequence, we find less variation in the leisure patterns of blacks than we find among whites.

THE USE OF PARKS AND RECREATION AREAS

The relationships we have found between social and economic status, particularly between family resources and patterns of leisure, as well as the racial differences in the homogeneity of leisure activities and community cohesion are, we believe, reflected in the differential use of local, state, and national parks.

As might be expected, given the easy access of local and neighborhood parks compared to the more distant state and national parks, there are considerable differences in the frequency of use of local or neighborhood parks compared to the state and national parks. The frequent use of local parks and recreation areas characterizes our sample of families. Ninety percent reported that they and their families had used such parks at least once during the month prior to our interview. Most used them several times each month. This is true for both blacks and whites and for all social status groups. Although more blacks do not use the parks at all, those who do use them do so more often than whites. In general, respondents of lower status are less likely to use them than those of higher status, but there is little relationship between social status and the use of neighborhood parks. Within racial groups we find some difference. Among blacks, there is a higher rate of use of local parks among those respondents of lower status. Among whites there is no difference between status levels.

The results obtained concerning the use of the more distant state and national parks stand in sharp contrast to those of local or neighborhood parks. Fifty-five percent of our urban respondents indicated that they had not been to such a park in the last 2 years. Unlike local parks, the users and nonusers of state and national parks are not so evenly distributed in the urban population. They are more frequently used by whites and by middle-class families than by blacks and lower and working-class families. Sixty-eight percent of whites of lower status and 78% of blacks of lower status have not used a state or national park in the last 2 years. Within every social status group, the proportion of blacks who use state and national parks is lower than the proportion of whites.

There are at least four hypotheses which might be used to explain these differences. Differences in the use of these parks may reflect differences in recreation and leisure associated with various social and

economic status groups. Such a hypothesis suggests that one reason middle-class whites use national and state parks more frequently than the lower class and blacks is because they prefer the activities which are available in such parks.

Based on our data comparing leisure activities in local parks with those in state and national parks, the overriding conclusion must be that there is little difference. Activities which exist in local parks also are found in state and national parks. In both cases, eating and picnicking, hiking or walking, swimming, fishing, boating, and "just having fun doing nothing" are popular activities. There are some differences. Baseball is a frequent activity in local parks, but it is rarely played in state and national parks. Camping is unique to state and national parks while relatively rare in local neighborhood parks. The relationships between these activities and social status are consistent with the life-style hypothesis; that is, baseball is associated with the lower and working class and camping with the middle class. These data provide some support for the argument that the general relationship between state and national park use and socioeconomic status is in part explained by the activities which characterize different parks. Yet given the overall similarity of park activities, it is difficult to accept this as the single explanation for the differences found in frequency of park use.

There is a second life-style hypothesis. This one, rather than focusing on the specific recreation and leisure activities associated with different social and economic groups, suggests that racial and social economic differences in the more general adaptations to urban life are reflected in the differential use patterns for local and national parks.

There is a considerable literature in the social sciences suggesting that the lower and working classes spend their leisure time in somewhat limited geographic areas.[7] Especially with regard to their nonwork time, the lower and working class might be termed "locals" while urbanites of higher status are "cosmopolitans." This difference can be seen in studies of the urban working classes which have shown that relatively strong interpersonal networks of neighbors and strong attachment to neighborhoods characterize many working-class residential areas. While neighborliness is found in all social strata, once the distribution is made between casual acquaintances and relatively high levels of interdependence with neighbors, research indicates that the lower classes are more closely tied to their neighborhoods than are the middle class. Among the lower class, friends are more likely to be neighbors. Among the middle class, while one might be friendly with his neighbors, friends are more likely to be chosen for common interests rather than physical proximity. The implication is that the lower and working classes spend

more time and are much more comfortable when they remain in the familiar surroundings of their own neighborhood.

When local parks are scattered throughout the city as they are in Nashville, the lower and working classes may use such parks without going beyond what is their local territory or "turf," yet, in the case of the more distant state and national parks, these obviously require movement out of familiar neighborhood territory. Among the middle class, the more cosmopolitan character of their life styles is compatible with trips to the more distant state and national parks.

The differential use of state and national parks may also be explained in terms of the variable access to such parks and recreation areas as access is determined not by life style, but rather by the resources which families have at their disposal for recreation. State and national parks located out of the city require considerable time and transportation expense if they are to be used. As we have seen, these extra resources are not readily available to families of lower status.

In addition to the level and security of economic resources that are apparently required to use state and national parks, an extended trip to such a recreation area requires considerable organization and planning before it is made. There is a considerable literature on the urban lower class, both black and white, which indicates that its condition of economic marginality and insecurity reduces the family's ability to develop extended time perspectives and control which are required to make such a trip.[8]

The lower frequency of use of state and national parks by blacks may reflect the general pattern suggested earlier, i.e., that there has developed within the black community higher levels of community cohesion, and a general pattern of not venturing into what has traditionally been regarded as white territory. The more limited life-space of blacks has not yet been extended to include state and national parks. Even though civil rights legislation may have removed official barriers, either a 'cultural lag' or perhaps the continued use of informal sanctions by whites may be inhibiting the use of such parks by blacks. Thus middle-class blacks who have the incomes and resources to use state and national parks are inhibited and use them less frequently than whites of similar status.

IMPLICATIONS FOR PUBLIC POLICY

One implication that might be drawn from our data is that the first priority for all government agencies is the provision of social and economic security for American families. Particularly those data generated from our question concerning the spending of $1000 suggest that lower class families are primarily concerned with satisfying basic

requirements for living and only secondarily with elaborate forms of recreation and leisure.

Public parks and recreation areas can be viewed as a social welfare service which is provided by local, state, and federal governments. Clearly, they are a public service and serve the public good. They provide green spaces which enhance the esthetic quality of cities, provide a means of preserving natural areas, and, as we have seen, provide the locale for recreation and leisure activities which serve to maintain and develop informal social groups of family and friends. These are important services, especially for families who do not have the resources required to purchase such services themselves.

Our data regarding the differential use of this service, especially in the case of state and national parks, do raise some questions concerning the equitable distribution of the service. State and national parks, while for the public good, are used almost exclusively by those of higher status. Only in local parks and recreation areas do we find a more equitable distribution of these public benefits.

We have suggested that this differential use pattern is a reflection of the more pervasive system of social stratification and the corresponding differences in life styles found in American cities. There is relatively little that the National Park Service can do to increase the use of national parks by the lower classes if the patterns we have found reflect the adaptations of urban poor families to social and economic marginality. On the other hand, the data indicating the more equitable use of local parks and recreation areas suggest that if the federal government is interested in providing this social service to the urban lower class, it should extend its domain to facilitate the development of parks and recreation areas within the cities.

REFERENCES AND NOTES

[1]This research was conducted under a contract with the National Park Service: Contract No. 14-10-6:990-315. It was supported in part by the Urban and Regional Development Center, Vanderbilt University.

[2]A detailed report of these findings is in William L. Yancey, David Britt, and Jane Snell, *Patterns of Leisure in the Inner-City*, The Urban and Regional Development Center, Vanderbilt University, Nashville, Tenn. Sept. 1971.

[3]Comparing the distributions of the blacks and whites on income, education, and occupational status we find some differences. In education the black sample is slightly higher than the white sample. In occupational status they are closely matched. In income the white sample is slightly higher.

[4]See S. M. Lipset, *Political Man*, Doubleday and Co., New York, 1963.

[5]These findings are consistent with considerable literature on this subject, most especially that stemming from Gunnar Myrdal, *The American Dilemma*, Harper and Row, New York, 1944.

[6]For a recent discussion of cohesion in the black community see Joseph S. Himes, "The Functions of Racial Conflict," *Social Forces*, Vol. 45, Sept. 1966. p. 1-10.

[7]See Herbert Gans, *The Urban Villagers*, Free Press, New York. 1962 and Gerald Suttles, *The Social Order of the Slum*, University of Chicago Press, Chicago. 1968. For a review of the literature on patterns of neighboring see William L. Yancey, "Architecture, Interaction and Social Control: The Case of a Large Scale Public Housing Project," *Environment and Behavior*, 1971, Vol. 3, No. 1.

[8]Edward Banfield has recently used the concept of time perspective to define and to a large degree explain much of the behavior exhibited among the urban lower class. We take a different position here in that we see the shorter time perspective of the lower class as an adaptation to economic marginality and insecurity rather than the cause of poverty. See Edward Banfield, *The Unheavenly City*, Little, Brown, Boston. 1969.

Interchangeability of Parks with Other Leisure Settings[1]

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Once established, the management of a park presents an interesting challenge to any individual or group who would assume such a task. It is an interesting challenge because the two major components which will interact in a park—people and resources—require a substantive expertise somewhat unique but not independent of the other. Parks are an interrelationship between man and resources. We are well on our way to providing planners, developers, and managers with basic knowledge concerning the resource, but somehow we have failed to incorporate equivalent knowledge and sensitivity toward the human resource and social dimensions of a park (Burdge and Field 1972).

Too often, park planning groups have operated from a resource perspective in toto, failing to understand people, the nature of recreational publics, or the social meaning of leisure places in the society. At best, a resource perspective of park development emerges with a narrow set of assumptions about man that excludes a human behavioral component. A park is not a park without people. In fact, considered in its broadest context, parks are a product of culture (Klausner 1971).

Created by man, parks are but one type of leisure setting where man interacts with other men and with the environment for the purpose of engaging in leisure pursuits. In order to understand man-park relationships in a society, we need to understand how outdoor leisure settings are utilized in the society and by whom. Parks may be unique. Yet at the same time, parks appear to be interchangeable as leisure places with many nonpark settings in the manner in which human groups interact

[1] This paper was the impetus for a series of articles concerning human behavior and leisure places. Variations on the theme appear in the *Journal of Leisure Research* and *Water Resources Bulletin*.

with each other and the resource. This paper explores the similarities between parks and nonpark leisure settings as places for people to gather. It is hoped that such an approach will help us generate broader insights into parks and the function they serve in American society.

SOCIAL GROUPS: A BASIS FOR INTERCHANGEABILITY

We indicated previously that the interchangeability of leisure places hinged upon the social group. Groups attach social meanings to leisure places by defining for themselves what a leisure place is and how it is to be utilized. This is not a unique situation for groups engaging in leisure. Human ecologists (Hawley 1950; Theodorson 1961) have demonstrated that the nature of population aggregates (in this case social groups) occupying a given space influences the nature of human activity and social meaning which arises.[1] If we can establish that parks share common-user groups with other leisure places, then a basis upon which interchangeability can occur has been established.

As a resource, parks, like nonpark areas, are devoid of human definition until man applies one (Burch 1971). Parks, like other leisure places, derive their social meaning from the society and from the social groups who engage in outdoor leisure pursuits within their boundaries (Burch 1971:51-108). Consequently, in a sociocultural context, parks as leisure places may have a universal attractiveness, resulting in not one social definition but rather in a multidimensional set of definitions. Some definitions associated with parks include a resource component; others are based solely upon social interaction criteria. Both, however, are articulated within social groups and between social groups.

By the nature of their social origin, parks can share social definition with other leisure places, depending upon the focus of attention for user groups, their culture, and previous experience with parks and other outdoor leisure settings. Cheek alludes to a more general context in which parks might be viewed when he states: "In short, it is unlikely that going to a local park is an empirically unique example of a non-work setting. It shares a common social structural characteristic with several other settings" (Cheek 1971:254). We suggest that one of those structural characteristics to which Cheek refers is the presence of social groups as the primary unit for participation in leisure.

It would appear logical to focus upon the social group as a unit of analysis for an exploration of leisure involvement and social meaning of leisure places in the society. The social group is the theoretical basis upon which sociology rests (Broom and Selznick 1968). The consideration of human groups as an entity within which action originates or is defined by members is not new. The development and refinement of this concept as an operational measure have a long history. Warringer

(1956) suggests that in one sense groups are real. They influence individual action and are capable of altering individual action (Davis et al. 1961). In short, groups represent something more than the summation of the individual constituent parts (Burch 1971:51).

Group behavior, over time, develops regularities of action which are observable (Shevky and Bell 1955). Yet, until recently, very few sociologists or recreational researchers have seriously examined the utility of this concept for understanding leisure behavior. Meyersohn (1969) indicates, in a review of leisure research, that the group has been neglected as a unit of analysis, and consequently, understanding human behavior in leisure situations has been limited. Cheek (1971) has, perhaps more than any other person in leisure research, drawn attention to this void through the incorporation of the concept social group in his own research efforts and theoretical concerns. Our research is an expansion of his initial effort.

It is hypothesized that similar groups participate in like activities in various leisure settings. To the extent that parks and nonpark leisure places share similar social groups and human activity, they contribute to a potential basis upon which a similar social definition for leisure places can be articulated.

Therefore, our analysis proceeds in the following manner. First, types of social groups associated with leisure places are examined. Next, leisure activities associated with various leisure places are identified. Finally, an examination is undertaken whereby leisure activities, social groups, and leisure places are considered simultaneously.

DATA AND METHODS

The data for this investigation were gathered as part of a larger effort by the National Park Service in conjunction with the University of Washington. The area for the larger study includes the adult population 18 years of age and older who reside in Western Washington, Western Oregon, and Northern California. Geographically, the study area is bounded by the Cascade Mountains and Sierra Nevadas on the east, the Pacific Ocean on the west, the United States-Canadian border on the north, and the greater San Francisco metropolitan area on the south.

A probability sample of 1504 residents was selected from this area for examination. The method employed for respondent selection involved a series of intermediate sampling steps. Initially, all 58 counties representing the area were arranged in order of descending population size. A sample of counties was selected ensuring geographical and population distribution. Within each county, smaller units were selected. Minor civil divisions as defined by the Bureau of the Census were the basis upon which selection was made. A minor civil division may be a town,

township, city, or part of a city. The probability that any particular division would be selected in a county was proportional to the population in the area.[2] Thus the larger a minor civil division, the greater the likelihood for inclusion.

The next step in sampling design introduces an innovative departure from traditional methods. Rather than relying upon maps for each minor civil division, master telephone directories were generated to determine where, within a given area, interviewing would take place. Within each master directory, all working exchanges were noted. Utilizing telephone area codes and telephone prefixes, telephone numbers were then drawn by systematic random procedures. To correct for unlisted numbers, a computer technique generated the remaining four digits of an individual number.

All interviews were completed by telephone during the months of August and September 1971. Sampling criteria ensured that an equal number of interviews were undertaken with male and female heads of household. The average length of time per interview was 20 minutes.

Data were obtained from respondents through leisure information sets. This report is based upon one of those sets. The dependent variable is the leisure setting (place) where the respondent, on his most recent outdoor outing, engaged in some form of leisure activity. A leisure setting is defined as any place which affords the opportunity for people to gather to engage in some leisure activity. A park has an added dimension in that it is defined as any place set aside by governmental or private action for the purposes of allowing groups of people to gather. The major independent variables are (1) the social group within which the respondent shared his leisure experience,[3] and (2) leisure activities engaged in by the respondent and his social group while visiting a leisure place.

GROUP TYPE AND LEISURE PLACE

The commonality of social groups associated with leisure places is considered as a basis for interchangeability. Cheek(1971) noted that the social group is the most common unit of participation for those people going to parks. Burch and Wenger (1967) and Yancey and Britt (1971) reported comparable data for specific recreational activities. When other leisure places are considered, a similar finding emerges. The most common social unit of participation in our investigation regardless of leisure place is the social group (Table 1). Ninety-six percent and 97% of respondents engaged in leisure within a social group at parks and beaches, respectively. Ninety-one percent did so at playgrounds, schools, tracks, stadiums, and ballparks, while 69% participated in leisure within a social group at home or at the home of a friend or relative.

TABLE 1. Proportion of individuals who participated with someone else in a leisure place.

Place	Percent	N
Neighborhood; at home or the house of a friend or relative	69	340
Parks	96	268
Playgrounds, schools, tracks, stadiums, and ballparks	91	347
Beaches, lakes, rivers	97	525

While noting the importance of a social group as the unit of participation in leisure, insights into additional features of groups provide a vehicle by which groups can be distinguished in the manner in which they became involved with specific human activities. Knowledge about group composition is one.[4] With regard to a specific outdoor activity, Burch and Wenger (1967) report that among family groups, compositional variation is associated with leisure setting in which camping takes place.

For purposes of the present investigation, social groups have been subdivided into friendship groups (peer groups), family units, and a combination of family and friends. The most frequent group appearing in parks is the family unit. When the analysis is expanded to include parks and nonpark leisure places, the family unit again emerges as the most common social unit participating in leisure (Table 2). A minimum of 40% of our respondents were with family groups while visiting all leisure settings. Fifty-one percent and 50% were members of a family group visiting parks and beaches, respectively. When family groups and combinations of family and friendship groups are considered, the proportion of family-related groups increases to 73% for parks and 76% for beaches, lakes, and rivers, as well as 60% for playgrounds and 57% at

TABLE 2. Group composition by leisure place.

Place	Percent					N
	Alone	With friends	Family	Family and friends	Other	
Neighborhoods; at home or the house of a friend or relative	31	11	43	14	1	340
Parks	4	22	51	22	1	268
Playgrounds, schools, tracks, stadiums, and ballparks	9	28	44	16	3	347
Beaches, lakes, and rivers	3	20	50	26	1	529

home. There is a slightly higher proportion of friendship groups found at parks than at beaches, but friendship groups as a separate unit were found to be most common at playgrounds, schools, stadiums, and ballparks. Participating in leisure activities alone occurred most often at home or in the neighborhood. Thirty-one percent participated alone (Table 2).

HUMAN ACTIVITY AND LEISURE PLACE

There is an abundance of recreational literature available in which authors have focused upon participation in various types of outdoor activities. A distribution of involvement by various client groups in selected activities has been a common focus of such reports (Owens 1970). Very often estimates of demand for specific activities associated with recreational places have been included. Unfortunately, the predictive capabilities have been less than desired partly because of an underlying assumption that activities are place specific, and/or facilities are conducive to a limited range of human involvement.

Within the present investigation, we extended the scope in which activities are considered; and even in so doing, similarities emerged among leisure places. Respondents identified 30 different activities in which they participated at playgrounds, schools, etc. Twenty-five such activities were identified for parks, beaches, and neighborhoods (Table 3).

Furthermore, activities are not place specific. When we examine the commonality among leisure places, we find that, of the 26 different activities associated with recent visits to parks, 17 activities were pursued in neighborhood areas and 17, at beaches. Social groups participated in 21 of those 26 park activities at playgrounds (Table 4). Similar findings are noted when each leisure place is compared to another. Twelve activities were common to all leisure places. It is interesting to note that the 12 activities were also the most popular outdoor activities as reported in an Outdoor Recreation Resource Review Commission (ORRRC) (1962).

TABLE 3. Number of different activities.

Place	Number
Neighborhood; at home or the house of a friend or relative	25
Parks	25
Playgrounds, schools, tracks, stadiums, and ballparks	30
Beaches, lakes, rivers	25

TABLE 4. Activities shared among leisure places.

Place	Number
Parks share with neighborhoods	17
Parks share with beaches	17
Parks share with playgrounds	21
Beaches share with neighborhoods	17
Beaches share with playgrounds	18
Playgrounds share with neighborhoods	18

Activities shared among all four leisure places (13) are cooking-out, visiting friends, sightseeing, picnicking, bike-riding, walking, jogging, boating, camping, fishing, swimming, golf, hiking.

Activities shared between parks and two other places (5) are touch football, baseball, skiing, visiting a museum, motorcycling.

ACTIVITY PROFILES OF GROUPS

It was mentioned previously that conclusions drawn from activity research have been incomplete (Burdge and Field 1972). Attempting to draw conclusions regarding human involvement and/or behavior associated with leisure through traditional activity research is tenuous at best. Recreational activities are too encompassing. Additional variables need to be incorporated for discerning behavioral similarities or differences associated with leisure activities. Within an activity or between like activities, extreme variation can occur depending upon the focus of the participating group. Burch (1969) and Bultena and Klessig (1969) illustrate various participation strategies associated with camping.

When considering human activities with social groups and leisure places simultaneously, a clustering occurs (Table 5). To illustrate clustering, 12 of the 14 most popular outdoor activities as presented in the ORRRC (1962) report were analyzed. In rank order of occurrence, swimming and walking were the major activities for respondents participating alone, regardless of leisure place. When friends as a group participated in leisure, the following activities were found to occur in all places: cooking-out, visiting with friends, sightseeing, picnicking, playing football and baseball, swimming, golf, and hiking or walking. Similar activities were found to occur in all leisure places for families with the exception that fishing, boating, and camping replaced golf, football, baseball, and swimming. Participation in leisure activity by a combination of friends and family centered on the same activities in all leisure places as noted for family groups.

TABLE 5. Activities by social groups occurring in various leisure places.

Composition	Neighborhood	Parks	Beaches	Playgrounds
Alone	swimming walking	swimming walking	swimming walking	swimming walking
With friends	cooking-out visiting friends sightseeing picnicking baseball/football swimming	cooking-out visiting friends sightseeing picnicking baseball/football swimming golf	cooking-out visiting friends sightseeing picnicking baseball/football swimming golf	cooking-out visiting friends sightseeing picnicking baseball/football swimming golf
Family	cooking-out visiting friends picnicking walking/hiking boating camping	cooking-out visiting friends sightseeing picnicking walking/hiking boating fishing camping	cooking-out visiting friends sightseeing picnicking walking/hiking boating fishing camping	cooking-out visiting friends sightseeing picnicking walking/hiking boating fishing camping
Family and friends	cooking-out visiting friends sightseeing picnicking boating camping	cooking-out visiting friends sightseeing picnicking boating camping fishing	cooking-out visiting friends sightseeing picnicking boating camping fishing	cooking-out visiting friends sightseeing picnicking boating camping fishing

The focus of attention for the future will be to extend our analysis to include social characteristics of particular social groups with activities and leisure places. Analysis of variance and a variation of multiple correlation are two statistical techniques currently being employed to generate group-activity profiles.

CONCLUSIONS

In this paper, we have considered the interchangeability of parks with nonpark leisure settings by examining the type of social groups and leisure activities associated with leisure places. Social groups are the predominant unit of participation for park and nonpark areas. Family

units are the most common type of social group participating, and similar groups do participate in similar activities regardless of leisure place. Thus, a context within which the potential for ascertaining a common social definition associated with leisure places exists. Finally, a further delineation of group properties, especially a consideration of social organization, will help identify the social dimensions of parks as leisure places in the society. Populations respond to various conditions of the environment through social organization. We have initiated an exploration of group compositional features as a beginning step. In this sense our analysis is partial and suggestive rather than definitive.

FOOTNOTES

[1]Other dimensions are social organization, technology, and environmental influences. We are assuming that while the total of human activity occurring in leisure space is much more inclusive than specific recreational activities, we can obtain initial insights to group interaction with a leisure environment by examining leisure activities.

[2]Elaborate sampling procedures were employed to ensure that population area units were selected which represented the total population as it appears in reality. Residential income, educational, and occupational criteria were built into the sampling procedures.

[3]A social group is defined as a plurality of individuals (2 or more) who are in contact with one another, who take one another into account, and who are aware of some significant reason for being together (Olmsted 1959:21).

[4]Derived through observation techniques, compositional features might include relationship of group members to one another, social roles of group members, stage in life cycle, social age of members, and size of group. Taken together, a compositional profile of a group can be generated and its association with specific human activities measured.

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The Worth of Wilderness: With Interpretations from a Study of Wolves and Moose on Isle Royale[1]

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Over the past ten thousand years, human activities have brought about widespread changes in the biosphere. Early influences were the effects of fire, grazing animals, forest cutting, and cultivation. More recently other types of disturbance have burgeoned, and certain contaminants (e.g., radionuclides and pesticide residues) have become nearly ubiquitous in the environment.

Among permanent changes that have taken place is the disappearance of certain living things that were scarce and specialized or particularly vulnerable and marketable. Many more species and ecotypes are now in jeopardy. Some persons point out in complacency that such disappearances have been occurring since the beginnings of life on this planet. Others warn that the disadvantage of insecure minority species is aggravated unnaturally as all available lands and waters are taken over by the human swarming and its technological demand.

In recent decades a particularly significant development has been the increasingly rapid distribution of people and things from one part of the earth to another. As a result of this mobility, indigenous biotic communities are being modified in additional ways that are, in a practical sense, irreversible. Where exotic plants and animals become naturalized outside their native ranges, the character of invaded ecosystems is altered and primitive adjustments obscured. The progressive homogenizing of fauna and flora is part of our creeping, worldwide loss of environmental diversity (Dasmann 1968; Allen 1970).

These accumulating changes bespeak the increasing difficulty of finding areas representative of truly aboriginal conditions. If this kind of

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[1] Journal paper number 4642 of the Purdue University Agricultural Experiment Station

"wilderness" is important to generations of today and tomorrow, its functions should be understood and its benefits secured while some of it still exists.

Realities of the present indicate that any currently valid definition of wilderness must be hedged with expedience. If we adopt a standard of strictly primordial conditions, then it is indeed questionable whether any biotic association of today can qualify. Therefore I use the term to describe ecosystems with relatively little permanent modification by man. Thus it includes used habitats where time and biotic succession will help restore essentially primitive conditions.

Wilderness must encompass the gamut of seral stages, these being the dependence of many living things. Such disturbances as fire, wind, animals, and other irregular influences are part of the age-old pattern. Time is one of the critical dimensions in which ecosystems operate. Actually, ecosystem is another of those terms that is difficult to define with complete satisfaction. I regard it as most useful in describing associations of living things that are extensive enough, old enough, and varied enough to be self-perpetuating under their given physical conditions of substrate and climate. The term, of course, includes this environment.

Public agencies administering wilderness are coping with the realities of disturbance communities and learning, we may hope, to draw a fine line between what is natural and what is not. Whatever their efforts and degrees of enlightenment, wilderness will be as good as we can do under conditions of the present and future.

CHALLENGES TO ECO-UNDERSTANDING

It is my position that our major urgency in preserving adequate samples of remaining ecosystems lies in the long-term possibilities for scientific study. We have only begun to investigate these life associations that embody, in their capacities for biological production and self-perpetuation, the trial and error of nearly unlimited geological time. There is a convincing rationale for regarding the infinitely organized adjustments among living things as the ultimate complexity in the universe as we know it. This is, literally, a limitless field for useful understanding, requiring long-term effort and new technical approaches.

Whatever continuing challenge these unknowns may pose, there is also an element of immediacy in our need for ecological knowledge. Looking backward to early origins, one might say that mankind has a generic history of 2-3 million years. Such a perspective is poor orientation for events in this fast-moving century. We find ourselves at a geo-instant when rapidly accelerating increases in population and resource impacts threaten a large-scale reduction of environmental quality, which is to say carrying capacity. The long-evolving human culture is confront-

ing its ultimate test—that of making a durable ecosystem of the entire earth, which we now use or occupy. Adaptation on such a scale at the necessary rate is something new to the organic world. The technology that broadened the resource base and produced today's population and environmental problems is now the only hope of solving them.

If mankind is to survive on terms we may regard as respectable, it must be our great preoccupation in the century ahead to convert the present unplanned, worldwide disturbance condition into something orderly and durable. Our earthly support system must be renewed as it is used, and thus rendered capable of sustaining our species into the indefinite future. Inevitably, this assumes a reduced and relatively stable population, which will continue to refine its level of living according to changing standards. It is a fact of life that we cannot and need not anticipate long-range specific problems and accomplishments.

There should be nothing disconcerting about this, for in the face of unmanageable complexities, the ecologist frequently finds himself dealing in trends and influences. Unquestionably, the development of new knowledge and finding ways to apply it are the hope for lasting human benefits and security. The constructive outlook is for continuing improvements in managing the vegetation and animal life that constitute our production mechanisms in the biosphere. The intensity of land and water use ranges from totally unstable crop monocultures on the one hand to self-maintaining forests, grasslands, watersheds, and scenic spaces on the other. The monocultures must be observed over time for a full evaluation. The renewable systems need experimental management to determine their best use for human benefits. In all situations there are applications for what we know of the primitive order, its internal controls, its preservation of site, and its flexibility under change. It should be evident in today's society that those who do not recognize the natural order are having great difficulty recognizing unnatural disorder. In wilderness there is much to be learned of such things.

The above social incentives to preserve and study wilderness are not widely understood. They tend to be abstract and of low priority relative to the immediate concerns of individual citizens. They are poorly supported, as might be expected where a cause seems to require costs in the present and promises benefits in the future. There appear to be few aggressive exponents of what is everybody's business. In any event, our budgetary processes being what they are, it is likely that natural areas would seldom be set aside and they would be little studied simply on the basis of incentives I have just described.

Fortunately, there is a much more effective justification for research on natural areas. The agencies administering land have a pressing concern with management, which demands a factual foundation. Storey

(1968) has listed a broad array of research needs that pertain especially to the multiple-use responsibilities of the U.S. Forest Service and the Bureau of Land Management, although the results of such work have much wider applications on public and private lands. Obviously, much of the research on renewable resources will not be carried out on wilderness areas, but the primitive ecosystem or its facsimile furnishes indispensable baselines and check points for comparisons that must be made.

The National Park Service was the first public agency to be given specific responsibilities in wilderness preservation, via the now-famous wording of the act of 1916, which declared that the newly established Service would manage its lands ". . . to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

These ideas were largely repeated in the Wilderness Act of 1964, which asserted the intent of Congress ". . . to secure for the American people of present and future generations the benefits of an enduring resource of wilderness." It was provided that the federal areas so designated ". . . shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness . . . ."

We may be thankful for the high-minded idealism that went into the rhetoric of some of our land-use directives. However, individual national parks are seldom established in an ecological frame of reference. Boundaries have been decided primarily as a result of land ownership and political considerations. The consequent management problems were pointed out by the Advisory Board on Wildlife Management in the National Parks in its report to Secretary Udall (Leopold et al. 1963). The board noted that "Few of the world's parks are large enough to be in fact self-regulatory ecological units; rather, most are ecological islands subject to direct or indirect modification by activities and conditions in the surrounding areas. These influences involve such factors as immigration and/or emigration of animal and plant life, changes in the fire regime, and alterations in the surface or subsurface water." Accordingly, as pointed out by Houston (1971), management that must draw upon research in the parks frequently is directed toward ". . . preventing or compensating for man's altering of natural ecological relations."

THE RECREATION VALUE

Government acts and documents pertaining to wilderness consistently reflect the view that the principal justification for setting aside such

areas is "recreation." This concept ranges all the way from a sometimes-heard generalization that "if people can't get there, what good is it?" to a sensitive assumption that the human being has an innate need for intervals of isolation, privacy, spiritual refreshment, self-accompaniment, and even darkness and silence. There appears to be a growing recognition that under too much public use a wilderness habitat ceases to be wilderness and that in some degree this kind of recreation is self-defeating. A notable statement of the Outdoor Recreation Resources Review Commission (1962) was that "In theory, the validity of wilderness areas and other so-called 'natural areas' as ecological controls is inversely proportional to the intensity of recreational impact on them." The ORRRC group was particularly impressed with the esthetic contribution of natural scenes to the total landscape.

The Public Land Law Review Commission (1970) was little concerned with the wilderness idea, but it too acknowledged the problem of preservation in the face of increasing recreational use: "The values for which national parks and wilderness areas have been set aside should not be destroyed by an over-use for intensive outdoor recreation purposes." The report saw the possibility that population growth and increasing recreational demand could "overwhelm" such areas, and it recommended the immediate setting of use limits by a rationing system. This undoubtedly will be the way of the future, the real question being whether we will anticipate and avoid the heavy damage that is possible.

A critical parameter, and one commonly neglected in appraisals of the recreational value of wilderness, is the time dimension. Logically, over unlimited time, a protected wilderness can sustain the use of unlimited numbers of people. In the short run, it cannot be overloaded without going out of business as a wilderness. Thus the concept of wilderness as a recreational resource is sound only if we concede that mass benefits must accumulate slowly. If we insist on anything more, we are consuming our resource capital rather than collecting the interest.

In view of all the above considerations, it seems valid to conclude that both the scientific and recreational values of natural areas are long-term human benefits, and that any attempt to force them into a different pattern will inevitably be unsuccessful. This exemplifies the conservation outlook that resource use must be a planned cultural continuum rather than an episode of consumption perpetrated by a self-interested generation of men.

THE ISLE ROYALE ECOSYSTEM

With this background, it should be instructive to examine the connotations and applications of 13 years of biological research in Isle Royale National Park. I refer specifically to our Purdue University stu-

dies of several mammalian species, most notably the wolf (*Canis lupus*) and its prey, moose (*Alces alces*) and beaver (*Castor canadensis*). This work began in June 1958, and here I draw upon results of three doctoral dissertations (Mech 1962; Shelton 1966; Johnson 1969) and two post-doctoral programs of 3 years each (Peter A. Jordan, 1963-66; Michael L. Wolfe, 1967-70). In winter most of our observations have been made from a light, ski-equipped aircraft from late January to mid-March. Summer work on roadless Isle Royale has involved extensive use of the hiking trails. The research has been supported principally by grants from the National Science Foundation and the National Park Service.

This Michigan island of 644 km^2 (210 miles^2) lies in northern Lake Superior, at different points 24-29 km (15-18 miles) from the Ontario shore. Its ancient basaltic and conglomerate bedrocks are covered by shallow, largely organic soil and an interspersion of two vegetational climaxes: the boreal spruce-fir forest and the northern Lake States hardwoods, the latter characterized by hard maple and yellow birch (Linn 1957). The fauna is distinctly limited as compared with the adjacent mainland (Mech 1966), the most influential mammalian herbivores being moose, beaver, snowshoe hare, red squirrel, and one species of mouse. The principal carnivores are wolf and red fox. Notably absent from this list are the white-tailed deer, porcupine, raccoon, skunk, and black bear. In winter few avian predators are present, and small bird populations are highly variable from one winter to the next. The island harbors only one species of grouse (a remnant population of sharptails) and only two species of snakes.

The significance of research findings will be discussed relative to some of the questions or problems to which they apply. Supporting details may usually be found in the references cited, including investigations previous to our own. However, the most recent work is unpublished and will be referred to in only general terms. My present purpose is to illustrate the pertinence of wilderness research in adding to our fundament of biological knowledge and to the factual base of management in the National Park Service.

THE QUESTION OF STABILITY

It probably can be regarded as an ecological tenet that "old" biotic communities that integrate many species are more stable than what are usually more recent associations composed of relatively few kinds of living things. Thus, with greater complexity and long-standing adjustments, there are more governing mechanisms to counter the effects of changing conditions or variations in the status of individual species (MacArthur 1955).

Since the recession of glacial ice, Isle Royale has had about 9000 years to accumulate its present fauna. The limited diversity of vertebrate life and the fact that the island range is relatively small as a habitat for the larger species of mammals suggest that it should offer an outstanding example of biotic instability. The record is not entirely clear in this respect, and a longer period of observation may be necessary for reliable interpretation. There have been major fluctuations, but at least some of the faunal changes on the island probably are related directly to historic events on lands north of Lake Superior.

Early in the century, logging and burning were converting the northshore country from a woodland caribou habitat of forests and muskegs into brush and early tree successions favorable to moose. Moose colonized Isle Royale (probably by swimming) before 1910, and the caribou that had been residents or migrant visitors disappeared in the twenties (Mech 1966). At that time there was no effective big game predator on the island. Moose built up rapidly to a level of heavy overpopulation and practically wiped out the available browse. A moose herd that may have numbered 3000 or more was drastically reduced in the early thirties by malnutrition and disease (Murie 1934; Hickie 1936).

Furbearers were heavily trapped on Isle Royale during the century previous to establishment of the national park, in 1940. The once-plentiful martens disappeared about the time moose were becoming established. Lynx lasted about 20 years longer and were not seen after the early thirties. At that time, the heavy destruction of ground cover by moose browsing may have been involved with a reported scarcity of hares, which in turn could have affected the welfare of the lynx, but this is entirely speculative. Beavers were increasing, coyotes probably were building up, and some foxes were present. The two canids undoubtedly scavenged on moose as a primary food supply.

In the drought of 1936 a fire removed forest cover from about a quarter of the island (Aldous and Krefting 1946). This large burn supported a regrowth of browse as moose built up again in the forties. The island appeared headed for further cycles of browse depletion and moose die-off. Krefting (1951) reported a substantial loss of moose and a decline of the herd in 1948-49. At this time a major reduction of beaver began—probably extending to the mid-fifties— which Shelton (1966) associated with an epizootic of tularemia that decimated beavers widely in the northern Lake States. Krefting (1969) found that coyote scats of this period contained moose, beaver, and hare, in the order named.

A breeding pack of wolves evidently reached Isle Royale in the winter of 1948-49, although individuals may have been there or visited the

island previously. They found feeding conditions on moose and beaver (almost exclusively their foods in this range) quite favorable. In the fifties they increased as coyotes declined. In 1957 James E. Cole of the National Park Service recorded the last coyote track. It appears that an intolerable food-niche overlap and/or behavioral conflict led to the disappearance of the smaller canid. Since that time, at least, the red fox has prospered on Isle Royale, as a winter scavenger on wolf-killed moose and as a predator on snowshoe hares (Johnson 1969). Wolves on the move (i.e., hunting) kill an occasional fox, but at a moose kill when full-fed, they commonly pay little attention to the foxes that frequent such environs.

Intensive work on the wolves began in the winter of 1959, and for the next 5 years the total population was relatively stable at minimum levels of 20-22 animals. The one large pack on the island numbered 15-17, with groups from one to three comprising the remainder. From 1964 to 1966 there were increases accounted for by pup survival to midwinter, and total numbers probably were 25-28, with the large pack showing one count of 22 in 1964. This pack usually numbered 11 or 12 in 1966, after which the dominant male (who was disabled) evidently was killed (Jordan et al. 1967). This marked a signal change in the pack structure of island wolves; packs numbering six to eight were the large groups for 2 years. A pack of seven, containing four melanistic individuals, crossed the ice from Canada in 1967, bringing the island count to a probable 30 in that winter. In 1968 a pack of six probably left the island via the same route, leaving a group of seven as the largest aggregation and a total population of 17-20. For the following 3 years, this pack continued to be the single breeding pack on the island, showing a maximum count of 10 in 1971. During the same period, the total population was 17-19.

Wolf numbers have been relatively stable, with a low rate of recruitment, the greatest changes occurring as a result of an uncommon exchange of packs with the Ontario mainland. The wolves evidently have brought a high degree of stability to the moose herd, which has numbered about 1000 animals as of midwinter in recent years (Jordan et al. 1971). Although vegetation studies have not been part of this investigation, it is evident that browse species on the island have made a substantial regrowth since the advent of wolves at the end of the forties. In the large burn of 1936, aspens and other food trees have grown beyond the point of high productivity.

On Isle Royale there is a long-term trend of forest maturation that will reduce food supplies for the moose and, in turn, for the wolves. Support of a moose herd at the present level will require recurring fires to induce a patchwork of early successions. As of midwinter the island has

about one wolf per 50 moose, which seems to be a maintainable ratio. Beavers evidently contribute about 15% of the annual diet.

If wolves had not reached Isle Royale, it is reasonable to suppose that the fluctuating moose herd would have greatly reduced annual browse production. Eventually, they probably would have achieved a relative stability at a low level of numbers, with the heaviest mortality brought about by malnutrition in the most severe winters. This condition has been described by Houston (1971) for moose in Jackson Hole, elk in certain Yellowstone herds, and elk and mule deer in Glacier National Park. Adjustments since the coming of the wolf to Isle Royale promise, by analogy, somewhat different habitat relationships for the north Yellowstone elk herd if wolves build up there and become a major limiting factor. In that case vegetation would be protected at a higher level of productivity, and a larger turnover of elk would be available to feed the wolves. This might well be a closer approximation of primitive conditions than what has developed since the early period when wolves and mountain lions were extirpated (or nearly so) in the Yellowstone region.

It is evident that this brief faunal history of Isle Royale is pertinent to certain basic management problems of the National Park Service. In particular, it supports the realistic policy that recognizes fires as a part of wilderness dynamics, and it emphasizes what might be expected from achieving a predator-prey balance in such areas. It has other implications which will be discussed.

PREDATION BIOLOGY

The relationships of predators to their prey have come under increasing study, and our biological understanding has been substantially improved in the past decade. The subject cannot be reviewed here, but certain features of the Isle Royale findings will be pointed out. The most nearly comparable published work is that of Murie (1944) on the wolf and Dall sheep in Mount McKinley National Park.

Thirteen years of continuous work have permitted us to examine the remains of more than 600 moose that died naturally on Isle Royale, by far the majority of which were wolf kills. Moose were "aged" originally by tooth wear, but more recently by cementum annulations (Wolfe 1969). Selective killing by the wolves has been evident since the first winter (Mech 1966).

Calves are under-represented in this sample because their remains are highly perishable and often almost totally consumed. But calves sustain the highest predation rate of any single year class. In most winters about 25% of animals killed by the wolves are calves, a rate that may more than double in the presence of exceptionally deep snow. Under these

conditions also, the killing rate increases and carcasses show a lesser degree of immediate utilization.

From age 1 through 5, few moose are killed, after which vulnerability increases to the greatest known age (three specimens) which is 17+ years. Advancing age and the incidence of killing by the wolves are correlated with more frequent evidence of several kinds of pathology, including peridontal disease, arthritis and bone deformations, and heavy infections of the hydatid tapeworm (*Echinococcus granulosus*). Michael Wolfe is preparing for publication a life table and mortality and survivorship curves for this moose herd based on 374 specimens accumulated through 1968. The great significance of this information is that it portrays something close to the natural age structure of a moose herd under the culling of its principal predator, the wolf. Only in a protected wilderness, where both moose and wolf are free from man-caused mortality, would such research be possible. Vital statistics show that the wolf "manages" its prey by removing poorly protected calves at one end of the life cycle and the least healthy adults at the other, leaving the more vigorous segment of the population to utilize available browse in producing more generations of moose.

This is a view of an ancient biological mechanism that has helped preserve this type of ecosystem. The highly selective pattern of wolf predation has had its evolutionary effect on the moose. The gun obviously has a different kind of effect. Thus, where big game herds are limited primarily by the annual hunting kill, it can be expected that, over time, speciation will be directed along unnatural lines. This suggests the inadvisability of attempting to manage any animal immune from the attentions of its natural enemies. Questions of this kind must likewise be raised relative to those big game herds in parks that are stabilized at low level by the deficiencies of a long depleted range.

WOLF SOCIOLOGY

When wolves were first known to be on Isle Royale, a major question was, how numerous would they become? In the region it was popularly assumed that they would undergo a build-up to be limited only by disappearance of the moose. Actual densities achieved have fluctuated around a mean of about a wolf per 16 km^2 (10 $miles^2$). Pimlott (1967) regarded this as the maximum density for most ranges. Population control has been effected by an extremely low recruitment rate brought about by a severe limitation on the number of females that breed, plus a low survival of young. Only for short periods has more than one breeding group been present on the island. Usually sexual activity is seen in only one pack, the largest at the time, which may be considered "dominant" in having territorial rights to at least half the island.

We have two records of a wolf being killed by its own kind. One such case has been referred to—elimination of the ailing dominant male of the large pack in 1966. The second occurred in 1969, when it appeared that the (then) major pack encountered a lesser group at or near the territorial boundary. Two, or perhaps three, cases of wolf injury through fighting were recorded when the immigrant pack of seven arrived on the island in 1967. These episodes might be regarded as incident to disruptions in the commonly existing social order, but they are part of the wolf's population dynamics. Ordinarily, the social hierarchy and its inherent behaviorisms are a peace-keeping type of organization designed to enhance genetic superiority and the cause of racial survival.

Since only a few individual wolves can be recognized in our surveillance from the air, the significance of many behavioral observations is questionable. However, dominant animals (alphas or betas) can be identified frequently, and subordinates often leave no question of their status. Pups of the year may reveal themselves by a combination of behavior and appearance.

It is logical to expect that a dominant carnivore be self-limiting in numbers. The wolf on Isle Royale fulfills this expectation by mechanisms that are by no means explained fully. For example, we know nothing of socio-economic relationships that might be critical during the denning season. By whatever means, it appears that the wolf has achieved the maximum density that is socially tolerable under these conditions. If this is true, then numbers of the moose have been controlled secondarily through some realistic relationship between supply and demand. This relationship is not a constant, for moose vulnerability is not absolute in terms of physical condition. In winter it varies with weather and ground conditions and may, in turn, involve the adequacy of local food supplies. Probably there are logical reasons why some sites on the island are more heavily browsed than others.

These studies of the wolf and its prey have furnished convincing examples of the close linkage of behavioral and physical requirements in determining ecological status. The wolf defines its place in the community not only through its structure and physiology but also by acting like a wolf.

PROTECTION AND RESEARCH

As has been suggested, these investigations of the predation phenomenon would not have been possible in an area where the age structure of the moose herd was being altered by hunting or where the wolf was subject to attrition by man. In fact, it is quite likely that this wilderness national park is the only place in the world where adequate records of the kind necessary to our purpose could have been gathered.

The importance of the protection factor on Isle Royale has been emphasized by the fact that it has not been complete. In the first two winters of this work, Mech found that the large pack of wolves ignored the aircraft even at the closest possible working range—sometimes less than 100 feet. In the third winter it was noticed that the animals were using evasion tactics. During the following winters of 1962 and 1963, members of this pack were so obviously frightened by the aircraft that they frequently took refuge in heavy cover when approached within a quarter-mile. In March 1963, Shelton and pilot Donald E. Murray intercepted a strange plane in the park and reported it to FAA. It was found to be unlicensed and on that basis was grounded. In subsequent years wolves showed much greater tolerance, but we believe subjectively that they have never returned to the condition of nearly total unconcern that permitted such profitable observations in 1959-60. In 1971 another plane was observed at close range in the park as two groups of wolves were "buzzed" and scattered on the open ice.

For 2 years during Shelton's study, close observations of the large pack were almost impossible, evidently because the animals had been harassed and possibly shot at. This was costly to the research, and it also indicates the incompatibility of such activities as hunting with aesthetic utilization, including photography, in natural areas. Neither scientific nor recreational values of wilderness can be realized fully without effective protection against unnatural disruptions. These considerations are obviously applicable in the recurring controversy over ill-advised proposals to open national parks to hunting.

CONCLUSIONS

Isle Royale National Park exemplifies the scientific values of nearly any primitive area, and it has its own unique advantages as an outdoor research laboratory: The striking limitations of its biota represent a measure of simplification over what is commonly found elsewhere. As an island, it offers relatively "confined" populations of animals, which can be inventoried somewhat more easily than is possible on study plots in more extensive habitats. This ecosystem is sufficiently far north in latitude so that its extremes of summer and winter weather help reveal relationships that would be more obscure in areas farther south. The latter point was illustrated in the winter of 1971 when we recorded five cases in which moose attacked or confronted by the wolves went over precipices. Observed for the first time in the 13th winter, this also emphasizes the need for long-continued work. Considering the total complexity of what we are studying and have only begun to understand, it is evident that the end of profitable learning is not in sight. I believe strongly in my reply to a skeptical correspondent who inquired when we

would be "satisfied" with our results and terminate our work: "If there are wolves and moose on Isle Royale in a century hence, I hope someone will be studying them."

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Progress in Restoring a Natural Grizzly Bear Population in Yellowstone National Park

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INTRODUCTION

Records on grizzly bear (*Ursus arctos*) injuries to humans in Yellowstone National Park between 1930 and 1969 and data which suggested causal relationships were compiled for reference purposes (Cole 1970a). These compilations indicate that unnatural food (human camp groceries or garbage) altered the natural habits and behavior of bears and was basically responsible for 60 injuries which occurred within park developments (campgrounds, cabin complexes, etc.). During this 40-year period, three other injuries to hikers in backcountry areas appeared to be due mainly to the natural defensive behavior of female grizzlies with young.

Changes in bear-control procedures seemed to be partly responsible for a fivefold increase in injury rates from the 1950s to the 1960s. Individual bears that became habitual users of developed areas and would have been destroyed during the 1950s were repeatedly captured and transplanted in the 1960s. This allowed grizzlies that learned to avoid capture or returned from transplants to mate and raise young within areas that received high levels of human use. The number of injuries in park-developed areas markedly increased in 1963 and averaged 4.5 per year between 1963 and 1969.

Repeated visits of bears to developed areas or garbage disposal sites to obtain food represent reward-reinforced behavior (Stokes 1970). The usual avoidance behavior of grizzlies toward humans was apparently lessened by repeated "rewards" of food in association with campers or with persons that worked at or hauled garbage to disposal sites. Unnatural movements and distribution habits apparently resulted from bears

having prior experience in feeding at garbage disposal sites (Jonkel 1967; Hornocker 1962; Murie 1961) or in campgrounds.

After reviews of available reference information and various recommendations, the Superintendent of Yellowstone National Park directed that a program be implemented to (1) restore bears to using natural food entirely, and (2) reduce injuries to humans. Research personnel were asked to assist on program design and to carry out studies to document and evaluate results.

Most of the data that were considered in developing the park's program are summarized in reports by Craighead and Craighead (1967), Martinka (1971), and Cole (1970a). The final program outlined a sequence of management actions to eliminate sources of unnatural food that attracted bears into park-developed areas, procedures for controlling bears and protecting visitors, and an open-ended schedule for closing the last two large garbage dumps that remained in the park. A more detailed description of the program, its backup contingencies, and its first year results in 1970 have been presented as a conference paper (Cole 1970b).

This paper will summarize the various management actions carried out in both 1970 and 1971, describe the procedures used for evaluation studies, and attempt a preliminary evaluation of program results. Evaluations will be in relation to the general objectives of reestablishing a natural grizzly population and reducing injuries, with an assessment of effects on bear numbers.

MANAGEMENT ACTIONS

Figure 1 shows the location of major park developments and garbage disposal sites that are referred to in this report. Bearproof tops had been placed on the garbage cans within all park campgrounds and picnic areas prior to 1970, within all but two cabin or residence complexes by 1971. Over 2000 such cans now are placed within the park.

Efforts were intensified to have visitors store food so it would not lure bears into campgrounds. This involved distributing literature at park entrances, posting warning signs, and advising campers by car radio messages, public address systems, and direct contacts. Literature on "how to camp and travel in bear country" was also distributed to backcountry campers and hikers.

The Rabbit Creek and Trout Creek garbage dumps inside Yellowstone National Park were closed (i.e., not used since the previous year) consecutively in 1970 and 1971. A large municipal dump that was just outside the park's west boundary and within 2 miles of West Yellowstone, Montana, was also closed by the U.S. Forest Service in the early summer of 1971. Most of the bears that used this boundary-area

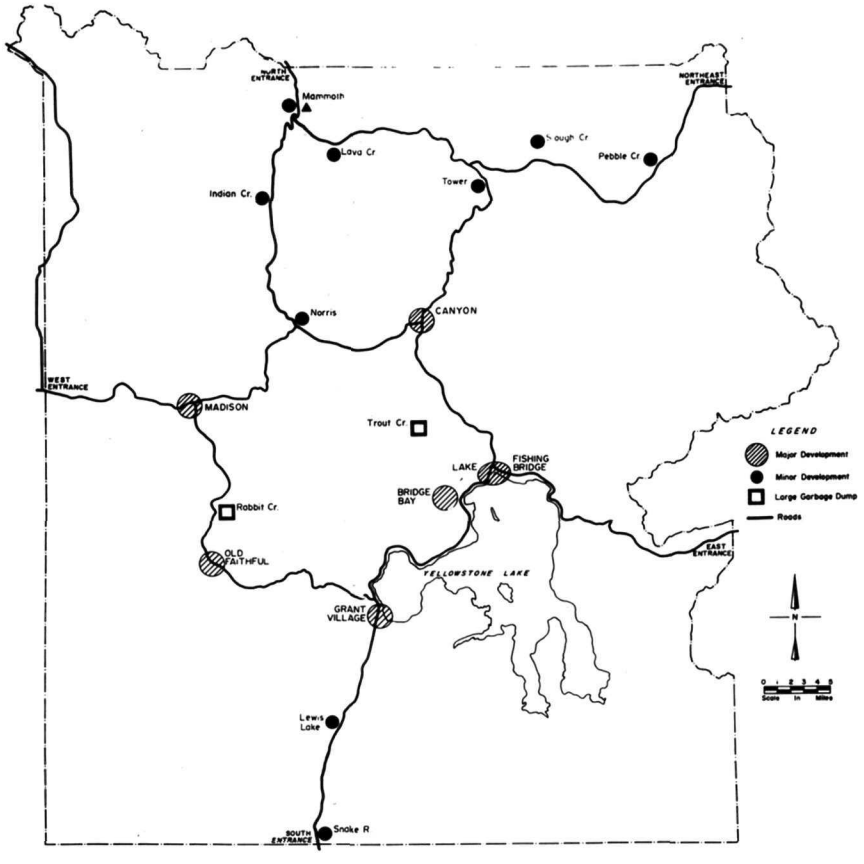

Fig. 1. Map of Yellowstone National Park showing the location of major park developments and garbage disposal sites.

dump were assumed to be members of the park population (discussed later).

Based upon studies by Hornocker (1962), up to 40 different grizzlies may have visited the Rabbit Creek dump over June-September periods. Up to 100 different bears may have visited the Trout Creek dump. Up

to 40 different bears may have visited the West Yellowstone dump. Refuse that had previously gone to these sites went to three fenced, sanitary landfills and two incinerators.

Park campgrounds in superior spring and fall grizzly habitat were opened later and/or closed earlier than previous years to avoid peak periods of grizzly activity. Other campgrounds provided substitute camping. Tent or sleeping-bag-only camping was prohibited in one campground to gain experience in applying such management actions if they became necessary.

One control action was recorded each time a bear was either captured and transplanted, shipped to a zoo, or destroyed. Efforts to promptly remove bears from park developments were intensified in 1970 and 1971. Bears were captured with baited culvert traps or with drugs (Sucostrin or M99) administered by a projectile syringe. A small, serially numbered tag was placed in the ear of animals that were to be transplanted and did not already have identifying markers. Transplants which placed bears an average of about 30 miles (6-51) from capture sites were made routinely by vehicle, boat, or helicopter.

Bears were intentionally destroyed and processed as scientific specimens if they could not be removed from a developed area by live capture methods, if they became excessively destructive or dangerous to humans, or if they had returned from one or more transplants. Young bears, as well as older animals that may have simply been passing through a developed area, were given repeated transplants. Unintentional deaths occurred when bears injured themselves in traps, charged personnel that were attempting immobilization, or failed to recover from drugs.

A central monitoring system that recorded grizzly observations, human injuries, property damage, and bear control actions on a daily basis provided current information for guiding the overall program and data for evaluation studies.

STUDY PROCEDURES

The hypotheses being tested to evaluate the park's program are:

(1) The various management actions to remove unnatural food sources and bear control procedures applied in the 1970s will: (a) progressively reduce the incidence and numbers of grizzly-caused injuries in park-developed areas from the 1963-69 average of 4.5 (2-8) per year; and (b) restore a more natural grizzly population than existed in the 1960s, as evidenced by bears occurring in scattered distributions in summer, an increase in avoidance behavior toward humans, and progressive reductions in the numbers of bears controlled and destroyed.

(2) The bear control procedures applied in the 1970s will not prevent the park grizzly population from maintaining or rapidly reestablishing its numbers at natural carrying-capacity levels.

A general model of the different units in the park's grizzly population was constructed in 1970 to predict probable removals of bears and assess what would constitute excessive control mortality. Data from Hornocker's (1962) censuses of bears at dumps, as well as park records on bears within different developed areas, were used to estimate the numbers of grizzlies that used unnatural food. Field observations of grizzlies and their sign in different areas by park personnel, as well as the findings of Barnes and Bray (1967) on grizzly and black bear (*Ursus americanus*) numbers in remote areas, were employed to estimate the numbers of grizzlies that would not be directly affected by eliminating unnatural food. The various population units with estimated numbers were as follows:

Population Units	Estimated Nos. in 1970
A. Bears that use garbage dumps, but are either too wary to habitually use developed areas or can be successfully transplanted	130
B. Bears that will habitually use developed areas and cannot be successfully transplanted	40
C. Annual production of cubs	30
Subtotal	200
D Other bears that stay in remote areas and are not directly affected by control or closing dumps	50-100
Grand total	250-300

The effects of removing bears on population numbers were assessed from considerations of the logistic growth equation

$$dN/dt = rN([K-N]/K)$$

Stated in words, this is simply that the rate of change in population numbers with time (dN/dt) is due to the difference between birth, death, and emigration rates which are influenced by the size of the population

(N) in relation to the carrying capacity of its environment (K). The relationship where dN/dt averages zero when N equals K was assumed to apply to Yellowstone grizzlies. Immigrations are ignored because of the relatively low grizzly densities outside the park.

The carrying capacity of the park environment for grizzlies was probably determined by social interactions among the bears themselves, and by intraspecific and interspecific competition for natural fall or spring foods that were periodically in limited supply. These relationships were inferred from studies by Jonkel (1967), Murie (1961), Martinka (1970), and Cole (1972).

Additionally, a "core" population of grizzlies that remained within the park and was not subject to hunting or conflicts with agriculture was distinguished from an unknown number of bears that had all or portions of their home ranges outside park boundaries. Emigrations of young adult or displaced old bears, or kills of such animals outside the park, were considered to show that the core population was at carrying capacity (Cole 1970a). Bears that made summer migrations into the park to use garbage dumps (Craighead and Craighead 1971) were not considered members of the core population. According to Jonkel (1967), such migrations probably result from a subadult bear acquiring experience in using a dump, before it has to emigrate to find a vacant home range.

The 200 bears that were estimated to be variously affected by removals of unnatural food were also assumed to be at carrying capacity with dN/dt averaging zero. Craighead and Craighead (1971) reported increases of about six bears per year in this population segment, but they did not consider that emigrants were no longer members of the park population.

PROGRAM RESULTS

Injuries

Table 1 shows the number of injuries in park-developed areas that were attributed to grizzlies during 1970, 1971, and four previous decades. The details relating to previous years have been published elsewhere (Cole 1970a). The two persons injured in 1970 were at the same campsite. A female bear which may have reacted to "defend" her cub injured both persons. No injuries were recorded for 7 years during the 1930s, 6 years during the 1940s, and 5 years during the 1950s. Injuries occurred every year in the 1960s. The zero injury record for 1971 was the first in 15 years.

TABLE 1. Numbers of injuries to humans from grizzly bears by periods and years, Yellowstone National Park, 1930–71.

Years	No. grizzly-caused injuries per year [a]		No. of visitors per injury
	Developments	Backcountry	
1930s	0.6 (0–3)	0	800,000
1940s	1.2 (0–7)	0	610,000
1950s	0.6 (0–2)	0	2,720,000
1960s	3.6 (1–8)	0.3 (0–2)	510,000
1970	2	1	700,000
1971	0	0	0

[a] Averages for decades with range in parentheses.

Bear Control Actions

The numbers of control actions (CA's) that occurred in different park developments from 1968 to 1971 are shown in Table 2. Data prior to 1968 were incomplete because all captures and transplants of unmarked bears were not recorded. Unmarked bears also precluded knowing the number of individual animals handled in 1968 and 1969.

TABLE 2. Numbers of grizzly bear control actions in Yellowstone National Park developed areas, 1968–71.

Developed areas	Control actions [a]			
	1968	1969	1970	1971
Old Faithful	1 [b]	0 [b]	22	1
Canyon	14	16	9	11
Lake Outlet	16	25	11	20
Grant Village	20	5	15	5
Bridge Bay	8	9	0	1
Eleven other units	0	2	13	1
Total control actions	59	57	70	39
Total bears destroyed	5	10	12	6

[a] Number of times bears removed by capturing for transplanting, shipping to zoos, or destroyed.

[b] Repeated attempts to capture other grizzlies unsuccessful.

Numbers of Control Actions and Bears

In comparison with 1968 and/or 1969, the increase in CA's during 1970 occurred mainly in the Old Faithful development and some smaller units (Table 2). Six of the 13 CA's in small units and 2 in other large developments involved bears that had been transplanted from the Old Faithful area. In total, 30 of the 70 CA's in 1970 could be attributed to 18 Old Faithful bears. The remaining 40 CA's in other developments involved 32 different bears. Of the 12 bears destroyed, 6 were intentional and 6 were unintentional. Eight other animals (seven had returned from one or more transplants) were shipped to zoos.

Table 2 shows the numbers of CA's within the park decreased in 1971. The 39 CA's involved 33 different bears. Of the six bears destroyed, four were intentional and two unintentional. In contrast, the number of CA's in Montana's West Yellowstone area during 1971 increased from previous years. Here Montana Fish and Game personnel carried out 23 CA's which involved 19 different bears. Twelve of these bears were known to be killed: one bear that was considered excessively dangerous and four that returned from transplants into the remote Absaroka Range north of Yellowstone National Park were intentionally destroyed; one failed to recover from drugs; three were illegally shot; and three others were legally killed by hunters. Additional bear mortality due to humans occurred within the park with two grizzlies struck by cars in 1970; one, in 1971.

Transplant Success

Twenty-two marked or identifiable grizzlies were transplated a total of 54 times and returned to the same or another park-developed area 36 times in 1968 and 1969. This amounts to only 33% of these transplants being successful in preventing returns to developed areas. About 60% of 50 transplants were successful during 1970. About 80% of 33 transplants were successful during 1971, and only three bears that were transplated the previous year were rehandled.

DISCUSSION AND CONCLUSIONS

The basic premises of the park's program were (1) the "right" number of grizzlies within Yellowstone National Park is the number that occurs naturally (i.e., without human influences on bear behavior, habits, or population dynamics); (2) removals of unnatural food and incorrigible bears will allow young bears without human-altered behavior or habits to progressively replace incorrigible animals in the population; and once this is accomplished (3) the control of human influences alone will prevent corruptions of new bears and thereby substitute for controlling bears.

Some inadequacies were evident in the program. Despite the intense efforts to inform campers on how to store food in bear country, some ice chests or boxes that contained groceries were left out each night. Sufficient amounts of such food were available in larger campgrounds to encourage repeated visits by at least one and sometimes several grizzlies. Unless this food-storage problem is solved, the need to control bears in some campgrounds could continue indefinitely. Some possible solutions are to strictly enforce an existing regulation which requires proper food storage, condition bears to avoid camp groceries, enclose problem campgrounds within a bearproof fence, or provide substitute campgrounds outside the park.

Some unnecessary control actions and potential for injuries occurred from a reluctance to dispatch the few adult female bears that continued to frequent park campgrounds in the 1970s. These females attracted males that became highly aggressive during the June and July breeding period. The survival of such females could also allow family groups of bears again to become habitual users of campgrounds. Unnecessary control actions also occurred because individuals in cabin areas, trailer courts, and residences did not place refuse in bearproof cans. A possible solution to such negligence is to assess the cost of capturing and transplanting bears to persons who make control action(s) necessary.

Appropriate tests for differences in the incidence and numbers of grizzly-caused injuries in park developments between the 1960s and 1970s will require data from several more years. Based on the preliminary 1970 and 1971 data, the hypothesis that the park program will progressively reduce injuries does not need to be rejected. The alternative hypothesis that the program will increase injuries, or the null form that it had no effect on injuries, is not supported by the preliminary data. Progressive removals of certain bears that had been repeatedly handled and transplanted in the past are suspected to have contributed to the absence of injuries in 1971.

Adequate tests of the hypothesis that the park program will progressively restore a more natural grizzly population will also require a longer time span. Monitoring records for 1970 and 1971 were obtained from a total of 1188 grizzly observations. These suggested that with the closure of the last garbage dump in 1971, the majority of the park's bears stayed in scattered distributions on natural foods through the summer. Records of grizzly occurrences in developed areas, as well as the reduced numbers of CA's and bears destroyed in 1971, also show that considerably fewer grizzlies used park-developed areas than in previous years.

The increased success in transplanting bears (33% in 1968 and 1969, 60% in 1970, 80% in 1971) probably was due partly to selective removals of bears that had prior experience in returning from trans-

plants. It is also suspected that with reduced food rewards in developed areas, the capture and transplant process became sufficient "punishment" to discourage bears from returning to these areas. The distances that bears could be transplanted in the park (up to about 50 miles) did not seem significant to overcome the homing capabilities of most adults. Transplanted adults that returned to Montana's West Yellowstone area traveled over 70 miles.

Reference literature from the applied field of wildlife management shows that mortality from humans can substitute for density-influenced mortality from natural causes when animal populations are at or near the carrying capacity of their environment. It should be added that human-induced mortality could also reduce the number of emigrants when population densities are influenced by social or competitive interactions.

If the park grizzly population was at or near carrying capacity in 1970, the removal of 20 bears by control operations and the deaths of two animals hit by cars could be expected to substitute for some mortality or emigrations that would have otherwise occurred. Another increment of even less than 30 cubs in 1971 could be expected to reestablish population numbers at or near original 1970 levels. The removal of 6 bears by park control operations and one car-caused death in 1971, as well as the additional deaths of 12 bears that resulted directly or indirectly from the Montana Fish and Game Department's program, also do not seem of sufficient magnitude to prevent the park grizzly population from regaining its numbers by 1972 or 1973. Here, it is anticipated that the numbers of CA's within the park will continue to decline and bear control in Montana's West Yellowstone area will follow the pattern shown by the 1970 and 1971 data for the park's Old Faithful area (Table 2). The foregoing considerations of bear population dynamics in relation to human-induced mortality suggest that the control procedures applied in the 1970s will not prevent the park grizzly population from maintaining or rapidly reestablishing its numbers at carrying capacity.

Appropriate summary conclusions are as follows: the preliminary results of the program show initial trends toward accomplishing the objectives of restoring a natural grizzly population and reducing injuries to humans. Thus far, the removals of bears from the core park population could temporarily reduce density-influenced emigrations. Such emigrations will probably be reestablished at higher-than-previous rates because the first-year survival of cubs is considerably greater in free-ranging bear populations than in population segments that concentrate at garbage dumps (Martinka 1970). Removals of bears have not been

and probably will not be sufficient to preclude the park population from maintaining or rapidly reestablishing its numbers at capacity levels by density-influenced recruitments of young. The "need" to remove or otherwise control bears will probably decline to relatively low levels in subsequent years.

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Acknowledgments

Dr. Allen W. Stokes and Dr. Barrie K. Gilbert, Utah State University; Dr. Douglas B. Houston, Reserach Biologist, and Mr. Dale H. Nuss, District Ranger, National Park Service, Yellowstone National Park, reviewed the manuscript and made helpful suggestions. This paper is a contribution from the National Park Service Natural Sciences Project YELL-N-38.

Grizzly Bear Population Studies in Glacier National Park, Montana[1]

CLIFFORD J. MARTINKA, Glacier National Park, Montana

A population of grizzly bears (*Ursus arctos*) inhabits Glacier National Park as a native faunal species. Management of the park as a natural area requires that the integrity of this population be preserved as an integral component of park ecosystems. The presence of a grizzly population also requires certain management practices to provide for the safety of park visitors.

A study was conducted from 1967 through 1971 to obtain quantitative data on status, dynamics, habitat relationships, and management of the park's grizzly population. Preliminary results relating to status of the population and management to protect visitors have been reported elsewhere (Martinka 1971). This paper presents additional data on the status and characteristics of the grizzly population. The effects of management on the bear population and the park's status as a natural area are also discussed.

STUDY AREA

Glacier National Park includes 1583 miles^2 of mountainous terrain in northwestern Montana (Fig. 1). Topography is characterized by a central core of precipitous peaks and ridges with glacial cirques, moraines, and lakes as prominent features. Extensive talus, persistent snowfields, and remnant glaciers are common. Streams radiate from the park as headwaters of the Saskatchewan, Missouri and Columbia River systems. Elevations vary from approximately 3100 to 10,500 ft.

[1]Edited contents of this paper have been published in the *Journal of Mammalogy* but are included in these proceedings to provide a complete record of the symposium. Please refer to: Martinka, C. J. 1974. Population characteristics of grizzly bears in Glacier National Park, Montana. *J. Mamm.* **55**:(1):21-29.

Park climate is classified as continental, with decided Pacific maritime modifications on the western slopes (Dightman 1967). Weather records from Summit (5213 ft) along the southern boundary are considered to illustrate the general moisture and temperature regime within the park. Mean annual precipitation was 38.29 inches, of which approximately 60% fell as snow from November through April. Annual snowfall of 251 inches resulted in maximum accumulations which frequently exceeded 60 inches. Mean monthly temperature was 35.9°F, with extremes of 15.3°F (January) and 56.7°F (July). Data from other areas show that precipitation increases and decreases, respectively, at higher and lower elevations.

Vegetation of the park has been described by Habeck (1970). In general, habitats include a complex interspersion of climax and seral plant communities. Alpine types occur at high elevations and include outcrop, talus, meadow, and krummholz communities. Lower elevations are dominated by coniferous forests with alpine fir (*Abies lasiocarpa*), Engelman spruce (*Picea engelmannii*), lowland white spruce (*Picea glauca*), and Douglas fir (*Pseudotsuga menziesii*) as the principal climax species. The historical influence of wildfire is reflected by extensive successional stands of lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), and Douglas fir. Snowslides occur frequently on more precipitous mountain slopes and create disclimax communities characterized by alder (*Alnus* spp.), willow (*Salix* spp.), mountain maple (*Acer glabrum*), and serviceberry (*Amelanchier* spp.). Grasslands occur infrequently on drier sites, particularly east of the Continental Divide, and are generally dominated by bluegrass (*Poa* spp.), fescues (*Festuca* spp.), or bluebunch wheatgrass (*Agropyron spicatum*).

METHODS

Characteristics of the park's grizzly population were studied from sightings of grizzlies by the author, park personnel, and others who were considered qualified observers. Bears were observed while traveling the park's trail system on foot or horseback, from a vehicle on main and secondary roads, or during aerial flights. The date, location, number, description, and other pertinent information were recorded for each sighting. Descriptions included size, color, and distinguishing features. Bear locations, sighting dates, and descriptions were used to exclude duplicate sightings and determine the number of individual bears seen each year. These data were used to compute population parameters.

Numerical estimates of the population were obtained from a 290-mile^2 sample area in the north-central region of the park (Fig. 1). Sample area boundaries were selected to include a distribution of habitats and physiographic features which was representative of the entire park.

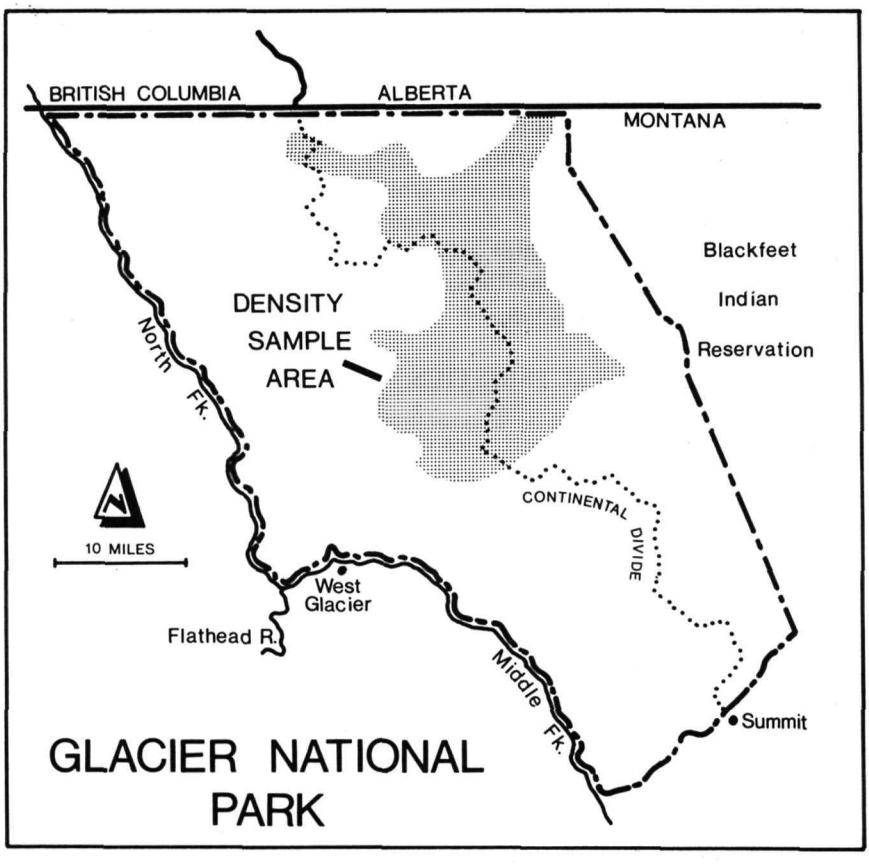

Fig. 1. Map of Glacier National Park, Montana, showing location of the density sample area and other geographic features.

An extensive trail system within the area permitted more intensive observational coverage than in other parts of the park. The number of individual bears observed within the sample area was determined each year and densities computed. These densities were expanded to estimate the population for the 1583-mile^2 park area.

The sex and/or age classes in yearly samples of individual bears were used to compute population composition. Unclassified adults (males, females, subadults), productive females, and young classes were recognized. Young accompanied productive females and were distinguishable as cubs (0.5 years) and yearlings (1.5 years) on the basis of relative size.

The yearling class contained an undetermined number of subadults as discussed later in the text. Sizes of cub and yearling litters were computed from yearly sightings, and frequently included sightings of the same litters during consecutive years.

Records were maintained for each known grizzly bear mortality which occurred within the park during the study. Carcasses were subjected to routine post-mortem examinations, which included aging according to the tooth-sectioning method described by Mundy and Fuller (1964). Additional data on mortalities adjacent to the park were provided by the Montana Fish and Game Department and the United States Bureau of Sport Fisheries and Wildlife.

POPULATION CHARACTERISTICS

Density and Size

The number of different grizzlies observed on the density sample area each year, computed density, and expanded estimate for the park's population are presented in Table 1. The mean computed density of one grizzly per 8.2 mile^2 was intermediate as compared to that reported for other populations. Troyer and Hensel (1964) and Mundy (1963) reported respective densities of one grizzly per 0.6 and 5 mile^2 for Kodiak Island, Alaska, and Glacier National Park, Canada. Both of these areas were characterized by extensive alpine, subalpine, and shrub habitats. In contrast, Jonkel (1967) found a density of one grizzly per 15 mile^2 on an area of extensive coniferous forests immediately adjacent to Glacier National Park, Montana. An intermediate population density in Glacier National Park possibly relates to an intermediate composition and interspersion of important habitat types (Martinka, unpubl. data).

The expanded park population estimates of 175-230 grizzlies were greater than those made prior to 1967. These ranged from 90 to 130 and were generally derived from a combination of reported observations, area counts of grizzlies by park rangers, and estimates from previous years. Higher figures during this study are considered to reflect greater efficiency of the sample-area census technique rather than a population increase.

Annual differences in density and population estimates probably resulted from differences in the observability of bears, sampling bias, and other variables. General difficulty in observing grizzlies, even when they were known to frequent an area, suggested that expanded population figures were minimum estimates. In contrast, inclusion of some bears that had only part of their home range within the sample area may have tended to inflate the estimates. Increased estimates would also have occurred where random wandering of subadults inadvertently contributed to duplicate observations. However, the generally comparable

TABLE 1. Density and population estimates for grizzly bears in Glacier National Park from 1967 through 1971 as determined from sightings on a 290 square mile area within the Park.

Year	Number of different bears observed	Number of square miles per bear	Expanded estimate for the total park population
1967	32	9.1	175
1968	34	8.6	184
1969	42	6.9	230
1970	37	7.8	203
1971	33	8.8	180
Mean	36	8.2	194

figures obtained during the 5-year study period and the comparisons with other populations suggest that density and population estimates were reasonable.

Sex and Age Composition

Results of classifying grizzly bears according to sex, age, or both are presented by years in Table 2. The data are considered to reflect the general composition of the park's population from year to year and show that unclassified adult grizzlies were the predominant class observed. This class included adult males, nonproductive adult females, and subadults of both sexes.

TABLE 2. Composition of the grizzly bear population in Glacier National Park as determined from classifications of 350 bears from 1967 through 1971.

		Percent observed by age class					
		Adults			Young		
Year	Total classified	Unclassified	Productive females	Total	Cub	Yearling	Total
1967	61	57	15	72	28	0	28
1968	83	53	17	70	10	20	30
1969	67	45	19	64	19	17	36
1970	76	50	20	70	18	12	30
1971	63	40	22	62	11	27	38
Mean	70	49	19	68	17	15	32

Productive female grizzlies annually comprised 21-35% of the total adult population segment. Mean proportions of cubs and yearlings were nearly equal for the 5-year period, but variability within years and classes was characteristic. A potential population growth rate of 20% annually was computed from the mean annual increment of 17% cubs.

The mean annual increment of cubs in the park's population was lower than those reported for certain other grizzly populations. Craighead and Craighead (1971) found a mean annual increment of 19% cubs for Yellowstone National Park. The population segment involved was subject to unnatural mortality because the animals concentrated at refuse dumps and frequented campgrounds (Martinka 1970; Cole 1971). A mean annual increment of 22% was described for a hunted grizzly population on Kodiak Island (Troyer and Hensel 1964). Relatively low production of cubs in Glacier National Park possibly reflects low mortality from unnatural causes.

Litter Size and Maternal Relationships

Observation frequency by size and mean sizes for 65 grizzly bear litters are presented by age class in Table 3. Litters containing one or two young were observed most frequently. Percentages of litters with two or three young increased in the yearling class, suggesting that complete yearling litters were more easily observed than cub litters. The trend shown by observation frequency was reflected by a slightly larger size of yearling as compared to cub litters. Small litter sizes in the park's grizzly population probably contributed to the relatively low reproductive rate observed. Troyer and Hensel (1964) reported mean litter sizes of 2.36 and 2.17 for the cub and yearling classes, respectively, of a more productive, hunted grizzly population in Alaska.

TABLE 3. Observation frequency by size and mean sizes for grizzly bear litters in Glacier National Park as determined from yearly observations of individual litters from 1967 through 1971.

Age class	Number of litters observed	Percent frequency by size			Mean size
		1	2	3	
Cub	35	43	46	11	1.7
Yearling	30	33	53	14	1.8
Mean	65	38	50	12	1.7

Comparable sizes for cub and yearling litters indicated that first-year mortality of cubs was low in the park's population. This was supported by observations of five recognizable family groups where litters accompanied the maternal female for 2 or more years. In each case, the integrity of the litter was maintained for the entire period of observation and no mortalities occurred.

In contrast, field classifications showed a lower percentage of yearlings than cubs in the population (Table 2). This appeared related to observational bias since individual family units with cubs were generally more positively identified than those with yearlings. As a result, a greater proportion of family groups with yearlings would have been excluded from basic data as possible duplicate observations. Some first-year mortality of cubs was also considered a potential contributor to the observed difference. In this case, complete losses of litters may be postulated since mean litter sizes for cubs and yearlings were comparable. A minimum mortality of 12% annually was computed, assuming that cub mortality was entirely responsible for the observed difference and that the yearling class contained no subadults.

Differences in productivity of the grizzly population between years (Table 2) were possibly related to variations in length of the maternal relationship. Hensel et al. (1969) utilized reproductive data from a hunted population to hypothesize that grizzlies normally breed at 3-year intervals. This resulted in a 2-year relationship between the female and young, with dissolution of the bond occurring prior to breeding the third summer. Field observations during this study support the hypothesis with exceptions. In one case, a recognizable family group remained intact into the fourth summer. Several additional family group sightings were recorded where young were sufficiently large to assume that they were older than yearlings.

Extension of the breeding interval by at least some adult females would have contributed to the comparatively low reproductive rate observed in the population. Stokes (1970) considered social intolerance as an important factor which may lead to reproductive responses of this type in a grizzly population. The specific nature of the interaction was not established but inhibition of ovulation, extended lactation, or a combination of both could permit a longer maternal relationship. Erickson and Nellor (1964) reported that lactating female black bears (*Ursus americanus*) were unreceptive toward males during the normal breeding season. During this study, a relationship between low productivity and high proportions of yearlings was particularly evident in 1968 and 1971.

Grouping Habits

Most grizzlies in the park's population were observed as single individuals or in family groups (Table 4). Cohesive groups of two or more adults, subadults, or both were observed less frequently. These groups appeared to include adult breeding pairs in June and, more commonly, subadult litter mates which remained together following the dissolution of maternal bonds.

Four reports of unusual groupings of grizzlies were recorded during this study and similar reports were located in park wildlife records. These appeared to result from breeding or maternal behavior. In one case, an adult male was observed with a family group containing a female with three 2-year-old young in May 1969. Dissolution of the maternal bond followed and the female apparently produced two cubs in 1970. Three other sightings of family groups along with detailed descriptions suggest that females with young may occasionally tolerate the presence of subadults or young adults for short periods.

Several reports of large groups of grizzlies appeared to result from seasonal concentrations in the vicinity of preferred food sources. In Glacier National Park, such concentrations have been reported on lowland meadows and snowslides in spring, subalpine areas in late summer, and along a nonnative kokanee salmon (*Oncorhynchus nerka*) spawning

TABLE 4. Observation frequency for grizzly bear singles, groups, and matriarchal family units in Glacier National Park from 1967 through 1971.

Year	Number of singles and groups observed	Percent frequency			
		1	2	3	Families
1967	37	59	14	3	24
1968	53	64	9	0	27
1969	37	54	11	0	35
1970	46	52	15	0	33
1971	37	57	5	0	38
Mean	210	57	11	1	31

stream in fall. Descriptions of these indicate that distinct spacing among individuals and different social units was characteristic. It seems likely that concentration sites were utilized by those animals with home ranges including or immediately adjacent to the site, as has been described for black bears by Jonkel (1967).

Mortality

Ten grizzly bear deaths were recorded in Glacier National Park from 1967 through 1971 (Table 5). Nine were caused by direct control for management purposes (Martinka 1971) and one by an apparent collision with a motor vehicle. Control deaths generally resulted from attraction of the bears to unnatural food sources and their age distribution suggested a disproportionate involvement of subadult or older adult animals. These were considered as social equivalents and their attraction to unnatural foods may have resulted from their subordinate social rank.

Population losses resulting from control actions averaged two grizzlies per year during the study. This comprised approximately 1% of the esti-

TABLE 5. Summary of known grizzly bear mortality in Glacier National Park from 1967 through 1971.

Year	Number of mortalities		Sex		Ages
	Direct control	Accidents	Male	Female	
1967	4	0	0	4	9, 13, 22, 30
1968	2	0	2	0	1, 12
1969	3	0	2	1	2, 2, 3
1970	0	1 [a]	0	1	4
1971	0	0	–	–	–
Totals	9	1	4	6	–

[a] Road kill.

mated population and 6% of the computed mean annual production of 33 cubs. It appears doubtful that this low rate of unnatural loss was of sufficient magnitude to significantly alter population dynamics.

During the study, 32 grizzly bear deaths were reported for areas immediately adjacent to Glacier National Park (Fig. 1). These included 14 legal kills by hunters and 18 control actions resulting from attraction to unnatural food sources, depredations, or both. Fourteen deaths, which occurred on the Blackfeet Indian Reservation, apparently resulted from bear depredations on livestock. Considerations of habitat requirements and their proximity to the eastern park boundary suggested that some of these bears occupied home ranges which extended across park boundaries.

Four control actions and one hunter kill in the vicinity of West Glacier appeared to result from the presence of an open refuse dump which attracted grizzlies to the area. One additional grizzly was captured and removed from the area. Observations suggested that these were bears that occasionally moved outside the park to use the dump. In contrast, the locations and age classes of 13 hunter kills in the North and Middle Fork Flathead River drainages indicated removals from populations resident to those areas (Jonkel 1967).

DISCUSSION

Results of this study show that a viable population of 175-230 grizzly bears inhabits Glacier National Park. Numerical stability and relatively low productivity during the study imply that the grizzly population was at or near habitat carrying capacity. Social stress resulting in emigration of subadults may be an important factor contributing to natural regulation of the park's grizzly population. Stokes (1970) considered social intolerance and associated dispersal of subadults as mechanisms which probably contribute to natural control in grizzly populations. Intensive observations of marked black bears by Jonkel (1967) are pertinent to this hypothesis. In that study, home ranges of black bears overlapped broadly among adults of both sexes, but mutually exclusive home ranges were occupied by adults of the same sex. This pattern apparently restricted home-range establishment by subadults, resulting in both dispersal to marginal habitats and higher mortality rates.

Grizzly bears coexist with an increasing number of visitors in Glacier National Park each year (Martinka 1971). However, present levels of visitation do not appear to be sufficient to have adverse effects on the grizzly population. Wild, free-ranging grizzlies commonly frequented areas close to human developments or activity. Control actions which were necessary to protect visitors resulted primarily from improper refuse disposal or human encounters with maternal female grizzlies.

Population removals within the park resulting from direct controls were sufficiently low to have minimal effects on dynamics of the grizzly population. Effects were minimized further because control was mostly limited to socially subordinate individuals. Capture and transplanting of nuisance grizzlies that frequented developed areas also had minor effects on the population. Only two such actions were recorded during 1967-71.

Certain human activities in areas immediately adjacent to Glacier National Park were a potential source of impact to peripheral segments of the park's grizzly population. Deaths resulting from bear depredations on livestock and attraction to unnatural food sources were of particular significance. In cases where adults were removed from established home ranges, temporary effects on the park's population were implied where those ranges extended into the park. These losses were probably replaced by recruitment of subadults to the population. In contrast, extrinsic control actions involving subadults or older adults possibly included emigrants from occupied park habitats which could no longer be considered established members of the park's population. It is doubtful that legal hunting of grizzlies during recent years in areas surrounding the park has appreciably affected the numbers or dynamics of the park's population.

Cole (1972) discussed relationships between grizzly bears and natural area values which are applicable to Glacier National Park. He concluded that the presence of a grizzly population in Yellowstone National Park was essential to (1) have representative natural equilibriums among associated secondary consumers; (2) maintain natural relationships between a variety of primary and secondary consumers; and (3) retain the scientific values of ecological systems with an intact native biota. In Glacier, management procedures which provide for human safety do not appear to have detracted significantly from these values. Effects of a continued increase in visitation cannot be predicted from present data, but it has become apparent that a wild, free-ranging grizzly population offers the least opportunity for conflict with man.

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Acknowledgments

The author is indebted to G. F. Cole and D. B. Houston, National Park Service; R. J. Mackie, Montana State University; and S. Herrero, University of Calgary, for critical review of the manuscript. Technical assistance in aging grizzlies was provided by K. R. Greer, Montana Fish and Game Department. Cooperation of park personnel in reporting grizzly bear sightings made the study possible. The paper is a contribution from National Park Service Natural Sciences Project GLAC-N-16.

The Future of the Parks: I

STANLEY A. CAIN, The University of Michigan, Visiting Professor of Environmental Studies, University of California, Santa Cruz

The Yellowstone Act of 1872 coupled the purposes of preservation and the use of the park as a "pleasuring ground." The National Park Service Act of 1916 also stressed preservation and stated that parks were for the "pleasure of the people."

Over the years there has developed a variety of interpretations of these purposes, including a feeling that they are in conflict, even incompatible. This difficulty can be resolved if the meaning of these acts of Congress is: preservation for the enjoyment of the people in the natural values being preserved.

Congress could not have anticipated the changes that have brought new pressures on the national parks. A century ago, not only Yellowstone but most of the West was wilderness. Fifty-six years ago the Industrial Revolution was well under way but private autos were still few in number and most roads were narrow, rough, and unpaved. Mechanization had not yet produced high-powered outboard motors, over-terrain vehicles, and snowmobiles by the millions. Camping equipment was primitive and much of it was World War I army surplus. The few auto-campers were mostly home-built. The large and luxurious house trailer was yet to come. Campers expected to rough it.

Some parks were reached by railroads. Some rather grand hotels were built to house the comparatively small percentage of Americans who were better off. Travel about the park was mainly by horse-drawn vehicles. Many of the visitors expected to hike and climb for their special views. I believe that we can assume that most of the park visitors during these early years did expect to take their pleasure in the natural values that were being preserved in perpetuity. The recreation explosion is a phenomenon of the last quarter of a century. Because the parks are public land, many persons seem to feel that they have a right to take

their pleasure in them in almost any way they please. These antithetical uses have produced a dilemma for the National Park Service.

Most important have been the demands arising from the prevalence of private autos. Time and distance ratios have changed, and as families crossed the continent to flood the western parks, roads and campgrounds became inadequate. New and different facilities were needed. Much of wilderness quiet disappeared with the throngs of people, noisy cars, and blaring transistor radios.

Historic and archeological sites and structures were added to the system with the same purpose of preservation that lay behind the formation of the great wilderness parks. Recent years, however, have seen the system greatly expanded in kinds of areas as well as in numbers of units. The system now contains national recreation areas, seashores, lake shores, wild and scenic rivers, and linear trails and parkways extending for hundreds of miles. The most recent thrust is toward urban-related areas for recreation, open space, and some remnants of nature.

These newer areas in their great variety serve many purposes but central among them is that of active recreation, often organized and frequently mechanized. Still, the pressure remains on the great wilderness parks and the dilemma is with the management of them as each year sees the visits increased by millions. Some innovations are being made and imaginative and bold measures are contemplated, but the National Park Service is not yet well prepared to enter its second century since Yellowstone.

This sketchy historical account leads me to some remarks on research in the parks, the central theme of the symposium. I will bypass archeology, anthropology, and history because they have been better served and funded over the years and will confine my remarks to the social and biological sciences.

Although the social sciences have not been thought by Congress to be a need of the National Park Service, that opinion seems to be changing. On the face of it, it is absurd to manage many millions of acres of public property worth unestimated billions of dollars and serving hundreds of millions of citizens and know almost nothing about the customers, or should I say, clients. There is great need to employ the modern methods of survey research to learn the motivations and expectations of park visitors. Careful studies need to be made of the behavioral patterns of park visitors, with an effort to determine why people do what they do.

Without knowing the answers to the questions, even what the questions should be, we can assume that most persons who misbehave—I use the expression to mean behavior that is inappropriate to the purposes for which Congress established the various units of the National Park System—do so out of ignorance. If this is true, the extent

to which it is true, suggests that there is a need for public education. In my opinion, the National Park Service should be encouraged and well funded to use all the media to explain what it is about—newspapers, magazines, movies, radio, and television. This would not go far enough. It should use the opportunities that exist in the schools and in citizen organizations of a thousand kinds. The Service should produce more abundant, free, and cheaper informative material about the parks. And these technically accurate and attractive brochures, pamphlets, and books must go farther than to describe geology and the plant and animal life of the parks. There should be brochures that describe the structure and functioning of the Service, and especially the problems it faces in meeting its obligations for pleasure of the people while guarding what must not be allowed to be destroyed or even diminished. Most obvious are the captive audiences—the park visitors who look at the museum exhibits and attend the campfire programs, who walk the trails and read the trailside signs. Let us talk problems to them, and not just about things. An informed public could help the park management meet its every need, instead of causing it ever-greater headaches.

Every employee of the Service needs basic training in public relations as well as thorough grounding in the purposes of the Service. There is need for a sizable staff to help train existing personnel and to do various kinds of social science studies, especially in sociology and psychology. Beside the in-house efforts, there should be funds and a system of investing them in support of contract research in these fields.

One would expect the situation to be much better in the fields of biological research, but there are glaring deficiencies. Every park should have a base map that shows the cover types. It is relatively easy with today's remote sensing techniques to overfly a park and obtain images that can be translated into the various kinds of forest, grassland, and other types of plant-animal communities. Such a map is basic to two needs. It provides the base for an inventory of the cover types and for locating special features that assist research and interested visitors. The park naturalists and investigators can identify on such a map the location of special communities and rare and endangered species as well as the sites selected for special investigation. The second important use is to determine where developments should not occur. The biological importance of prime examples of community types and of the location of special features such as the habitats of rare species or the sensitive breeding grounds of animals have all too seldom been a factor in the location of roads, campgrounds, and other constructions. Engineering and cost considerations, even simple convenience, have typically been the determining factors. These have led in the past to bringing the people and their activities as close as possible to special park features. Fortu-

nately, this trend is being reversed.

The wealth of research opportunity in the great wilderness parks has attracted numerous investigators from the colleges and universities. At various times in the past, qualified park personnel have been granted time for on-the-job research, but most park staff are subject to extensive distraction from research by duties related to the public and management needs. There is a clear need for a greatly enlarged scientific staff with a variety of skills and understandings to carry on much needed studies. The results of such research would serve the public in providing richer and more varied information about the natural history of the parks and would be an important ingredient in management and planning decisions of the Service. This line of thought leads to a recommendation that there be identified for each important cover type three typical locations. These would serve different purposes. One example of each type should be selected in places convenient to visitors so that they could freely get into the stands and see for themselves just what a given plant-animal community is like. This experience could be guided or self-guiding on a basis of the nature-trail approach, perhaps with a descriptive booklet. Such stands would be living museum-type exhibits. A second example would be located far from the centers of visitation and would be regarded as isolates to be given as complete protection as possible. The third stand of each type would be reserved for experimentation. It should be located somewhere essentially out of sight of the public. In such places basic research could be carried on that requires some harvest of specimens or other experimental manipulations. Such research should be designed to serve the needs of basic understanding or, in some cases, the needs of management. As to the latter point, experimentation with controlled fire would be an example.

Rare and endangered species deserve particular attention. From the point of view of any one park, the local rareness of a species population is important whether or not the species as a whole is rare and endangered. The first consideration is to provide as much protection as possible. Nothing that the Service does or allows visitors to do should weaken the survival possibility of any such species or species population.

Each community type should be analyzed and described as to composition and structure and, where feasible, as to matters of energy flow, mineral recycling, and the like. Parks are almost devoid of this kind of basic data. Most studies are directed at the life history and ecology of selected individual species. This is fine and more of it needs doing not only for the public information value but also because of the importance of such knowledge when management problems arise. Such studies just do not go far enough.

I have stressed the need and the opportunities for basic research on the natural history of parks, park management problems, and the social science inputs which are desperately needed to improve public relations and service and to improve the management of parks under the guidelines of the basic statutes.

If the National Park Service undertakes such a research program, it will need an enlarged staff and a variety of skills that are not presently available to it.

The Future of the Parks: II

ROBERT CAHN, Council on Environmental Quality

In the exuberance of self-congratulation on the progress that has been made in the 100 years since the establishment of Yellowstone National Park, it might be salutary to pause long enough to ask some basic questions about the future. Can we take for granted that our National Park System will flourish in coming years? Or is blight likely to set in? What will our parks actually be like 10 years from now?

As an exercise in prognostication, I would like to propose two simulations of what a visitor's experience might be like in 1982. One model is built on the presumption that we continue with present practices and trends, and at current financial support levels. The other model is based on doing what is necessary through achieving changes in government action and citizen attitude and by obtaining required funds and personnel.

Inasmuch as I am speaking before a convention of scientists, it might be well to set forth some facts about the present before conjuring up models of the future.

But first a caveat. Despite some shortcomings that I will be pointing out, it must be acknowledged that in general the National Park System is the best of its kind in the world and is today providing outstanding opportunity for recreation, education, and inspiration for millions of people each year.

Yet behind the glow of success there are some big problems. Many of them relate to the proliferating popularity and growth of the parks. Over the past decade, visits to National Park System units have risen from 100 million to 210 million, an increase of 110%. In those 10 years, 91 new areas have been added to the system as it expanded from 193 areas in 1962 to 284 areas today. In addition to five new national parks and four new national monuments, many historical areas have been added, plus an assortment of new recreational units (national seashores, lakeshores, scenic rivers and trails), as well as a scientific reserve, and

even a cultural park. But unfortunately, the "service" part of the National Park Service has suffered somewhat in the growth syndrome. Only 2000 additional personnel have been added in the 10 years to serve the additional 110 million people, the National Park Service also has had to spread itself thin staffing 91 new park areas acquired in the past 10 years.

While funds for land acquisition in new areas have been generously forthcoming in almost an adequate amount, funds for park operating programs, i.e., maintenance, interpretation, and protection, have failed to keep pace. Scientific research has never been given the emphasis it deserves. Nor have there been funds for collection of adequate basic data on park resources. Funds for development and construction have actually dropped in the past 5 years. Nineteen of the areas added since 1962 have had little development for visitor use, and are really just "paper" parks, with minimal protective and planning staffs on hand. On the other hand, the fact that these 19 and other areas have been authorized is a large plus that should not be overlooked.

Now let us look at some current practices which have implications for our construction of future models:

> Some national parks have severe overcrowding problems, based on the philosophy that every citizen has a right to visit the park of his choosing at the time of his choosing. As a first step to limiting park access, park administrators are seeking to establish carrying capacities by estimating what the planners believe are the physical capacities for each park. These estimates, however, are not backed up by scientific research. Three national parks (Rocky Mountain, Sequoia, and Kings Canyon) now prohibit wilderness use beyond a maximum daily carrying capacity, and restrictions also have been placed on use of camping sites, and for attendance on some guided tours within park areas.
>
> Many national park areas are underutilized. The crowding of some national parks comes partly from heavy use by nearby residents who may visit the park every weekend during the summer.
>
> Main U.S. highways go through several national parks such as Olympic, Yellowstone, Great Smoky Mountain.
>
> National Park Service rangers, often graduate biologists or natural scientists, are needed in some parks to run campgrounds and to patrol highways.

Practices inappropriate to national parks are still authorized in some places: mining in one park and three monuments, controlled shooting of wildlife in one park.

The national parks are visited mostly by white, middle-class people. The poor, especially the black poor, are rarely seen in the parks due to lack of transportation, funds, and desire to visit wild areas.

Regional planning, and regional coordination among federal agencies responsible for recreation, is extremely limited.

Transportation systems within parks are outmoded.

Before getting to our models, we should link these and other practices to current trends such as:

The surge of environmental interest in the nation which has made more people aware of national parks and has also brought with it an increased desire for protection of the parks and the wildlife in them. Environmental education is increasing, and more urban youngsters are getting the desire to visit national parks.

The shorter work week, longer vacations, higher salaries, increased number of automobiles, recreational vehicles, campers, jeeps, snowmobiles, and dune buggies, lowered air transport prices for groups, and larger planes—all increase the pressures of use on national parks.

The expansion of off-season use of parks.

The developments of civilization which encroach on wildlife habitat.

Relating current practices and trends, we can arrive at the first of our models for the future, based on an assumption that we continue in the present mold. The visitor to Yellowstone National Park in the summer of 1982, let us say, would face a situation like this:

Four days after leaving Philadelphia—four days of constant driving along crowded super-highways and stopping at crowded motels—the Arthur Brown family approaches the eastern entrance of the park on U.S. 16. After waiting an hour at the entrance gate because the single ranger on duty cannot cope with the traffic backup, the Browns are informed that all camping spaces and lodges are full. They start the loop drive making 50 miles an hour between traffic

> jams. They want to stop at Fishing Bridge, but the ranger moves them on because the bridge is jammed with fishermen, and the parking lots are full. At Canyon Village they have lunch, waiting an hour in line at the cafeteria. Because it is getting late, they take the short cut west to Norris Junction and get caught in a massive traffic jam as 200 cars stop to see one elk a mile away running for his life as tourists with cameras swarm out of cars and head across the meadow. The Browns reach Old Faithful late in the afternoon, just missing an eruption of the geyser. They cannot find a ranger to ask questions, but the girl in the concession souvenir shop tells them that it will be an hour or more before the next eruption of Old Faithful. Mr. Brown decides they had better head for West Yellowstone to get a motel for the night so they can get an early start for the next day's planned visit to Grand Canyon National Park. They have thus visited Yellowstone, seeing none of its natural wonders, nor any wildlife.

Possibly this model does exaggerate things a bit. Yet in my most recent visit to Yellowstone 4 years ago, I ran into all the elements of such a park visitation.

Obviously, we do not have to accept that model. If certain changes are made, the experience of a visitor to Yellowstone in 1982 can be greatly different. A blue-ribbon citizen commission and five citizen-manned task forces are now looking into the basic problems and issues confronting the National Park System. The task force findings will be made public next spring and will constitute the source material for discussions at a National Parks Symposium in April 1972. I am certain these task forces, and the commission which reviews the results of the symposium, will make constructive suggestions. The National Park Service itself already has a number of new policies in the works, many of which, however, require added personnel and funding.

From the viewpoint of one interested observer, I would like to suggest what I think are certain basic needs to be met in the next 10 years.

1. Extensive research should be started immediately in order to establish a carrying capacity plan for each area. Because some crowded parks would be damaged by over-use, or the visitor's park experience could be ruined by crowding, we will not be able to wait for results before taking some trial-and-error actions, such as placing limits on visitation in certain areas.

2. A reservation system should be established, tied-in to a regional interagency computerized recreation use system. Unlimited access to parks is not necessarily a right for all citizens at all times.

3. Increased funding should be obtained for interpretation, maintenance, and scientific research related to preservation of ecological systems. Yosemite—the national park that due to riots, smog, crime and crowding has had the worst public image—at present needs, say National Park Service officials, an additional $8.5 million over present funding levels for visitor services and maintenance.

4. Until a reservation system can be installed and needed personnel added (without raiding the staff of several parks just to keep one troubled park in order), some national parks should be closed. Three years ago lack of personnel and operating funds forced the National Park Service director to take the drastic action of shortening the hours some parks or park facilities were open during off-season, and even closing a few small historic sites. Should this situation occur again, and should parks be seriously threatened by lack of personnel or maintenance funds, a more effective solution might be for Congress to temporarily shut down public use of Yosemite Valley in Yosemite National Park and the entire Grand Canyon National Park, areas which require large staffs and tremendous maintenance funds. The benefits would be twofold: enough funds and personnel would be freed to help most other parks in trouble; and the shock to Americans might be enough to force recognition of the need to adequately support the National Park System.

5. A list and timetable should be established for acquisition of all presently identifiable historic and natural areas needed to fill out the National Park System, and to purchase privately owned land within boundaries of older parks. A special priority should be placed on acquiring a national park in the Brooks Range of Alaska, a park preserving one of the few remaining prairie ecosystems in Kansas or Oklahoma, and a Channel Islands National Park in California, to name the more obvious. Priority should also be given to establishing marine parks, and for making marine sanctuaries offshore park beach areas.

6. Where possible and where habitat is sufficient, steps should be taken to reinstate native species of wildlife which have disappeared from a park. This should include wolves, mountain lions, coyotes, and other predators.

7. A sliding-fee schedule should be set up for visiting and camping, based on carrying-capacity studies which should show how long the average person needs in an area to adequately experience the values of each park. For instance, if it is determined that Yellowstone is a 3-day experience, those speeding through the park or lingering for an extended vacation, might be required to pay much higher fees, depending on length of stay. Also, a system of financial and transportation assistance should be worked out so that low-income families can visit a distant park.

8. Environmental education should be made a part of all elementary school curricula, and young children, especially in cities, should be taught about national parks and taken on supervised trips to nearby natural areas.

9. Formation of nonprofit service corporations should be encouraged to manage some park concessions. These nonprofit corporations could also run campgrounds and perform routine maintenance tasks, thus freeing National Park Service personnel for activities related to protection of the park and interpreting the park to the visitors.

10. All nonpark traffic should be banned from existing highways running through parks, and no new federal highways should be established within parks. When roads are needed into newly acquired parks, they should be designed by the National Park Service as low-speed, scenic routes, and not by the Federal Highway Administration as wide, straight, high-speed highways.

11. The transportation system within parks should be revised to place emphasis on declining use of the private automobile and accelerated use of public transportation.

12. The size of the naturalist force should be increased and methods should be devised for allowing the public to view wildlife in its native habitat.

13. Youth hostels and low-priced overnight accommodations should be provided at the fringes of parks.

14. Border parks with Mexico and Canada should be established, with camping and interpretive facilities that can be internationally shared.

If these and other changes take place in the next decade, combined with heightened respect for park values by those visiting the areas, and a willingness by the park-goers to accept some restrictions, the experience of the Arthur Brown family visiting Yellowstone in 1982 might more nearly follow this model:

> During January, the Browns go to a Department of Natural Resources Urban Planning Center in Philadelphia, one of a dozen such centers which were started in major cities in 1975. They are assisted by a ranger-counselor, who suggests that rather than spending most of their time in travel, and trying to see too many national parks, they instead make a regional visit to the Yellowstone area. He explains that in addition to Yellowstone National Park there are within a day's driving radius, U.S. Forest Service, Corps of Engineers, and Bureau of Reclamation recreation areas, and state parks in Wyoming, Montana, and Idaho. An itine-

rary is set. Using a computer, reservations are made for lodges on the edge of parks, and camping within some areas. The ranger-counselor then gives the Browns some educational material to study during the winter.

In July, the Browns head west from Philadelphia, camping along the way in state parks, with reservations having been made for them by the Department of Natural Resources computer, which is linked to state park systems. At Cody, Wyoming, they stop at a Department of Natural Resources regional visitor center. Here they obtain more information about the areas they will visit.

The Browns start their regional vacation at Bighorn National Recreation Area in Montana, then swing west to the Gallatin National Forest. They spend 2 days camping at Red Rock Lake National Wildlife Refuge, then go on to Yellowstone. As they approach the west entrance, they tune their car radio to a special wavelength. Out of the wide-open spaces comes the voice of a national park naturalist, identifying the trees, mountains, and wildlife they are seeing, and describing what lies ahead in the park. They find no delay at the entrance gate, where a staff of well-trained young men and women seasonal civilian park aides accept their fees and answer questions. They find their unitized camp site at one of the several small campgrounds established on the edge of the park away from crowded areas. They leave their car and take an electric-powered, open-air public minibus for a visit to Old Faithful. They walk the final quarter-mile because all roads and parking areas were removed from the fringes of the geyser back in 1973.

Later, at a road turnout in Hayden Valley, a National Park Service naturalist gives them information about the buffalo and moose grazing in a field nearby. He explains the ecology of the area—how each plant or animal (including man) fits into a total environmental order. Before returning to their camping site, they visit Yellowstone Falls and the Grand Canyon of the Yellowstone.

The next day the minibus takes them to the starting point of a 7-mile hike to Hart Lake. On the hike they see several black bears (strict enforcement of the "no feeding" rules has forced all panhandling bears away from roadsides and campgrounds). The Browns spend their last night at a wil-

> derness camp (food, bedding, and primitive facilities provided) at Hart Lake. The next day they leave Yellowstone for home, via Grand Teton National Park, where they spend the night at the Colter Bay Campground.

That's the way it might be in 1982. But to make that dream, or one like it, come true, we will need large increases in funding and greater public support and willingness by the average citizen to change his attitude about national parks.

The then director of the National Park Service, George B. Hartzog, Jr., in testifying in March 1971 before the House Subcommittee on Appropriations, told Subcommittee Chairman Mrs. Juila Butler Hansen that the nation must change its "whole attitude about what these parks are." We must, Mr. Hartzog said, "recognize that these parks are symbols of our inheritance rather than simply resources of land, water, buildings, and structures; and that, therefore, when you are managing the symbols of your inheritance, it is a much more expensive proposition than just maintaining a forest environment or an agricultural environment or an open space environment."

Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina[1]

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ABSTRACT

In its recently assumed role of custodian of national seashore recreation areas, the National Park Service is under pressure to: (1) maintain unspoiled lands within reach of the major cities; and (2) control shoreline retreat. Each of these demands implies a need for a different policy. National Park Service managers thus are forced to try to reconcile conflicting demands and philosophies, often without hard data on which to base their decisions. Past studies of coastal ecosystems often have been so compartmentalized that the overall picture is not seen. It may be hard to determine what the "natural" ecological conditions of an area were in the past, and even when these conditions are known, it may not be practical to restore them. Attempts in this direction, in the form of erosion control or reforestation, sometimes have destroyed an existing "natural" ecology better adapted to today's conditions.

In their natural state, barrier island landforms are the result of, not the victim of, the oceanic environment. Having arisen from breached spits, engulfed dune ridges, or a combination of the two, the beaches undergo short-term cyclic changes in width, as well as longer-term retreat and rearrangement due to overwash, erosion, and the opening and closing of inlets. It is only by retreating that the islands are able to survive in the face of rising sea level. The island biota is uniquely adapted to stress in the form of storms, overwash, salt spray, and sand movement. In particular, certain grasses serve to absorb the energy of overwash water, trapping and growing up through the water-borne sand, thus keeping the island elevation and their own habitat above sea level. Even though

[1]This is an abstract of a presentation which has been expanded into NPS Scientific Monograph No. 9, under the same title, printed by the U.S. Government Printing Office, Washington, D.C.

the Cape Lookout National Seashore islands show a history of sweeping changes, evidence from old maps and records and from island stratigraphy indicates that they have maintained the same ecosystems and general appearance for hundreds of years. Such "dynamic stability" is the true natural state of barrier islands, but the processes that maintain it have been suppressed on managed strands. Total artificial control of a coastline, therefore, is recognized increasingly as physically and economically impractical.

In seeking a solution to the management dilemma, the relatively undisturbed islands of Cape Lookout National Seashore are here compared with the altered Cape Hatteras strand. The major ecosystems of the undeveloped islands are the beach and berm, maritime grasslands, woodlands, fresh marshes, and salt marshes; their vegetation, zonation, and succession are described and related to island dynamics. The most productive salt marshes are those that have grown up on recent overwash fans or on the flood tidal deltas of newly closed inlets. Maritime woodlands turn out to be transitory features, representing the natural vegetation of only the most protected sites; grasslands are far better adapted to oceanic stress. Ecological changes arising from attempts to stabilize these natural systems are discussed. It is suggested that a high, continuous, artificial dune designed to prevent overwash may actually exacerbate erosion of the foreshore, while preventing the build-up of the island's interior and the extension into the sound of the backshore salt marshes. Thus, islands held in one place become lower and narrower and inherently *less* stable.

Original settlers of the Outer Banks affected the natural vegetation by cutting wood and grazing livestock. Overgrazing may have encouraged sand movement in some cases, but the overall appearance of the undeveloped islands is due to natural forces rather than to the activities of early settlers.

By leveling dunes and interfering with natural island dynamics, modern man has increased the islands' susceptibility to storm damage. Temporary engineering solutions nearly always make the situation worse. Salt-water intrusion into the fresh-water lens, ill-advised dredging operations, off-road vehicle use, and the introduction of litter and derelict cars are further ecological and aesthetic problems accompanying modern use of barrier islands.

It is suggested that ideal management of these areas should avoid attempts to hold back the ocean or stabilize the land. Development should be minimal and should be located so as not to require extensive protection. The natural dynamics of sand and vegetation should function unimpeded; where grass planting and dune building are deemed necessary, they should mimic the natural pattern. Of course, allowing natural processes complete freedom on already developed islands is no more realistic than are continued attempts at total engineering protection of roads and buildings against rising sea level. Rather, a middle course, sensitively orchestrated for a different area, is indicated. Roadless, bridgeless islands should remain so; all recreation should proceed with a view to preserving, not degrading, the resource. Wilderness areas should be set aside on the islands to serve as controls against which human impact on the rest of the system may be monitored.

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U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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